Revegetation of Coal Spoils in Minto, N.B.: edaphic and ground cover responses to three management regimes.

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ABSTRACT

The proposal to revegetate unfertilized coal mine spoils with red pine in Minto, New Brunswick, may prove unsuccessful over the long term. Consequently, red pine, black locust and a control of pioneer tree species were used to study ground cover variations and edaphic differences on unfertilized spoil banks. Available bases and pH were acceptable for plant survival on all three treatments. Percent ground cover and species diversity were the greatest on the black locust sites. Establishment of ground cover on the red pine and control sites was most likely affected by a lack of litter and available nitrogen as well as wind, high temperatures, and crusty surface conditions. It was recommended that black locust be reconsidered as a reclamation species for the Minto spoils.

RÉSUMÉ

On a proposé d'utiliser le pin rouge pour recouvrir les déblais de mine non-fertilisés à Minto, au Nouveau - Brunswick. Ce plan pourrait échouer à long terme. Par conséquent, le pin rouge, le robinier faux-acacia, ainsi qu'un contrôle d'essences pionnières furent utilisés afin d'étudier les variations dans la couverture végétale et les différences édaphiques des déblais de mine de charbon a Minto, N.B. Les bases disponibles et le pH étaient propices à la survie des plantes dans les trois cas étudiés. Le pourcentage de couverture végétale et la diversité des espèces étaient le plus élevés aux sites de robinier faux-acacia. L'absence de litière et d'azote disponible, le vent, les températures élevées et un encroûtement de la surface ont vraisemblablement affecté l'établissement d'une couverture végétale aux sites de pin rouge et de contrôle. Il est recommandé que le robinier faux - acacia soit reconsidéré en tant qu'espèce apte à la réclamation des déblais de mine de Minto.

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1.0 Introduction

The Minto region of New Brunswick (Fig. 1) has been mined for anthracite coal since 1887 with stripmining being the dominant technique. To reduce erosion and improve the aesthetic quality of the mined areas, especially along public roads, the New Brunswick Department of Natural Resources (DNR) began reclaiming the area in 1967.

Stripmining for coal creates large areas of crushed overburden (the rock and debris found above the coal seam) commonly known as spoil. Greater public awareness of the environment and stricter laws governing the handling of that environment have led, in part, to the reclamation of derelict land left by stripmining. The actual legal processes governing methods of reclamation vary between legislative jurisdictions, however, the objective is normally to mitigate some of the undesirable conditions arising from surface mining. These conditions include erosion, the presence of toxic substances in soil and water, the lack of vegetation and the absence of a fertile soil medium.

Ecosystem development on degraded land tends to follow a pattern in which colonization by pioneer species is followed by the accumulation of nutrients in the plants and soil. Changes in soil structure due to plant and animal activity and reductions in the levels of toxicity further ameliorate the environment. The progress of this development can be speeded by

