VEGETATION AND SOIL DEVELOPMENT ON RECLAIMED MINE LANDS AT HIGH ELEVATION IN SOUTH EASTERN BRITISH COLUMBIA

by

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ABSTRACT

The establishment of a functioning soil/vegetation system on coal mine spoils near timberline in the southern Canadian Rocky Mountains is rapid under intensively managed conditions. Although the vegetation appears to be dependent on fertilization for a period of approximately five years, after this time the reclaimed areas are, in many respects, similar to unmanaged native grassland. The rate of development toward this condition is strongly influenced by microclimate and soil nutrient status as modified by fertilization and spoil characteristics.

A decrease in soil pH and increases in root and shoot biomass production, detritus accumulation, soil CO_2 evolution in both field and laboratory and cellulose decomposition occur during the first six years following seeding. High levels of total soil nitrogen exist in all sites because of indigenous nitrogen in the waste rock. Variable levels of available phosphorus appear to be related to the duration of snow cover and the composition of spoil materials and may influence soil microbial activity through an interaction with nitrogen.

The major differences between native grassland and mature reclaimed areas appear to be related to differences

in the quality of soil organic matter between these systems. Grassland soils contain higher levels of humus, causing lower C:N ratios and high nitrogen mineralization rates. Reclaimed areas may be considered nutrient self-sufficient when nitrogen mineralization occurs without fertilization at a rate adequate to support the desired level of plant growth.

The production of organic detritus by fertilization of reclaimed areas is a practical method to encourage nutrient self-sufficiency through the build-up of organic matter and the improvement of nutrient cycling. A three stage sequence describing the ecological development of high elevation reclaimed lands in southeastern British Columbia is proposed.

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INTRODUCTION

Studies of plant succession and soil development on naturally disturbed sites, such as glacial moraine, mudflow or sand dunes, provide an understanding of the processes affecting the rate and direction of successional change under unmanaged conditions. These processes influence the ecological development of man-made disturbed sites as well, but are strongly modified by the management procedures employed in attempts to rehabilitate these areas. As yet, little is known about the ecological implications of reclamation practices and a better understanding of their influence on long-term ecosystem development is required before the success of rehabilitation programs can be realistically evaluated. This study describes the changes which take place in reclaimed mine land during its transition from raw waste rock to a functioning vegetation/soil system and examines the processes of ecological development as they are modified by management procedures.

In recent years, growing academic and practical interest has been directed toward the rehabilitation of land disturbed by mining activity. Initially, reclamation research dealt with problems of species selection and site preparation with the aim of establishing an initial vegetation

cover on mined land. More recently, there has been increasing interest in the ecological development of reclaimed ecosystems. Most of these studies, while dealing with specific facets of soils or vegetation, have embraced an ecosystem concept of successional development in which the soil/vegetation association, with its micro-flora and -fauna, functions as an integrated unit with each element of the system interdependent with the other elements (Crocker, 1952; Dickson and Crocker, 1954).

For practical reasons, however, most research relating to the rehabilitation of disturbed lands has dealt with only one or two facets of the developing system. Jonescu (1979) and Sindelar (1979) have discussed the success of establishment of vegetation on spoil banks up to fifty years old in the Great Plains of Saskatchewan and Montana respectively. Factors which affect the rate of vegetation development on mining exploration disturbance in forested and alpine regions of the northern Rocky Mountains have been studied by Meidinger (1980). Ziemkiewcz (1979) has reported on translocations of nutrients within a shoot/root/detritus/soil system developed on three year old reclaimed sites in southeastern British Columbia. The production and decomposition of plant litter in reclaimed systems has been studied by Carrel *et al* (1979) and Lawrey (1977). The role of microorganisms in the rehabilitation of mined land

has been reviewed by Cundell (1978) and a detailed account of microbial function in mine spoil in the eastern United States has been published by Wilson (1965). Similar work has been described by Visser *et al* (1979) and Danielson *et al* (1979) who studied a number of facets of microbial function including respiratory activity, nitrogen fixation and decomposition potentials in the former and mycorrhizal development in the latter. Soil development on mine spoil from a physical and chemical point of view has been studied by Anderson (1977) and Schafer and Nielson (1979).

These papers have lead to a better understanding of a number of functional aspects of reclaimed ecosystems. In most cases, however, the specific nature of these studies and a general lack of information about the functioning of reclaimed systems has prevented the full interpretation of data in an ecosystem context. In addition, many of the studies have compared widely separated stages of development such as raw spoil with undisturbed areas (Viser *et al*, 1979) or raw spoil with vegetated spoil of undetermined age and with undisturbed areas (Lawrey, 1977) which has made it difficult to establish a clear developmental sequence. From a management point of view, the purpose of a reclamation program in mountainous regions of B.C. is, firstly to establish a cover of vegetation which

will reduce surface erosion and increase the aesthetic and economic value of the land, and secondly, to maintain the vegetation cover in such a way as to allow it to attain a self-sufficient condition in the shortest period of time. In a theoretical context, the objective of reclamation is to accelerate succession to produce, in a few years, a seral stage which fulfills the requirements of erosion control and aesthetic/economic value and which will continue to develop under natural processes.

Through plant species selection, site preparation and fertilization research, most problems associated with the initial establishment of vegetation on mine waste have been resolved. These techniques are primarily directed toward the management of plant growth and, in most instances, their effects on the other facets of the system (e.g. soil chemical and physical properties and micro- and macrobiology) remain unknown. Consequently, although the concept of developing self-sustaining vegetation on reclaimed lands through management practices has been much discussed, the characteristics of such ecosystems are poorly understood.

Two prerequisites are implicit in this concept of a self-sustaining system. First, it must be nutrient self-sufficient, relying solely on natural inputs from weathering of parent materials, biological fixation, and atmospheric

supply to balance nutrient losses due to leaching, volatilization and erosion. The cycling of nutrients within the system must be balanced as well, in order to avoid nutrient accumulation in any one compartment. Second, the biological components of the system, including the vegetation and soil macro- and microorganisms, must be able to reproduce successfully under the prevalent climatic and edaphic conditions.

This study is a preliminary investigation of the development of a high elevation reclaimed ecosystem with respect to the nutrient cycling processes. Specifically, the objectives are:

1. To describe selected features of a managed, reclaimed ecosystem at different stages in its early development.
2. To compare the managed system with unmanaged systems in similar environments, representative of both developing and self-sufficient states, in terms of these features.
3. To examine the interrelationships betweeen some of these factors to obtain a better understanding of the ecological implications of management practices, and of the characteristics of the hypothetical self-sufficient state.

This study investigates a sequence of managed ecosystems developing on coal mine waste from open pit operations near timberline in the southern Canadian Rocky Mountains. The systems range from unvegetated spoil to six years in age. Since the oldest reclaimed site is only six years in age and has been managed throughout its existence, data have been collected from an unmanaged native grassland adjacent to the reclaimed areas to represent an ecosystem in a self-sufficient state. An area which was disturbed by mining activities but which has revegetated without management was also sampled so that rates of development under managed and unmanaged conditions could be compared.

Since this study views the changes which take place over time on reclaimed sites as the development of an integrated ecosystem, parameters which relate to several facets of the system, specifically, the vegetation, the soil microbial populations and the soil chemical conditions, were chosen for evaluation at each site.

Plant aerial and root biomass (above and below ground living material) were measured as an indication of the ability of the system to support vegetative growth. Samples were taken during the period of peak standing crop so that these measurements were roughly equivalent to net annual biomass production and thus, an indication of site productivity.

The accumulation of detritus relates to past shoot production as well as the decomposition capacity of the system. It has been viewed as a "nutrient sink" through which nutrients are removed from the system for long periods of time (Ziemkiewcz, 1979) and therefore is of interest to this study.

The rate of CO_2 evolution from the surface of the soil (soil respiration) has been described by Macfadyen (1971) as an index of the "total metabolism" of the soil relating to combined activities of soil macro- and microorganisms. However, Singh and Gupta (1977) suggest that it is difficult to separate the contributions of soil organisms to the total respiration from the contributions of plant roots. Since microbial populations and plant roots, particularly in grassland, are closely interdependent, the approach adopted here views soil respiration as an index of the state of the total below ground system. Soil CO_2 evolution was also measured in the laboratory as an index of soil fertility or more specifically, as a measure of readily decomposable organic matter in the soil (Waksman and Starkley, 1924). The activity of cellulolytic microorganism populations was evaluated by the rate of decomposition of pure cellulose paper placed in the soil.

The soil chemical status relates closely to management practices, weathering of parent material, and internal

nutrient cycling. Analyses were carried out to measure levels of nitrogen, phosphorus, organic matter and pH in the soils of each site.

THE STUDY AREA

The study site is on the property of Kaiser Resources Ltd. in the Rocky Mountains of southeastern British Columbia (Figure 1). This company has been mining coal near the town of Sparwood since 1969 and has, over the past eight years, reclaimed over 160 hectares of waste dump and exploration disturbance, both at high and low elevations. With continuing expansion of mining operations at Sparwood and planned and potential developments in nearby areas, the extent of the disturbance which will require rehabilitation will probably be more than ten times this figure.

The regional topography is characterized by rugged terrain and high relief. High ridges and peaks rise over 1500 m. above the broad glacial valleys which dissect the region. The mountains are primarily composed of sedimentary rocks, mainly limestone and sandstone with siltstone and mudstones in the coal bearing formations. The study area itself is located near the crest of a high sandstone ridge at an elevation of 2000 m. The climatic recording station nearest the study site is operated by Kaiser Resources Ltd. and located at the Harmer Ridge maintenance complex 5 km away and 200 m. elevation lower than the reclaimed areas under consideration (Figure 1). Due to the difference in

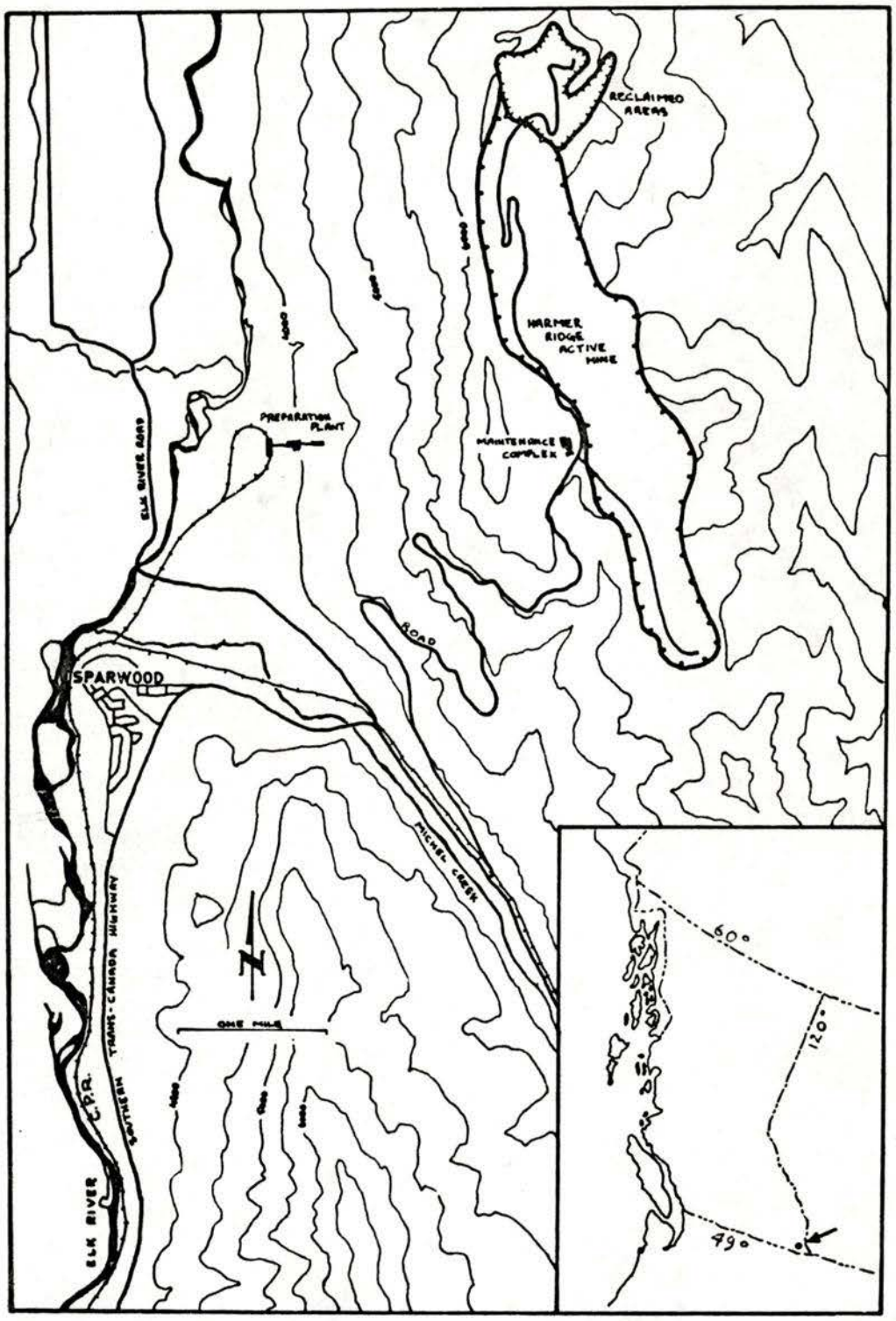

Figure 1

Location of the reclaimed area under study on the property of Kaiser Resources Ltd. near Sparwood, B.C.

elevations between the reclaimed areas and the recording station it is likely that the temperatures of the sampling areas are somewhat lower and the precipitation higher than recorded. A climograph summarizing the climatic observations recorded at this station over the last four years is presented in Figure 2.

In general, the growing seasons are short, cool and moist with the ground snow-free for five months of the year with only 40-70 frostfree days per year. The summer of 1978 was warm with precipitation throughout the summer and allowed record production on the reclaimed areas. The 1979 growing season was very dry between May and September. The drought conditions were reflected in the low productivity observed in this season.

Prior to mining, the vegetation of the study site was primarily late seral subalpine forest with lodgepole and whitebark pine, Engelmann spruce, and subalpine fir. Understory species included white rhododendron, false azalea, black mountain huckleberry and grouseberry. Scientific names of all species are given in Appendix I. The area would be classified as Engelmann spruce-subalpine fir zone according to the system of Krajina (1965).

The disturbed areas which form the basis for this study (Figure 3) are the end product of open pit coal mining. In order to expose deep coal seams for mining, the overlying

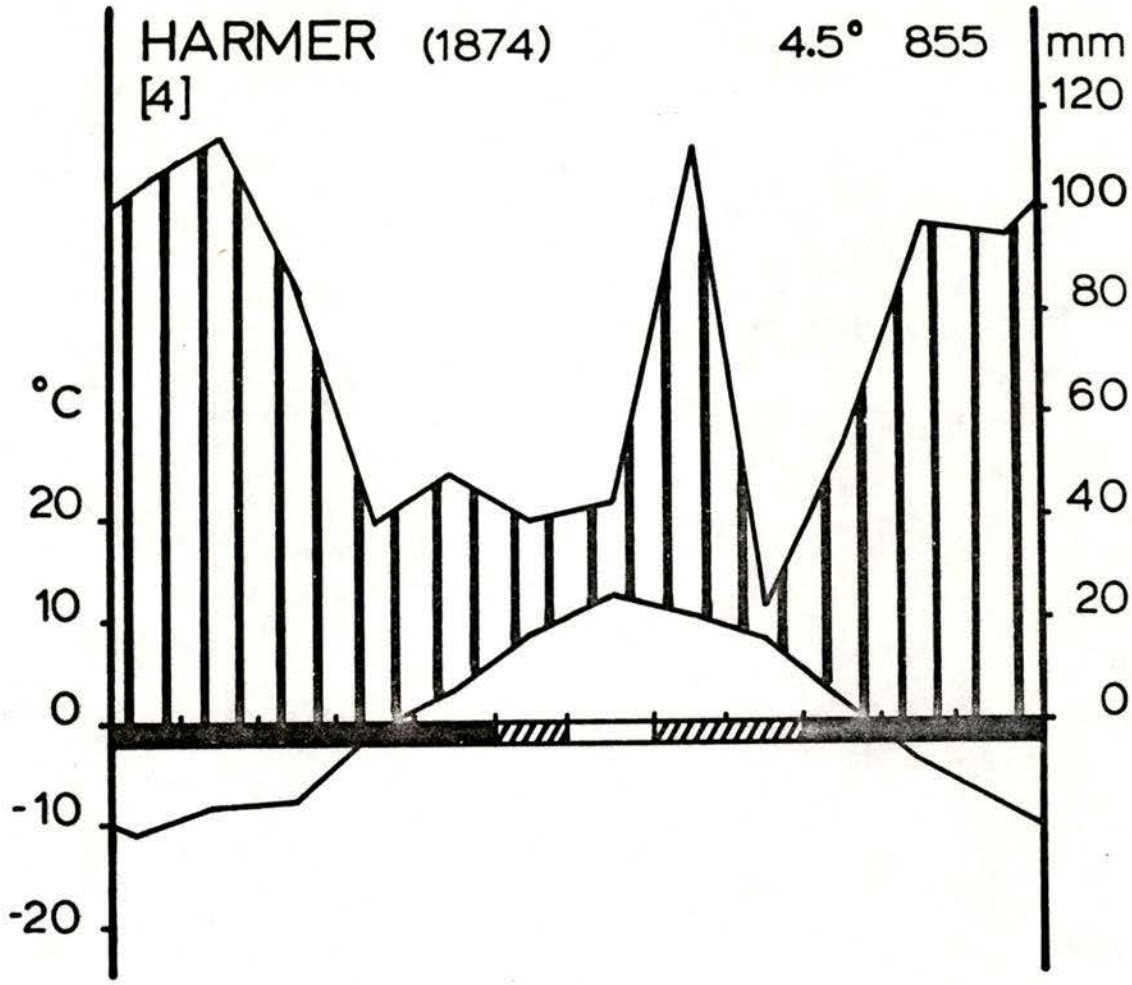

Figure 2

Diagram summarizing the major climatic features of the study site. Months are given on the abscissa with temperature (°C) and precipitation (mm) given on the left and right ordinates respectively. The upper curve depicts average monthly temperature. The period of excess rainfall is shown with hatching. The station and its elevation (m) is given in the left with the number of years recorded below. Average annual temperature and total precipitation are given in the upper right. The solid bar along the abscissa indicates months below 0°C while the cross-hatched bar shows months with frost. Figure is in the style of Walter (1973).