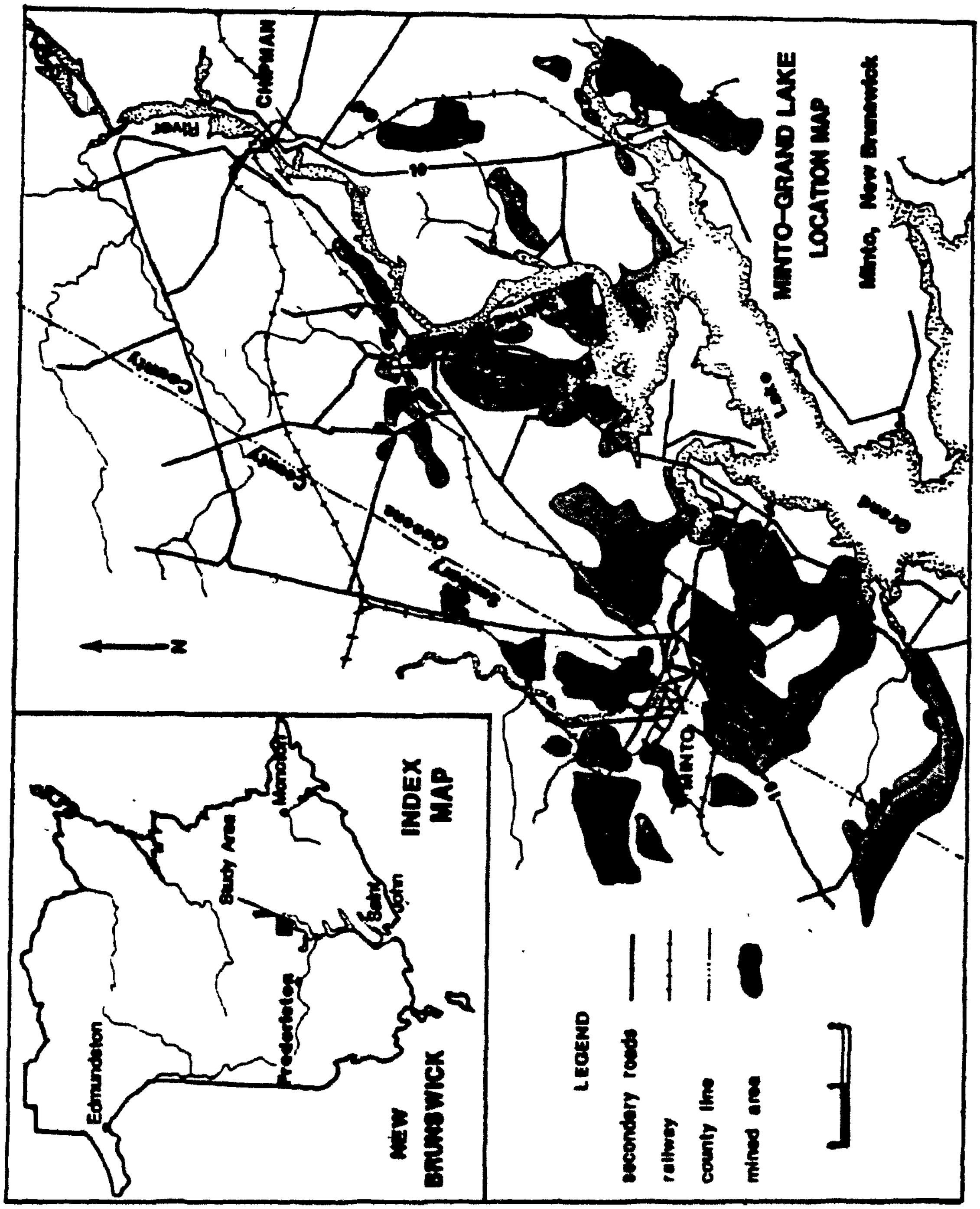


Fig. 1. Minto-Grand Lake study area location map.

human intervention since the planting of suitable species can occur far in advance of even aggressive colonization by native species. Low planting and maintenance costs and long term viability should be major criteria for species selection in the reclamation of areas with low accessibility. However, the measure of success of planting programs is rapid restoration of soil quality and of full vegetation cover.

To date, few attempts have been made to determine whether tree species planted on the Minto spoils have long term affects on a) the soil conditions or b) the underlying ground cover.

Previous studies on stripmine revegetation in New Brunswick - reviewed in more detail later in this thesis - have dealt with the introduction of various tree and grass species (Meadows 1967, 1968, Rowan 1969, Smith 1970, Rayworth 1971, Nightingale 1972a, 1973, Logan 1978), nutrient deficiency (Rivard and Smith 1978), the fertilization of trial plots (McDonald 1979), or were part of environmental impact assessements (Abbott 1976, Montreal Engineering Co.(MEC) 1978). A more detailed study dealt with the natural succession occurring around the surface mine ponds (Nightingale 1972b). However, there is a need to enlarge this data base to include the success of introduced species in sustaining continual vegetation on the spoils, in other words, to examine the long term effects of tree planting. This thesis proposes to evaluate the effectivenes of recent tree planting programs by examining sites of black locust (<u>Robinia pseudoacacia</u> L.), and red pine (<u>Pinus resinosa</u> Ait.). Sites where white birch (Betula papyrifera Marsh.), trembling aspen (Populus tremuloides Michx.) and pin cherry (Prunus pennsylvanica L.) recolonize naturally were used as a control for comparison.

1.1 The Minto Problem

The main coal reserve of the Minto coal fields, operated by New Brunswick Coal, Ltd. (N.B. Coal), is of low quality coal occupying 1133 ha at the northern end of Grand Lake and is known as the Salmon Harbour Mine (MEC 1978).

Mean monthly temperatures from May to September are 15°C (5 month max=21°C) and the frost free period is approximately 170 days. Rainfall from April to September is 500 mm and extended dry periods are infrequent (Table 1) (Abbott 1976, MEC 1978).