Figure 3

The Harmer Ridge reclaimed areas. The stand of alfalfa and grass species in the foreground is typical of the five year old site. The three year site is on top of the knoll in the center of the photo.

rock strata, often as much as seventy-five meters thick, are shattered by blasting, and removed by electric shovels and trucks. Surface soil material is not conserved but generally becomes mixed with the waste rock (spoil) and is buried in the dump. The spoil is hauled to a dump site, often a finished pit, where it is deposited, truckload by truckload in successive layers. At the completion of the dumping operations the composition of the dump is very heterogeneous being made up of hummocks of different spoil types deposited during the construction stage. The surface layers, which form the parent material of the developing soil, are made up of angular fragments of mudstone, siltstone and sandstone. Initially, the soil is very coarse textured and highly permeable but in most cases, the underlying layers of spoil have become severely compacted by the weight of heavy machinery and may restrict downward movement of water.

As a first step toward the rehabilitation of these waste dumps, the surface is resloped to an angle of 28° or less. This resloping smooths the hummocky dump surface, reducing it to an angle which will not inhibit the establishment of vegetation and, to a certain extent, mixes the spoil and breaks surface compaction. Spoil dumps may be resloped at any time of the year but seeding is usually left until spring or late fall. Prior to seeding, the

dump surface is prepared using a heavy pipe stem harrow to loosen the soil and provide micro-sites to promote seed burial and germination. Although seed mixtures have varied slightly from year to year the predominant species include creeping red fescue, meadow foxtail, orchardgrass, Canada and Kentucky bluegrass, timothy, alsike clover and alfalfa. Seed is applied by broadcasting, either by hand or, if a large area is to be seeded, by helicopter. The sites are fertilized in a similiar manner with a nitrogen/phosphorus/potassium fertilizer (13-16-10) at a rate of 200 kilograms/hectare. Finally, the dump is reharrowed to ensure burial of the seed and incorporation of the fertilizer. The reclaimed areas receive an annual maintenance application of a complete fertilizer at a rate of approximately 200 kg/ha. The vegetation of the Harmer Ridge reclaimed areas is presently dominated by orchardgrass, creeping red fescue and timothy with smaller representation of meadow foxtail, alfalfa and alsike clover.

The native grassland differs from the reclaimed areas in a number of respects. Although it is at the same elevation, it is steeply sloping ($\pm$ 35°) and has a more southerly exposure. The soil has developed on deposits of sandstone colluvium which probably had a physical structure comparable to the rock waste of the reclaimed areas, but has a smaller proportion of the siltstone and mudstone prevalent

in the spoil. The vegetation is composed entirely of native species as opposed to the seeded agronomics of the reclaimed areas. The species which dominate the site include Idaho fescue, sulphur buckwheat, fern-leaved lomatium, Hood's sedge and a wide variety of perennial herbs with scattered shrubs including flat-topped spirea and wild rose.

The disturbed site which is revegetating through natural colonization was included in the sampling. This site was originally an exploration disturbance adjacent to the reclaimed areas and is estimated to be fifteen years old. The soil of this site appears to have developed from coarse textured sandstone, weathered in situ, and represents the lower portion of the B horizon over the C horizon of a podzolic forest soil. The colonizing species are all natives and include spike trisetum, alpine hawkweed, pearly everlasting and rosey pussytoes. Further detailed information regarding site characteristics are contained in Appendix II.

METHODS

Site Selection

Six reclaimed sites were chosen to represent a developmental sequence from resloped but unvegetated spoil, to a developing system six years old. The techniques used in revegetation and the annual fertilizer maintenance were the same on each with the exception of the six year site which was not fertilized in 1979. One disturbed but unmanaged site and one south facing native grassland were chosen nearby for comparative purposes. Sampling plots were located within each site to standardize other environmental variables.

It was expected that climate, as modified by elevation, slope and aspect would have a major effect on ecological development. It was also expected that development would be influenced by factors associated with spoil type, such as nutrient availability (particularly phosphorus availability), particle size distribution and rate of breakdown of the rock.

Due to the nature of the mining process, which works with different rock strata at different times, it was not possible to standardize the composition of the spoil while

maintaining the site age series to be sampled during the study. Although the effect of spoil type on site development was unknown, it was thought to be small in comparison with the effects of management conditions, climate and site age, particularly in young reclaimed sites.

Previous research on waste dumps by Kaiser Resources Ltd. suggested that the responses to different fertilizers varied greatly over distances less than 50 m. (Fyles, 1979). It was not known how the factors governing fertilizer response would affect ecosystem development but it was felt that a relatively small sampling plot size was warranted to reduce variation in this regard. In addition, a small plot size would reduce variability related to changes in microclimate over short distances.

To reduce variability related to these factors, sampling plots were located on level ground with a southwest exposure, within an elevational range of fifty meters. One 10 m. x 20 m. plot was located on each site in an area which appeared homogeneous with respect to vegetation and spoil characteristics. Each plot was subdivided into five, 10 m. x 4 m. subplots or strata.

Despite the attempts to standardize environmental parameters between sites it was realized that the variability in microclimate and spoil type within and among sites was largely unknown. Throughout the study, informal observations

and measurements were made in order to identify the influence of any factors which had not been standardized so that valid interpretations of the data could be made.

Aerial Biomass

The standing drop of aerial biomass was assessed on each site by clipping all living, above ground plant material from 0.25 m^2 clipping frames. Five random samples were clipped from each subplot yielding twenty-five from each site. Samples were oven dried at 80°C and weighed. Samples were collected in mid-August to correspond with the period of maximum standing crop before the onset of autumn dieback. The data are expressed as grams dry weight per square meter standing crop but may be considered as a measure of net biomass production over the growing season.

Root Biomass

The soil of reclaimed areas, which is very rocky and, in many cases, heavily compacted, makes the measurement of root biomass very difficult and extremely time consuming. Research undertaken previously at Kaiser Resources Ltd. (Ziemkiewicz, 1979) used a 2.5 cm. diameter soil corer to sample roots. Data obtained using this method had high variability despite a large sample size and it was suspected that the area sampled by each core was too small to give a

precise estimate. In addition, cores could only be taken in areas of soft soil where root density would be higher than in the area overall.

In this study, the diameter of the root sample was increased to 10 cm. to allow cores to be taken with a small trowel, and thus avoid the difficulties of coring in hard ground. Core depth was standardized at 10 cm. Six random samples were taken from each subplot yielding thirty for each site. Samples were air dried, crushed and sieved through a 2 mm. mesh. Roots were collected from the mesh and from the residual soil, washed of any adhering soil particles, dried and weighed.

Detritus Accumulation

Detritus was defined as all dead plant material greater than 5 mm. in length either on the surface of the ground or still standing. Detritus samples were collected from the aerial biomass clipping plots and dried and weighed in the same manner as the aerial biomass samples.

Soil Respiration - Field Measurements

Measurements of microbial respiration were made in the field using methods similar to those used by Lieth and Ouellette (1962) and Witkamp (1966). Thirteen-litre plastic pails were used as respiration chambers. During sampling,

the pails were inverted on the ground over a 100 ml. sampling jar containing 10 ml. of 1N NaOH solution. The rocky soil conditions of the reclaimed sites did not allow the rims of the pails to be set into the ground as in previous studies but soil was added around the pails to seal the rims. The pails were left in the field for twenty-four hours after which the sampling jars were capped and returned to the laboratory where the alkali was titrated with standardized HCl to determine the amount of carbon dioxide absorbed during the sampling period. Blanks were used to correct for the amounts of carbon dioxide absorbed from empty pails and from sampling jars transported to and from the sampling sites. One respiration chamber was placed in each subplot yielding five per sampling site. The field respiration measurements were taken during the third week of August.

Soil Respiration - Laboratory Measurements

Composite soil samples were taken from each sampling plot in early October in order to measure soil respiration under controlled laboratory conditions. Samples were air dried, sieved through a 2 mm. mesh and stored at $4^{o}C$ before use. Sealed 1.4 litre plastic containers were used as respiration vessels. One hundred grams of dried, sieved soil were placed in each vessel, using three replicates

from each site. Distilled water was added to bring the soil to sixty per cent of the water holding capacity and the vessels were left to equilibrate for at least twenty-four hours. After this period the moisture content was adjusted where necessary, a sampling jar containing 10 ml. 1N NaOH was placed in each vessel, the vessels were sealed and incubated at 25°C for up to 92 hours. The carbon dioxide absorbed by the alkali was determined by titration at the end of the sampling period. The results were expressed as milligrams of carbon dioxide absorbed per hour per 100 grams of soil.

Cellulose Decomposition

To measure the rate of decomposition of cellulose in the field, pre-weighed, 5 cm. square chips of alpha-cellulose paper were buried 5-10 cm. below the surface of the soil on each site. One set of chips was buried in each subplot in late June and one chip removed from each set monthly until later October. The chips were washed and brushed clear of clinging soil particles, oven dried at 80°C for 24 hours and then weighed. The data were expressed as per cent weight loss per day.

Soil Sampling and Analysis

Soil samples, for chemical and physical analysis were collected from each site in late July and early August. Composites were made of three samples taken systematically from each subplot. The samples were air dried and passed through a 2 mm. mesh sieve. The size fraction greater than 2 mm. was weighed to obtain an estimate of the percentage of coarse fragments in the soil of each site. Chemical analysis of the size fraction less than 2 mm. was carried out in Kaiser Resources Environmental Services laboratory as follows: total nitrogen by a modified Kjeldahl method (Beecher and Witten, 1979), available phosphorus (sodium carbonate soluble) by the Olsen method (Olsen and Dean, 1965), soil pH (Peech, 1965), and organic carbon by the Walkley-Black method (Allison, 1965).

Data Analysis

The aerial and root biomass and detritus data were analyzed according to the method prescribed for stratified random samples by Snedecor and Cochran (1967). The soil analysis data were collected as a systematic composite of three samples in each subplot providing five observations from each plot while the soil respiration data were collected as a single observation from each subplot. These

data were treated as a simple random sample during analyses although the samples were not strictly random. Analysis consisted of calculation and graphic presentation of sample means with ninety-five per cent confidence limits.

RESULTS

The initial revegetation of mine waste appears to be rapid under intensively managed conditions. The plants become established in the first year, and attain significant growth by the second season with production remaining essentially constant at this level for a number of years before further increases occur (Figure 4). The aerial biomass production of the six year reclaimed site is similar to that of the native grassland. In comparison to the managed areas the naturally revegetated site supports a low level of shoot production.

The biomass of roots growing within 10 cm of the soil surface also reach a high level of production by the second growing season (Figure 5). In subsequent years root growth remains relatively constant, suggesting that the surface layers of the soil have reached a maximum root density. The unmanaged sites also exhibit this phenomenon with the native grassland supporting a surface root level similar to the naturally revegetated site even though the older area would be expected to have a much larger total root biomass.

Since present levels of detritus are related to shoot production in previous years, it is not surprising that the

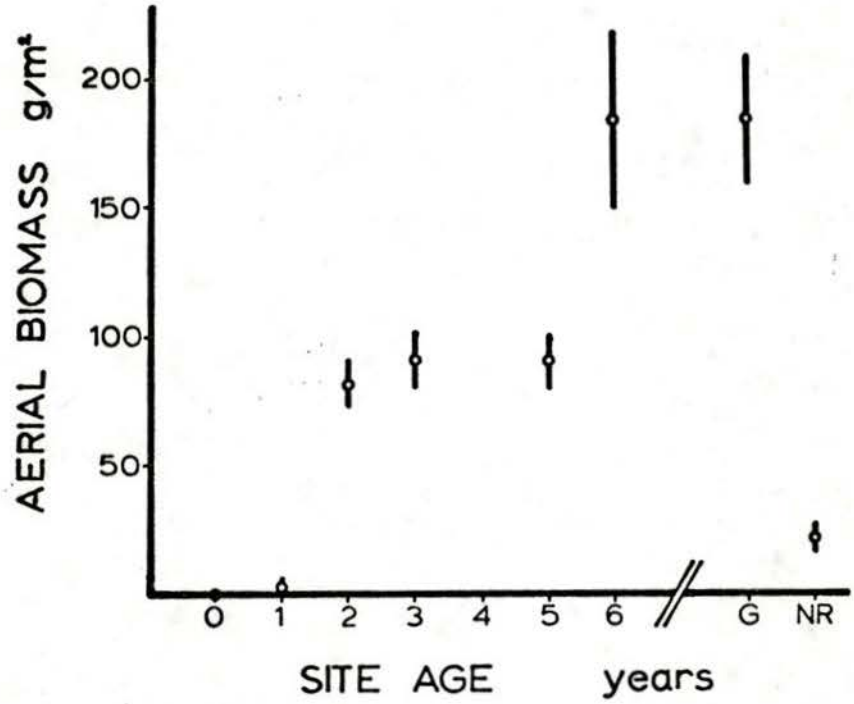

Figure 4

Aerial biomass of reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

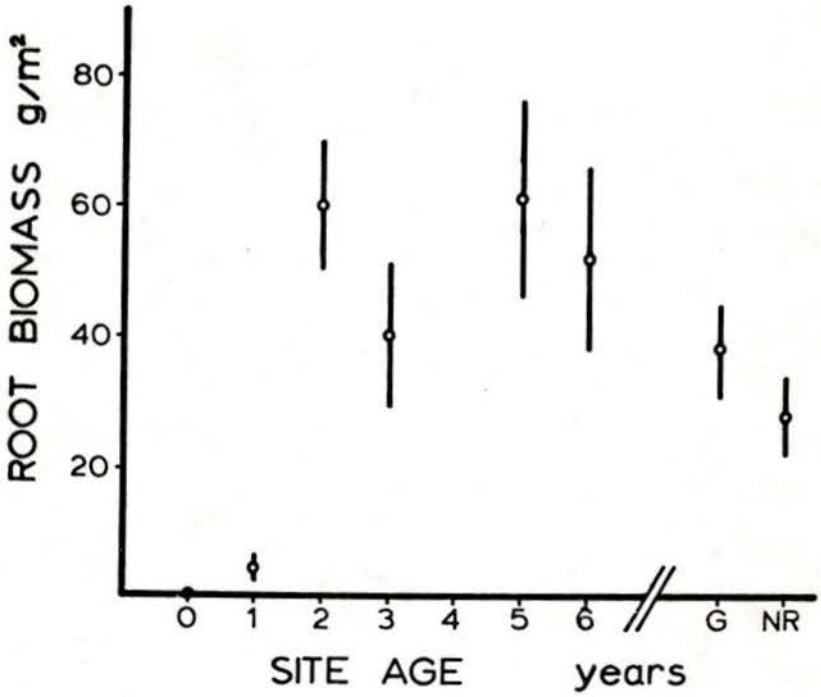

Figure 5

Biomass of roots in the surface 10 cm. of soil in reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

pattern of detritus accumulation on the sampling sites resembles that observed in aerial biomass production with a one year lag (Figure 6). Initial low detritus levels rise abruptly in the third year in response to the steep rise in shoot growth in the second growing season. By the sixth growing season twice as much detritus has accumulated on the reclaimed areas as on the native grassland. Since the naturally revegetated site supports a low level of shoot growth, its insignificant detritus accumulation is to be expected. It is interesting to note that the two unmanaged sites have accumulated a detritus level which is approximately equal to the aerial biomass production while the accumulation on the older reclaimed sites is twice the level of shoot growth.

Figure 7 shows an abrupt increase in the CO_2 evolution from reclaimed areas with the initial establishment of vegetation in the first year, followed by a general increase with age. The three year site does not follow this general trend but exhibits a respiration rate which is similar to that of the six year and grassland sites. The naturally revegetated area also had a high rate of CO_2 evolution particularly in comparison with the one, two and five year reclaimed sites which supported much higher shoot, root and detritus levels and would have been expected to have higher respiration rates as well.

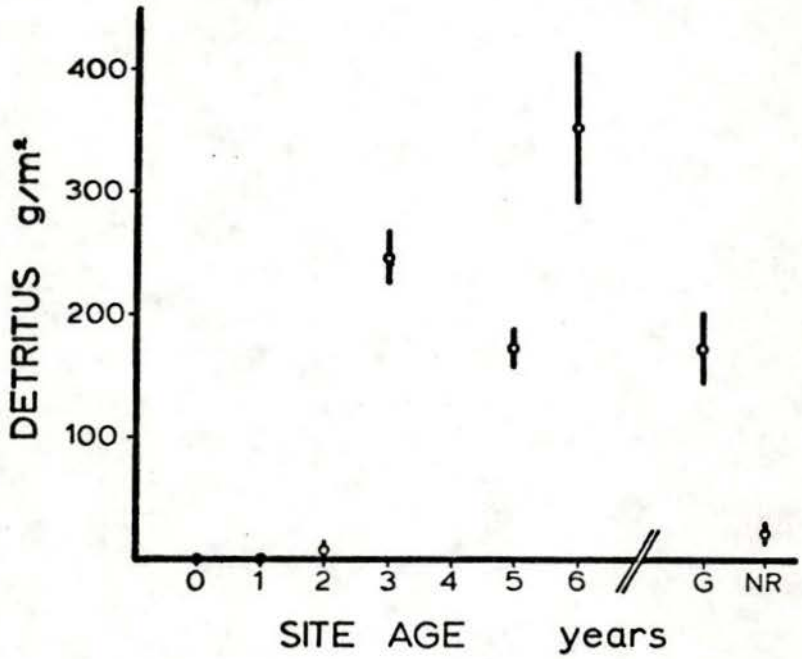

Figure 6

Detritus accumulation in reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

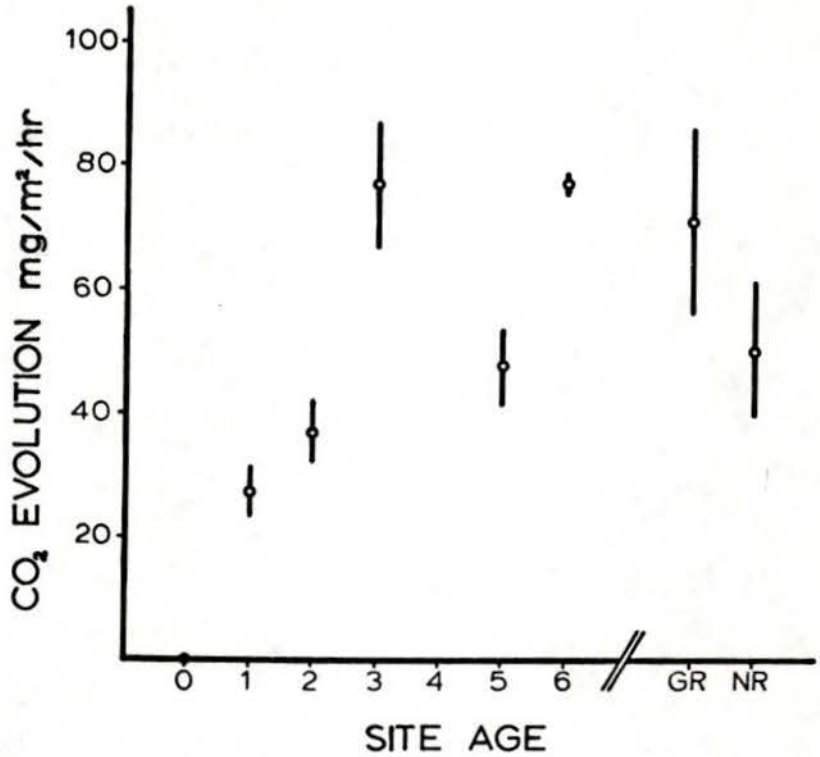

Figure 7

CO_2 evolution of soil measured in the field in reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