The native soils of the region are defined as the Queens, Harcourt and Midland series (MEC 1978). The former two were developed on basal or ablation till of clay loam and clay texture overlain by coarse materials derived from grey and red sandstones and shale. The latter series is composed of red sandy loam and is the result of sandstone and conglomerate. All three are moderately acidic soil types and support forest vegetation (MEC 1978). Soil capability for agriculture is generally poor ranging from those soils having moderately severe limitations that restrict crop type to those with no capability

TABLE 1.

Meteorological Information, Minto, New Brunswick
30 Year Average

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year Total
Temperature °C													
Maximum	-3	-5	3	10	18	21	25	23	20	13	6	-2	
Minimum	-15	-13	-8	-2	3	8	12	12	8	3	-3	-12	
Mean	-9	-9	-3	4	11	15	19	18	14	8	2	-7	
Degree days (+ 5.6°C)[1]			3	40	252	599	798	775	472	190	27		3156
Growing days (+ 5.6°C)[1]			10	22	31	30	31	31	30	29	11		225
Frost free days[2]			3	13	29	30	31	31	29	24	9		199
Sunshine (No. of hrs. bright sun)	100	117	138	158	206	198	234	225	160	144	90	91	1861
Precipitation[3]													
Mean rainfall (mm)	35.3	24.6	39.9	59.2	71.4	88.6	90.4	80.5	83.8	75.9	85.6	43.9	779.1
snowfall (cm)	48.8	47.2	38.6	14.0	T	0.0	0.0	0.0	0.0	1.5	11.9	41.4	203.4
total precip. (cm)	8.4	7.2	7.8	7.3	7.1	8.9	9.0	8.1	8.4	7.7	9.8	8.5	98.2
Max. precip. in 24 hrs. (cm)	5.6	3.8	5.4	5.5	3.6	5.9	6.8	6.4	6.9	8.0	5.3	5.1	
Mean no. days with													
measurable rain	3	3	5	7	11	12	12	11	10	10	10	4	98
snow	7	6	5	2	-	-	-	-	-	-	2	6	28
precip.	10	9	10	9	11	12	12	11	10	10	12	10	126
Mean no. days total precip. 0.25 cm	9			8			8			9			
Winds[4]													
Gust speed (kph)	145			129			121			137			
Mean wind speed (kph)		19.3 (winter)			16.0 (spring)			16.0 (summer)			16.0 (fall)		

1) Start of growing season: Apr. 22
End of growing season: Oct. 25

2) Last frost in spring: May 20
First frost in fall: Sept 22

3) Mean precip. Apr-Sept: 510mm
Oct-Mar: 510 mm
Mean annual runoff: 71 cm
Mean annual evaporation small lakes: 61cm

4) Wind direction (Frequency %)

	N	NE	E	SW	S	SW	W	NW
winter	12	7	7	6	10	14	32	12
summer	9	11	6	7	16	30	15	6
annual	12	10	8	7	14	19	20	10

(Abbott 1976)

for arable agriculture or permanent pasture (MEC 1978). Similarly, forest capability ranges from moderately severe limitations to severe restrictions for the production of commercial forest (MEC 1978).

Original vegetation on the stripmine area consisted of white pine (Pinus strobus L.), balsam fir (Abies balsamea (L.) Mill.), black spruce, (Picea mariana (Mill.) B.S.P.), red maple (Acer rubrum L.), wire birch (Betula populifolia) and aspen (Populus spp.) with black spruce and balsam fir being common on marshy sites (Abbott and Bacon 1977, MEC 1978).

The spoils resulting from the stripmining at Minto vary from older gently rolling slopes to the recently deposited steep ridges. Surface overburden is composed of crushed, weathered shale with pockets of sandstone. The older slopes which had little or no grading, lie at an angle of approximately 35 degrees, averaging 10-15 m high and are 15-30 m apart (Meadows 1967, Abbott 1976). The majority of the stripping is now done by the '8200' dragline which can reach depths of 37 m. Because of the greater depth excavated by newer draglines, grading and levelling are necessary for safety and planting purposes (N.B.Coal 1982, Shaw 1982).

The coal, which is in seams usually no more than 48 cm thick, lies beneath an average of 27 m of overburden composed largely of sandstone and shale (FENCO 1971, Abbott and Bacon 1977, MEC 1978). When the overburden is first removed it has a pH of approximately 7.0, but with the weathering of pyrites the pH decreases to 2.6 within 6 months of disturbance; a further problem is the presence of free sulphuric acid in the surface layers of some of the spoils, a result of the high sulphur content in the coal (Rowan 1969). The reduction of the acidity is partially inhibited by the high clay content which absorbs hydrogen ions thus maintaining acid conditions. However, after 2-3 years the spoils reach an equilibrium of pH 4.5-5.0 (Rowan 1972). Thus, attempts to revegetate occur following a 2-3 year waiting period to allow the breakdown of the shale, an increase in pH and a reduction of sulphuric acid within the spoil overburden.