The rates of cellulose decomposition (loss) appear to be relatively constant on most sites throughout the summer, and, with the exception of the three and six year reclaimed areas, exhibit a general increasing trend with site age (Figure 8). In comparison with the other reclaimed sites, the cellulolytic activity recorded on the three year area was very high during the first two months of sampling but dropped to a low level after mid-August. This high level of decomposition early in the season correlates well with the high respiration rates measured in mid-August as discussed above. The six year reclaimed site exhibited a high rate of decomposition relative to most of the other reclaimed areas during July but cellulolytic activity appears to have been substantially reduced for the remainder of the summer. As was expected, a high decomposition rate was observed on the native grassland. The naturally revegetated site was expected to exhibit a level of cellulolytic activity similar to the one and two year reclaimed sites but surprisingly, supported a decomposition rate more comparable to the five year reclaimed site or native grassland. There appears to be a correlation between cellulose loss and soil respiration on this site similar to that observed on the three year reclaimed area.

Available phosphorus levels seem to be relatively constant in the soils of both managed and unmanaged sites

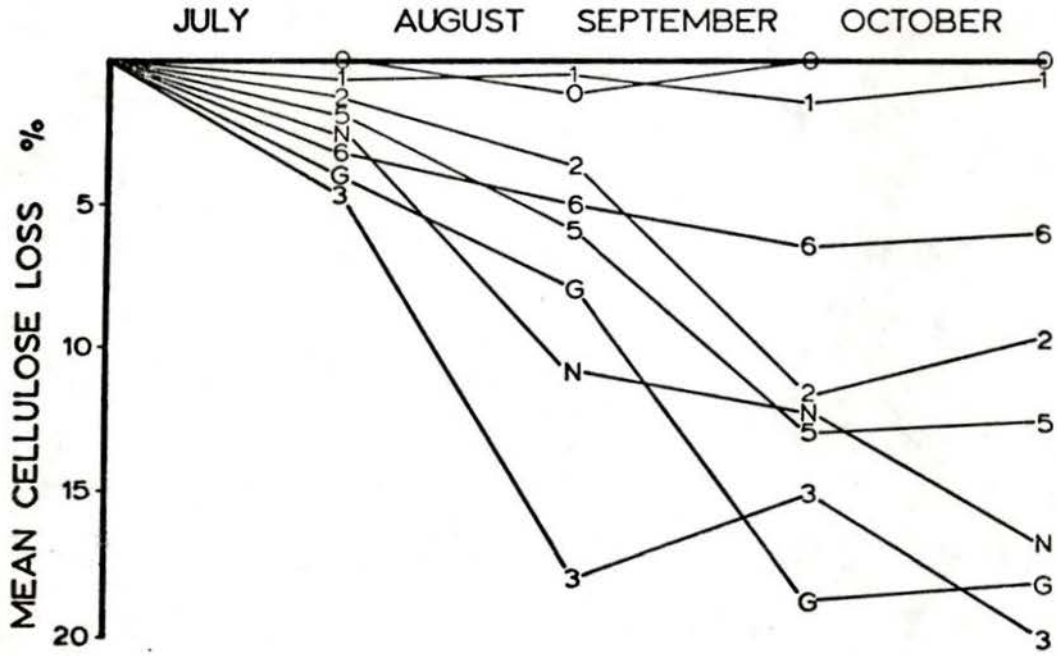

Figure 8

Cumulative loss of cellulose from July to October 1979. Numerals denote the age of reclaimed areas, G the native grassland and N the naturally revegetated site.

with the exception of the zero, one and three year old areas (Figure 9). The low levels observed in the youngest reclaimed sites are to be expected since there has been little time for weathering to release phosphorus from the parent material, and fertilizer additions have been minimal. The high phosphorus availability in the three year reclaimed area may be related to microclimate or soil factors which are specific to this location.

Essentially all of the nitrogen in terrestrial ecosystems has accumulated through biological fixation and is associated with living organisms or organic matter in the soil (Jansson, 1972). Since the reclaimed areas under study are composed entirely of broken rock and devoid of conventional organic matter it was initially assumed that all of the nitrogen in the reclaimed system originated from applications of fertilizer. It was expected that the percentage of nitrogen in the soil would therefore increase with site age. However, Figure 10 demonstrates that total nitrogen levels remain relatively uniform among sites, with the exception of a high percentage in the native grassland. The total input of fertilizer nitrogen through annual maintenance accounts for only 2-3 per cent of the total nitrogen measured on the six year site, suggesting that the spoil materials contain significant concentrations of nitrogenous compounds. This observation was confirmed

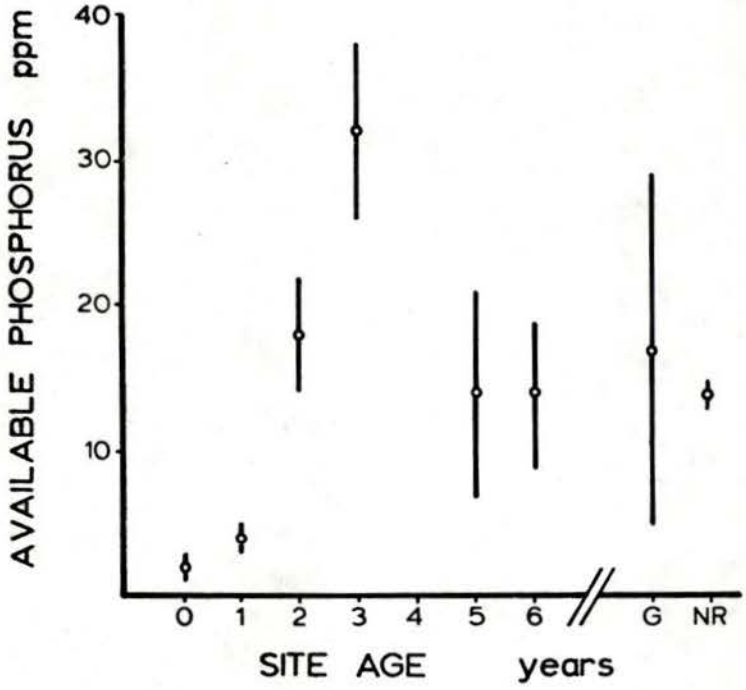

Figure 9

Available soil phosphorus in reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

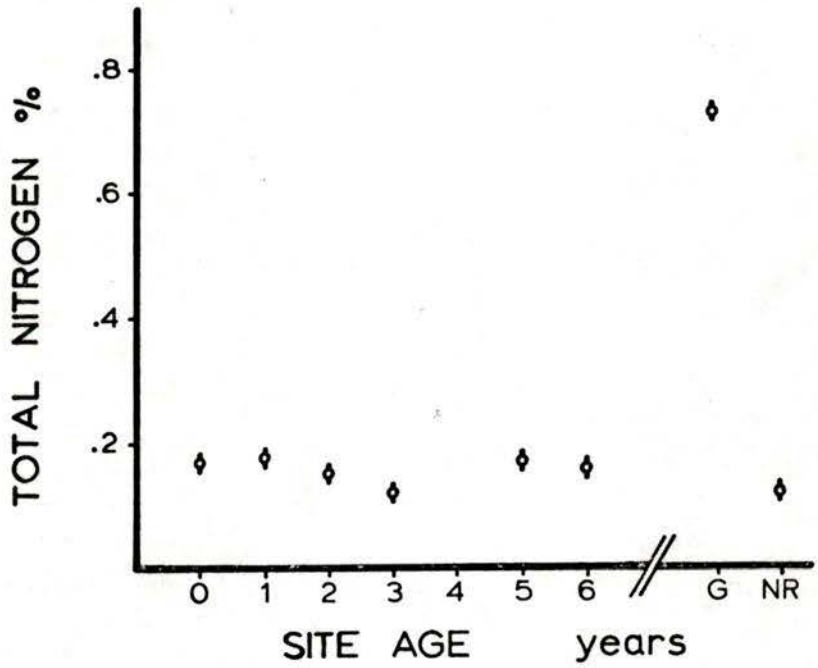

Figure 10

Total soil nitrogen in reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

by analysis of rock samples, collected from the reclaimed areas, which were found to contain up to 0.18 per cent nitrogen. Power and Bond (1974) and Reeder and Berg (197a,b), studying the mineralization of nitrogen from sedimentary rocks in the coal areas of Montana and Colorado demonstrated that nitrification occurs under certain environmental conditions but the significance of indigenous nitrogen to revegetation has not been established.

The analysis of organic matter in the soils of each site was similarly confounded by the presence of carbonaceous shale in the spoil. Although the Walkley Black wet oxidation method is intended to extract only the biologically active carbon, it is not known whether this applies to coal type materials and whether the coal carbon extracted would actually participate in the biological degradation and cycling of nutrients.

Only preliminary analyses for organic matter content were undertaken and the data set, therefore, has not been presented. The pattern of soil organic matter content of each site was similar to that of the nitrogen concentration (Figure 10), with comparable levels in all sites excepting the grassland, which has a very high value. It is suggested that the quantities of nitrogen and organic matter found on the reclaimed sites and the naturally revegetated area represent a base level, determined by the composition of

the original spoil. The high levels recorded in the native grassland soil probably represent natural accumulation over a long period of time.

The rate of CO_2 evolution from soils of each site, measured under laboratory conditions, is presented in Figure 11 as an index of the content of available organic matter in each soil (Waksman and Starkley, 1924). Available organic matter refers to organic substances which are readily utilized or decomposed by micro-organisms within the reclaimed sites. There is a definite increase in available organic matter with site age. Since the decomposition of plant residues produces organic acids, it is not surprising that the accumulation of organic matter in the soil is reflected by a decrease in soil pH with increasing age (Figure 12). The low pH measured on the naturally re-vegetated site is probably related to its origin as the subsoil of a coniferous forest.

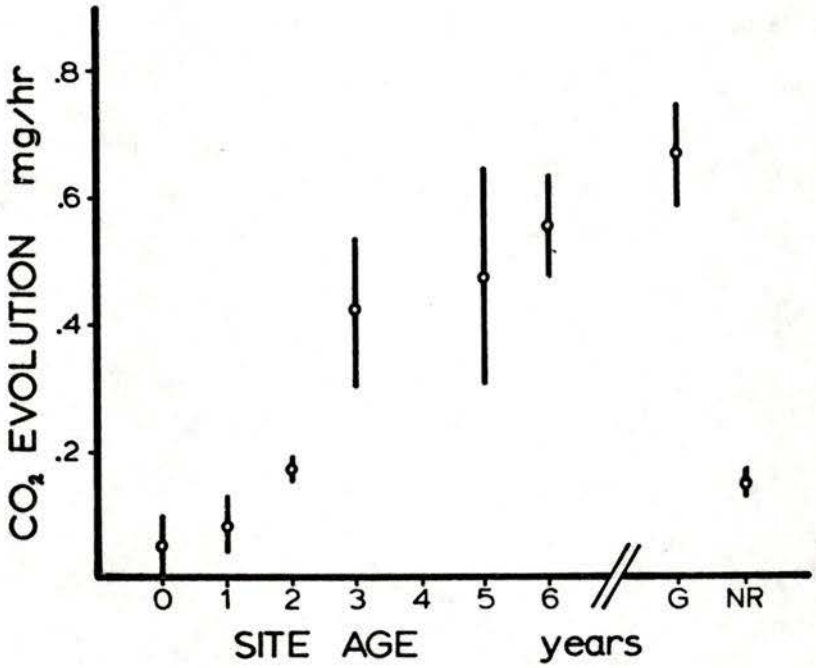

Figure 11

The CO_2 evolution of each soil measured under laboratory conditions in reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

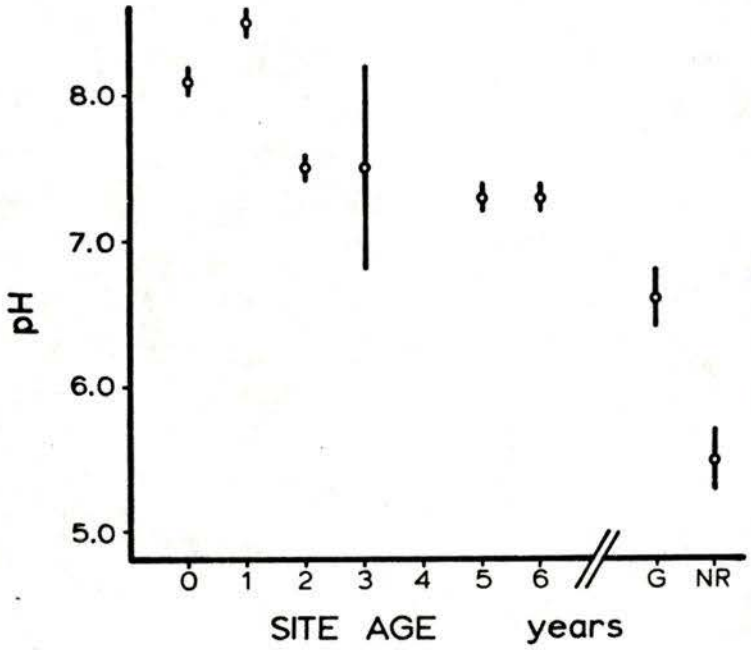

Figure 12

Soil pH in reclaimed areas of different ages, the native grassland (G) and the naturally revegetated (NR) site. Data points represent means with 95% confidence limits.

DISCUSSION

Effects of Fertilization

The aerial biomass data (Figure 4) suggests that in young reclaimed systems plant growth is strongly influenced by fertilization and the plateau period of biomass production between two and five years may reflect the dependence of the vegetation on the annual fertilizer applications.

Ziemkiewicz (1979) found a mean foliar nitrogen level of 1.7 per cent in plants growing on reclaimed areas adjacent to those presently under study. Using this value and assuming no available nitrogen inherent in the system and an annual input of 2-3 g/m^2 nitrogen from fertilizer, the maximum plant growth possible would be about 150 g/m^2. Allowing for some loss through leaching or volatilization, shoot production on two to five year old sites may, then, be primarily, if not completely dependent on fertilization as the source of the available nitrogen.

The six year reclaimed site was not fertilized in 1979 but maintained an unexpectedly high production of aerial biomass even without this additional nutrient supply. It appears that, without fertilizer input, this system main-

tains a pool of available nutrients sufficiently large to support substantial plant growth. Two sources of nutrients are possible in unfertilized systems. In most grassland, carbohydrates and nutrients are translocated to the overwintering roots so that they are immediately available to support spring growth. Ziemkiewicz (1979) suggested that the local grasslands function in this manner but that young reclaimed areas are more dependent on cycled nutrients. Carbohydrates and nutrients are also stored in the form of detritus and soil organic matter, and are made available to plants through the activities of micro-organisms. It is likely that growth on the six year site in 1979 was supported by nutrient inputs from both of these sources, with root storage making a major contribution in the early spring and cycled nutrients becoming more important later in the summer as microbial activity intensified.

Fertilization probably has a strong influence on root growth and distribution as well as an effect on shoot production. In the early stages of natural succession, a concentration of roots near the surface of the soil would be expected if the soil nutrient status was low. Under these conditions, a large proportion of the available nutrients in the system, particularly nitrogen, would be supplied to the soil surface by decomposing detritus, biological fixation or direct atmospheric input. On reclaimed areas, maintenance

fertilization would represent a large additional source of nutrients on the surface and would exaggerate this effect. The high density of roots in the surface layer of the soil on the young reclaimed sites may therefore be a result of the aerial application of fertilizer. It is expected, however, that rooting depth would increase with time as natural soil processes improved the nutrient status below the surface layer. Although it is not known how long the surface concentration of roots persists on reclaimed areas, roots were recorded to a depth in excess of 65 cm on the six year site, suggesting that it may be a short-lived phenomenon.

From a management point of view a large mass of roots close to the surface is desirable on young reclaimed sites as it reduces leaching losses, encourages efficient uptake of fertilizer and stabilizes the soil to prevent surface erosion. However, it is important that the rooting depth increase during the term of management so that the nutrient uptake may be maintained at a level sufficient to support the vegetation after maintenance fertilization has been discontinued.

Detritus Accumulation

Ziemkiewicz (1979) views the decomposition of plant residues as one of the major factors controlling the cycling of nutrients. He examined reclaimed areas adjacent to the present sampling sites and suggested that detritus was accumulating in these systems because of the low temperatures and short growing season associated with high elevation. The high levels of detritus recorded on the six year site appear to support this hypothesis. King (1979) reports, however, that the area in which the six year site is located had a mean aerial production of 280 g/m^2 in 1978, attributing this high level to the unusually warm, moist growing season that year. Detritus accumulation was approximately 130 g/m^2 in October 1978. Since the 1979 detritus load would be equivalent to the sum of these two values, it is suggested that decomposition is taking place at a rate which avoids long term tie-up of nutrients in dead plant material. Unfortunately, information regarding the 1978 shoot production of the other sites is not available, so that similar comparisons between years cannot be made.

Considerable attention has been directed toward the use of manure, sewage sludge and organic mulches such as wood chips or straw as methods of increasing the organic matter content of mine waste (Brown and Johnston, 1978; Kay, 1978;

Lant, 1978). In many instances, however, much organic matter is generated by the system itself, in the form of detritus and dead roots at a relatively low cost per hectare. For this reason, as long as environmental conditions allow adequate decomposition, the production of detritus, controlled by fertilization, can be viewed as a useful tool for the rehabilitation of mine waste.

Phosphorus Dynamics and Interactions

During the development of natural ecosystems, phosphorus is made available through the weathering of phosphorus-containing materials in the solid parent material (Brady, 1974). It is held in the soil in a number of forms which range from soluble in water and thus available to plants, to partially or completely insoluble. Alkaline soils with high calcium levels often have the capacity to fix large amounts of phosphorus in an insoluble form. Under these conditions soluble phosphate added as fertilizer may become fixed and unavailable soon after it is applied.