To appreciate possible improvements brought about by planned revegetation it is necessary to understand the natural succession of vegetation and edaphic conditions of untouched spoils. Several authors have documented the establishment of local species and the temporal change in spoil physical and chemical characteristics on coal mine spoils in the United States. Croxton (1928), in studying the natural revegetation of coal stripped lands in Illinois, found that sites with a pH of less than 5.0 were not well covered. However, with increased moisture overall stress was reduced thereby improving conditions for growth. Bramble and Ashley (1955) followed the natural succession on selected Pennsylvania coal mine spoils noting that exposure to wind, high surface temperatures, spoil surface permeability and acidity retarded the establishment of plants. The problems associated with toxicity of coal mine spoils have been dealt with at length (Berg and Vogel 1973, Knabe 1973, Vogel and Curtis 1978, Dollhopf 1979, Pionke and Rogowski 1979, Pole et al. 1979). The most frequent negative effects were the release of toxic elements such as manganese and aluminum at low pH and the presence of sulphuric acid.

The development of soils is slow on minespoils, and while nitrogen is the main limiting factor (Rivard and Smith 1978), other nutrients may be sufficient for growth of hardier species (Cornwell 1971, Indorante and Jansen 1981). Johnson et al. (1982), in a study of 49 unreclaimed Oklahoma coal stripmines ranging from 10 to 70 years old, found that the soils did not undergo any appreciable horizon development over that time span. However soil chemical properties improved and ground cover tended to increase with age. The authors concluded that sites having a high initial concentration of calcium and potassium and low concentrations of iron would probably support vegetation with little to no amendments.

The adverse conditions associated with coal spoils retard natural revegetation. Bramble and Ashley (1955) noted that it took four years for plant cover to begin invading Pennsylvanian spoils, while Abbott (1977) stated that a scattering of individual trees and plants were found only on Minto spoils 5 years or older.

The object of site amelioration is to speed up the natural process, thereby reducing the negative effects associated with coal mine spoils.

1.2 Revegetation efforts at Minto

Early planting techniques and species selection attempted by the DNR were based on programs carried out in the Central and Eastern United States (Meadows 1967), but lack of preliminary soil surveys, damaged stock and drought led to high mortality of tree species (40-60%) within the first experimental plots. However, after 1967 experimentation with varied tree and grass species, time of planting, root stock, fertilizers, grading and levelling, and topsoiling, improved methods of revegetation. Tree species which showed the best survival rates when planted in the spring as bare root stock were: red pine, jack pine (*Pinus banksiana* Lamb.), scots pine (*Pinus sylvestrus* L.), and black locust, (Nightingale 1973). Grass species planted on pond banks which showed moderate success were: white Dutch clover (*Trifolium repens* L.), birdsfoot trefoil (*Lotus corniculatus* L.), sweet clover (*Melilotus alba* Desr.), and red top clover (*Agrostis alba* L.) (Nightingale 1972b). (See appendix for a complete species list).

Since nitrogen is the main factor limiting tree growth on the spoils (Rivard and Smith 1978), fertilizer use or the planting of leguminous species were found to be necessary. Logan (1978) indicated that legumes were preferred to fertilizer since the latter was depleted within 5 years of application (Logan 1982) and without continual fertilization, growth slowed and vegetation became chlorotic within 3 years. Many legume species are intolerant to shade and once crown closure begins, mortality increases. The same applies to the legume black locust if it is shaded by surrounding tree species. In mixed stands with red pine, this could be avoided by planting locust on spoil tops above red pine. Locust is more drought resistant than the pine, and the nitrogen which it supplies will leach down to the less resistant red pine at the spoil bases (Shanks 1970).

Grading and levelling of the spoils is generally prohibitive in cost and so was confined to roadside spoils for aesthetic purposes (Meadows 1967). Bulldozing has been found to reduce a mulching effect of shale and so proved detrimental to revegetation during drought (Smith 1968). Further, the disturbance of the spoils also leads to the exposure of soil concentrated with sulphuric acid and causes compaction (Rowan 1969).

Replacing topsoil is inefficient not only because of its poor original quality but also because the topsoil has a high clay content and when dried hardens to form a crusty surface which is difficult to pierce when planting (Nightingale 1972a).

Of the 4 858 ha disturbed since 1887 the DNR had reforested 1 307 ha by 1978 (Logan 1978). With the purchase of the 8200 dragline in 1979, some of the older site management policies were changed to suit new conditions. New spoils must be graded to an average slope of 20 degrees directly following disturbance, with planting occurring after a 2-3 year period (Logan 1982, N.B.Coal 1982, Shaw 1982).

1.3 Revegetation plans

The DNR will plant red pine supplemented with jack pine on most of the graded spoils (Logan 1982). This species choice was based on the good survival rate of both trees and the aesthetic advantages of the red pine. Legumes will be planted on high erosion areas such as stream and and pond banks (MacLaggan 1984). The black locust will not be used as a revegetation species because of its thorns, poor economic value and the fear that it might become a pest species (Logan 1982).

N.B.Coal is interested in establishing a 40 ha commercial Christmas tree plantation using jack pine. They are also involved in a joint project with New Brunswick Power Ltd., constructing greenhouses which will be heated by warm plant waste water from the Grand Lake Thermal Generating Station and will be used for nursery stock for reclamation or agricultural produce for local markets. N.B.Coal will also continue to support the stocking of surface mine ponds which are used for sport fishing, and will update mapped information on the past and future reclamation to comply with governmental regulations (N.B.Coal 1982, Shaw 1982).

1.4 Trees vs. grasses as revegetation species

Current methods of reclamation have led to the establishment of a limited number of favoured plant species and the prospect of ecosystems of low diversity and thus restricted land use and wildlife habitat potential (Roberts et al. 1981). The preference for grass species expressed by many as a means of quick, easy coverage (Vogel and Berg 1968, Ruffner and Steiner 1973), leaves areas of limited use. Tree species, may not reduce erosion as quickly as grasses (Bradshaw and Chadwick 1980) but require less fertile soils and help to reduce the extremely high temperatures associated with dark shale coal mine spoils which inhibit the establishment of incoming successional species (Riley 1957). (Riley found that often a difference of 20° C existed between shade and open ground). Furthermore, their ability to withstand drought is stronger due to greater rooting depth (Ashby et al. 1978). Introduced grass species may discourage the influx of natural ground cover since most of the early successional herbaceous species colonize open spaces (Cornwell 1971).

Ashby et al.(1978) pointed out that trees help reduce dust from mining and reduce both wind erosion and water erosion. However, tree species introduced to the spoils vary not only in survival but in their ability to improve conditions suitable for the establishment of associated vegetation within a reasonable time period.

1.5 Black locust as a revegetation species

Nitrogen has been shown to be the major nutrient lacking in coal mine spoils (Cornwell and Stone 1968, Mays and Bengston 1978, Rivard and Smith 1978, Jeffries et al. 1981, Bloomfield et al. 1982, Bradshaw 1983). The nitrogen-fixing bacteria associated with the nodules on the black locust roots increase the nitrogen content of the soil in which the tree grows (Chapman 1935, Ike and Stone 1958). Further, the deposition and decomposition of the large annual litter layer increases soil calcium, magnesium, potassium, nitrates and pH (Garman and Merkle 1938).

The rapid decomposition of the litter releases nitrates which are readily available to other plants (Auten 1945), with this high annual turnover being principally responsible for the effects on associated vegetation (Ike and Stone 1958, Fowells 1975, Carpenter and Eigel 1979). Similarily, Stroo and Jencks (1982) found a rapid accumulation in the annual rate of nitrogen as well as improved microbial activity beneath black locust on minespoils in West Virginia. The positive effect to growth of other plant species grown in proximity to the black locust has been noted frequently (McIntyre and Jeffries 1932, Chapman 1935, Auten 1945, Ike and Stone 1958, Ashby and Baker 1968). Hence, planting black locust is synonomous with a continuous, inexpensive nitrogen fertilization program.

Extensive planting of the leguminous tree species black locust has occurred in the Eastern United States (Miles et al. 1973, Vogel and Berg 1973, Bennett et al. 1978, Plass 1978, Carpenter and Eigel 1979, Jencks et al. 1982), on sites comparable to those at Minto. Attributes of this species, other than nitrogen fixing, which are beneficial to reclamation include its ability to grow rapidly, to survive within a pH range of 4.6 to 8.2, to adapt to a large range of conditions such as dry and infertile sites, and to sprout prolifically through vegetative reproduction (DenUyl 1962, Vogel and Berg 1973, Lowe 1979, Jencks et al. 1982). It is also beneficial in creating suitable wildlife habitats on coal mine spoils. Riley (1957) found that of six hardwood species surveyed on Ohio spoil banks, black locust proved superior, providing a closed canopy within 8 years (at 1.8 x 1.8 m spacing) and shelter during the spring and summer months.