Comparison of the available phosphorus levels between sampling sites (Figure 9) provides some understanding of the factors controlling phosphorus availability in reclaimed systems. It can be expected that phosphorus dynamics in these systems will be affected by the natural processes of weathering and fixation as well as by fertilizer management

practices. The low levels recorded on the zero and one year sites suggest that phosphorus availability is low in unweathered spoil despite fertilizer applications. The significant increase observed in the second year probably relates to the combined effect of additional fertilization, continued weathering possibly accelerated by the vegetation and, to a limited extent, cycling through the decomposition of organic matter. The very high level of available phosphorus recorded on the three site is considerably greater than that predicted by the cumulative fertilizer input over the three seasons it has been maintained. The site is a level area situated on the top of a small knoll, some 5 m above the surrounding area. It is possible that this site blows clear of snow in the winter and loses its snow cover earlier in the spring than other areas. In late March 1980, field inspection indicated that this plot had 50-75 per cent less snow accumulation than most other sampling sites. Early loss of snow cover in the spring would increase the length of the period in which the ground surface was subjected to extreme freeze/thaw conditions, and thus would increase the mechanical breakdown of organic matter and spoil material with a concomitant increase in available phosphorus levels.

The lower levels of available phosphorus found in the soils of the older reclaimed sites may also be related to

weathering. This may be particularly important on the five year site which had a high accumulation of snow in March 1980. With late spring emergence, this area would not be subjected to the intense, early spring freeze/thaw period. The resultant reduction in weathering may explain its low phosphorus availability.

The native grassland is considerably older than any of the other sites and, presumbably, has a relatively well weathered soil, yet it exhibits a level of available phosphorus which is lower than would be expected if time was the only controlling factor. The parent material of the grassland soil is a coarse-grained sandstone colluvium which is probably more resistant to weathering and may have a lower total phosphorus content than the finer textured materials of the reclaimed sites. Since the parent materials of the naturally revegetated and the six year reclaimed sites include a large proportion of sandstone materials and the soils of these areas contain similar levels of available phosphorus, it is possible that availability is strongly controlled by the composition of the local bedrock.

Previous research on aerial biomass production under different fertilization regimes on Kaiser Resources reclaimed areas (Fyles, 1979) suggests that there is a strong interaction between nitrogen and phosphorus fertilizers in their effect on plant growth such that better utilization of

nitrogen occurred at high phosphorus concentrations. It is likely that these conclusions can be extrapolated to include root production and microbial productivity as well.

The cellulose paper used to measure decomposition rates contained essentially no nitrogen, and therefore the factor most strongly controlling cellulose loss was probably nitrogen availability. The pattern of decomposition and the soil respiration rate of the three year reclaimed site implies that the availability of nitrogen was high in the beginning of the summer but that the supply became depleted by mid-season. In the two and five year sites, however, it appears that there was a lower initial availability but that the nitrogen supply was not depleted until late summer, if at all, since microbial activity was probably restricted by cool temperatures in October rather than nutrient supply. This apparent difference in nutrient availability between reclaimed areas is surprising as all sites received the same inputs of fertilizer in the spring.

In view of the interaction between nitrogen and phosphorus, it is suggested that the three year site, with its high phosphorus level, was able to utilize the fertilizer nitrogen with greater efficiency and therefore maintain higher productivity than other sites. With this high rate of activity the free nitrogen sources were depleted by mid-summer, at which time productivity diminished to a low level.

The two and five year sites, however, with much lower phosphorus levels could not utilize the nitrogen as efficiently and, therefore, did not deplete the supply until later in the season.

If this hypothesis is correct, it is surprising that the greater efficiency of nitrogen utilization was not reflected in the aerial biomass or root production. It is possible that the interactive influence of phosphorus affects microbial function to a greater extent than plant growth and therefore would be expressed more strongly in soil CO_2 evolution than in plant growth. It is also possible that the sampling of aerial biomass and roots took place before the effect of increased nutrient utilization was expressed in shoot or root production.

Organic Matter Dynamics

Comparison of the native grassland with the oldest reclaimed site provides an understanding of the development of reclaimed systems toward a self-sustaining condition. The levels of aerial biomass and surface root production and soil respiration of the six year old site are similar to those of the native grassland, implying that these sites have equal productivity despite the great difference in age and soil development between them.

The high accumulation of detritus on the reclaimed area is probably related to maintenance fertilization during the previous growing season. With a large supply of readily available nutrients in the spring of 1978, along with the good growing conditions recorded for that period, the reclaimed areas could produce a substantial amount of aerial biomass while the native grassland, without this source of nutrients, would have lower production. This then, would be reflected in the detritus levels recorded in 1979 but would not necessarily be an indication of differences in decomposition or nutrient cycling between sites.

The rates of CO_2 evolution in the laboratory indicate that the soils of the native grassland and six year reclaimed site contain similar amounts of available organic matter. Chemical analysis has shown, however, that the grassland site has considerably higher total nitrogen and organic matter levels than any of the reclaimed sites. It is hypothesized therefore that although these sites have similar levels of organic substances which are readily available to support microbial activity, the native grassland contains a large pool of carbonaceous material which is not available. The group of organic compounds generally classified as humus are substances which are formed as residues of the decomposition process and are resistant to microbial degradation (Jannson, 1972). The unavailable

carbon pool hypothesized above is probably composed primarily of compounds of this type. The total organic complement of the native grassland soil can be simply described, therefore, as a small available pool in association with a large humus pool. In comparison, the organic matter of the six year reclaimed site is comprised of a similar sized available pool with a much smaller pool of humus.

Although the high levels of soil respiration recorded on the six year site suggest that general below-ground metabolism is quite high (Figure 6), the low rate of cellulose decomposition measured on this site in comparison with other areas (Figure 7) suggests that the factors controlling cellulolytic microbial activity are not consistent between sampling plots. Since a source of available nitrogen is necessary to allow the decomposition of cellulose, it appears that nitrogen availability is limited on the six year site. All of the other reclaimed areas received maintenance fertilization in June 1979 so that decomposition would have been supported by nitrogen from this source. The native grassland and naturally revegetated sites exhibited relatively high rates of cellulose loss without fertilizer input. This suggests that the soils of the unmanaged sites have the capacity to supply available nitrogen while the soil of the six year, and probably other reclaimed areas, have a much more limited capability in this regard.

The observed and implied differences between the cellulose decomposition and nitrogen availability of the unmanaged and managed sites may relate to the differences in the quality of organic matter in the soils of these areas. The availability of nitrogen is related to its rate of mineralization during the decomposition of organic compounds by micro-organisms in the soil. Alexander (1961) states that one unit of nitrogen is required to allow microbial utilization of approximately thirty units of carbon. Twenty of these carbon units are released as carbon dioxide while ten are incorporated into microbial tissue along with the nitrogen. Thus, in compounds with a carbon to nitrogen ratio (C:N) of thirty, nitrogen is neither required nor released in the process of decomposition. In compounds with low C:N ratios more nitrogen is available than is necessary, and the excess is mineralized by the micro-organisms. Fresh plant residues often have a C:N ratio to fifty or more while humus has a ratio between five and fifteen, equivalent to the C:N ratio of microbial tissue.

These data, therefore, support the hypothesis suggesting high humus levels in the native grassland since the high rate of cellulose decomposition measured must be supported by natural nitrogen mineralization through microbial degradation of low C:N ratio materials. Although

only one to two per cent of humus is decomposed annually (Janssen, 1972), its high level in the grassland soil allows the mineralization of substantial quantities of nitrogen. The relatively high rate of cellulose loss measured on the naturally revegetated area may also relate to higher humus levels in its soil. In addition, the effect may be augmented by the relatively high phosphorus availability in this site through the nitrogen/phosphorus interaction hypothesized previously. The organic matter in the soil of the six year reclaimed site, however, appears to have a high C:N ratio which permits lower rate of nitrogen mineralization and therefore lower levels of cellulose decomposition. Unfortunately, direct calculation of valid C:N ratios is not possible because of the influence of carbon and nitrogen in the parent materials. The ecological significance of the difference in the quality of organic matter between reclaimed and unmanaged sites and its relevance to management has not been discussed in the literature. Some speculative inferences however, can be drawn from the information provided by this study.

It appears that management practices may have a significant influence on soil development through the dynamics of soil organic matter. In an ecosystem developing under unmanaged conditions the production of plant residues is controlled to a large extent by organic

materials already in the soil, since plant growth is dependent largely upon nitrogen mineralization. Thus, a dynamic equilibrium is maintained between plant growth, detritus accumulation and soil organic matter. The increase in plant production and soil fertility will take place in small increments as nutrients are supplied to the system by biological fixation and rock weathering.

In a managed system, however, plant growth is controlled almost entirely by fertilization. Large inputs of nitrogen allow large amounts of high C:N ratio organic matter to be produced in a short period of time. In the initial stages of development it is expected therefore, that the C:N ratio of a reclaimed soil would be high relative to an unmanaged site at a similar stage of development. Under these conditions, nitrogen mineralization would be low and strong competition for fertilizer nutrients would occur between plants and microbial populations. The capability of the soil to maintain plant growth without fertilization would, therefore, be severely limited. Although the transformation of high C:N ratio plant residues to low C:N ratio humic materials would continue at a rate largely determined by climatic factors, the decomposition process would probably be increased by fertilizer nitrogen. It may be possible to develop a fertilizer management scheme which will provide a balance between plant residue

production and decomposition and thus allow the maximum rate of soil organic matter buildup without causing a detrimental accumulation of detritus.

Based on the previous discussion, it appears that a reclaimed area can be considered nutrient self-sufficient when nitrogen mineralization in the soil takes place without fertilization at a rate that will support the required level of plant growth. In this condition, a site will probably be able to continue to develop through natural processes without maintenance fertilization. Since the soil of the six year reclaimed site not only supported a high level of plant growth and microbial activity in 1979 but mineralized enough excess nitrogen to support the decomposition of extremely high C:N ratio cellulose paper, it is possible that this area has attained a nutrient self-sufficient state. Continued monitoring of this site will be required to test this hypothesis.

SUMMARY AND CONCLUSIONS

It is evident, from the results presented in the preceding sections, that the establishment of a functioning ecosystem on mine waste under the conditions studied, is rapid with intensive management. Although successional change is a gradual and continuing process, three relatively distinct stages in site development toward a maintenance free state can be identified in the reclaimed systems being studied. The hypothetical developmental series outlined below, appears to describe the processes which are active in high elevation reclaimed areas in southeastern British Columbia.

The prevegetation stage begins as soon as bedrock is blasted to expose coal seams. The rock is broken into progressively smaller fragments by heavy machinery working in the spoil. During this period the surface area of the waste material is increased tremendously and the natural chemical and mechanical processes of weathering initiate the first steps of soil formation. Within a short period of time following the final resloping of the dump it is likely that the spoil surface is colonized by micro-organisms from adjacent areas, through wind and dust fall. These probably remain dormant until conditions become suit-

able for growth but may utilize nitrogen and carbon sources which are inherent in the waste materials. The processes which govern succession in this stage are the same as in naturally disturbed areas, and the development toward a mature ecosystem proceeds at a very slow rate.

The maintenance dependent stage begins with the initial seeding and fertilization of the resloped dumps. One growing season is apparently required to allow the plants to become established. By the second season, a substantial level of root and shoot growth is attained and productivity continues at this level for several years as long as fertilization continues. In this stage, production is primarily dependent upon fertilizer input so that, within limits, any desired level of growth can be achieved by manipulating the fertilizer application rate.

The accumulation of significant quantities of organic matter in the system begins in the third growing season and colonization of the site by decomposer organisms and the initiation of decomposition follows rapidly. Dormant micro-organisms which arrived on the surface of the spoil prior to seeding probably participate in the initial colonization of the fresh detritus. Macro-decomposers, particularly arthropods, probably play an increasingly important role in decomposition but population sizes and levels of activity are not known. The decomposition of detritus on

the surface of the soil and of dead roots in the soil itself, is reflected in the continually increasing levels of available organic matter. The C:N ratio of the soil is maintained at a high level through input of plant residues and because of this, the availability of mineralized nitrogen is low. During the course of this stage, the C:N ratio is lowered by microbial activity and mineralized nitrogen levels begin to rise.

The maintenance independent stage of development is attained when nutrients begin to be cycled through the system in quantities which are sufficient to support an acceptable level of shoot growth and when nutrient input, under managed conditions, is greater than or equal to nutrient loss. A reclaimed system in such a state no longer requires fertilization but functions in a manner similar to natural seral systems. It has been suggested that this stage has been attained when nitrogen mineralization rates are sufficient to support the required level of shoot production. The six year reclaimed site, which supports shoot and root growth and microbial activity at a level similar to the native grassland, while providing mineralized nitrogen in quantities sufficient to allow microbial degradation of high C:N ratio cellulose material, may be closely approaching this stage.

Once the maintenance independent stage has been reached, the reclaimed areas can be managed toward a specific long term land use, such as wildlife habitat or forestry. At this stage, the fertility of the reclaimed soil has been improved to a degree which will probably allow the rapid and successful establishment of tree or shrub stands by planting or seeding. It is possible, however, that the competitive influence of the dense stands of agronomic grasses characteristic of this stage will discourage natural invasion and the growth of planted stock. It is still unknown whether continued successional change will take place by natural species replacement once a self-sustaining vegetation/soil system has been established.

In conclusion, it is apparent that reclamation activities by Kaiser Resources Ltd. have been successful in the initial establishment and early development of a functioning ecosystem on mine spoil at high elevation in southeastern British Columbia. However, the characteristics of the self-sustaining system, which is the goal of reclamation, remain poorly understood. This study implies that the role of soil organic matter and nitrogen mineralization may have a significant influence on the nutrient self-sufficiency of reclaimed systems but a greater understanding of the dynamics of this portion of the total system, and the factors which affect their function, is required before complete rehabilitation of mined lands is possible.

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APPENDIX I

Scientific Names of Plant Species Cited

Common Name	Scientific Name
alfalfa	Medicago sativa L.
alpine fir	Abies lasiocarpa (Hook.) Nutt.
alpine hawkweed	Hieracium gracile Hook.
alsike clover	Trifolium hybridum L.
black mountain huckleberry	Vaccinium membranaceum Dougl.
bluebunch wheatgrass	Agropyron spicatum (Pursh) Scribn. and Smith
creeping red fescue	Festuca rubra L.
Englemann spruce	Picea engelmanii Parry
false azalea	Menziesia ferruginea Smith
fern-leaved lomatium	Lomatium dissectum (Nutt.) Math. and Const.
flat-topped spiraea	Spirea betulifolia Pall.
grouseberry	Vaccinium scoparium Leiberg
Hood's sedge	Carex hoodii Bott.
Idaho fescue	Festuca idahoensis Elmer
lodgepole pine	Pinus contorta Dougl.
meadow foxtail	Alopecurus pratensis L.
orchard grass	Dactylis glomerata L.
pearly everlasting	Anaphalis margaritacea (L.) B. and H.
rosey pussytoes	Antennaria microphylla Rydb.
spike trisetum	Tristetum spicatum Richter
sulfur buckwheat	Eriogonum umbellatum Torr.
timothy	Phleum pratense L.
western sweet-root	Osmorhiza occidentalis (Nutt.) Torr.
white rhododendron	Rhododendron albiflorum (Hook.)
whitebark pine	Pinus albicaulis Englm.
wild rose	Rosa woodsii Lindl.

APPENDIX II

Physical Characteristics of the Study Site

Reclaimed Site	Date Established	Fertilizer Applied Since Establishment (Kg/Ha)	Exposure (degrees)	Elevation (meters)	Slope (degrees)	Soil Parent Material
0	1979	0	250	2000	18	mine waste, predominantly siltstone and mudstone
1	1978	220	170	2010	0	mine waste, predominantly siltstone and mudstone
2	1977 Fall	620	250	1980	0	mine waste, predominantly siltstone and mudstone
3	1977 Spring	620	258	2040	0	mine waste, predominantly siltstone and mudstone
5	1975	780	276	2040	7	mine waste, predominantly siltstone and mudstone
6	1974	950	-	2060	0	mine waste, predominantly sandstone
GR	Natural Establishment	-	113	2010	33	sandstone; colluvium
NR	Approx 1965	-	250	2040	0	sandstone weathered in situ

APPENDIX III

Summary of Biological Data

Site	Aerial Biomass (g/m^2)	Root Biomass (g/m^2)	Detritus Biomass (g/m^2)	Field Respiration ($mg/m^2/hr$)	Lab Respiration (mg/hr/100 gr soil)
0	0	0	0	0	.05 ± .05
1	5 ± 2*	4 ± 2	0	27 ± 4	.08 ± .05
2	81 ± 9	60 ± 10	19 ± 4	37 ± 5	.17 ± .02
3	91 ± 11	40 ± 11	196 ± 22	77 ± 10	.42 ± 12
5	91 ± 9	61 ± 15	171 ± 16	47 ± 6	.47 ± .13
6	183 ± 35	47 ± 14	352 ± 64	77 ± 2	.55 ± .08
G	184 ± 26	38 ± 7	172 ± 28	71 ± 15	.66 ± .08
NR	18 ± 7	28 ± 6	22 ± 5	45 ± 11	.14 ± 02

* Sample mean ± 95% confidence limits

APPENDIX IV

Summary of Soil Physical and Chemical Data

Size	Particle Size		pH (H_2O 2:1)	Electrical Conductivity (mmhos)	Available Phosphorus (ppm)	Total N (%)	Available Cations			
	% Fines < 2mm	% Coarse > 2 mm					Ca	Mg	K	Fe
							ppm			
0	24	76	8.1±0.2*	.11±.09	1.7±0.6	.17±.01	2500±1000	500+180	39±6	0.4±0.3
1	24	73	8.5±0.1	.10±.12	3.6±1.4	.18±.01	1300±300	370±98	45±4	0.6±0.2
2	23	77	7.5±0.2	.15± .24	18±3	.15±.01	1600±300	310±62	84±8	1.0±0.2
3	33	67	7.5±0.8	.23±.63	32±5	.12±.01	2300±600	310±58	93±9	2.1±0.3
5	16	84	7.3±0.1	.15±.14	14±6	.17±.01	1400±400	260±150	60±9	0.5±0.2
6	24	76	7.3±0.1	.17±.35	14±4	.16±.02	5000±1700	340±72	65±11	2.0±0.8
G	68	32	6.6±0.1	.15±.10	17±10	.72±.01	3200±100	280±85	220±6	1.0±0.5
NR	64	36	5.5±0.2	.06±.47	14±1	.12±.01	160±90	200±71	28±9	7.3±0.0

* sample mean ± 95% confidence limits

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Title of Thesis/Dissertation

Vegetation and soil development on reclaimed mine lands at high elevation in southeastern British Columbia.

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