Black locust can be used commercially if the stands are healthy, however because of disease and insect problems it often remains an unmarketable product (Bennett et al. 1978). Healthy stands reach heights of 8 to 12 meters and because of rapid growth, form crown closure and cover at an early age. This enables the locust to over top other species which, without release, may die.

The main disease prevalent amongst the locust on the Minto coal spoils is nectria canker (Nectria cinnabarina Tode) (Nightingale 1973), which causes dieback of the main stem and heavy sprouting, which in conjunction with the long thorns of the locust, creates impenetrable thickets. Here, nectria canker can be beneficial since dieback reduces competitive exclusion for associated species in the mixed stands of the Minto spoils.

Black locust is very intolerant to shade and if planted with herbaceous species, may not survive (Fowells 1975). However, Vogel and Berg (1973) showed good success when black locust were seeded with slower developing vegetation, or species that grew in late spring and summer.

The black locust introduced to the Minto coal spoils were imported from Holland and the Mid-central United States. (Using a closer source, the Appalachian Mountains, could mean greater seedling survival). The best survival rates were achieved by planting in the spring as bare root stock at 2.7 x 2.7 m spacing. Some selective fertilizer trials were attempted with phosphorus and potassium (2:1 ratio at 2 oz. per tree). Results were good but only lasted two years following which a reapplication would have been necessary (Smith 1970).

Thus, the advantages of using black locust as a reclamation species are: they improve soil conditions, do not require regular maintenance associated with legumes and are a self sustaining plant community.

1.6 Red pine as a revegetation species

The commercial viability of the red pine as well as its ability to survive on acidic,sandy soils have made it a common revegetation species on coal mine spoils (Aharrah and Hartman 1973, Bennett et al. 1978, Logan 1982). Further, it is indigenous to the area and therefore easily obtained and acclimatized to the regional conditions. However, survival of seedlings is often hindered by the high temperatures and winds associated with spoil tops (Nightingale 1972a, MEC 1978) and to achieve good growth on the nutrient poor spoils requires the regular application of fertilizer or the presence of leguminous species (McDonald 1979, Logan 1982).

Trials on the Minto spoils showed the need for fertilization. Following a ten year period pines which were fertilized reached heights of 0.9 to 3.7 m whereas those which were not were only 0.3 to 0.9 m high (Abbott 1976). Alban (1982) showed that soil under red pine plantations were slow to accumulate nutrients, especially nitrogen and phosphorus.

The amount of litter deposited annually by red pine is both meagre and low in fertility (Auten 1945, Alban 1982), and decomposition returns less than one third of the annual uptake of nutrients to the soil (Fowells 1975). The slow rate in accumulation of the litter layer was related to the number of seasons that the needles remain on the branches, which in the case of the red pine is four (Mergen and Malcolm 1955).

The red pine is intolerant to shade and can be overshadowed and replaced by associated vegetation if growth rates are slow. Lambert et al. (1972) showed that red pine increased vertical growth rate by 13 percent when weeds were removed from a young plantation.

This species does not produce a self sustaining community on mine spoils because not only is cone production rare (Aharrah and Hartman 1973) but emergence and survival of seedlings unlikely. Seed trials on spoil piles showed poor survival rates due in part to soil crusting and soil texture (Plass 1974). Conover (1953), in studying the effects of competition on red and white pines determined that the regeneration of red pine was hampered by competition of brush and the presence of a heavy overstory.

Although the red pine may endure site conditions and improve the physical soil structure (Auten 1945) continual maintenance is required if commercial yields are to be achieved. It is slow to improve soil nutrient availability as shown by Wilde (1964) who found that pine plantations younger than 20 years maintained most of the soil characteristics present at the time of planting and only after 35 years were soil deficiencies corrected. For coal mine spoils this could be a limiting factor to rapid natural development and colonization.

1.7 Thesis Rationale

This thesis studies edaphic parameters and ground cover on selected sites at Minto. The results are used to describe successional models (Section 5.0) and management alternatives (Section 6.0) useful for future reclamation. The interaction of soil and ground cover can provide a cross-reference for site differences. Soil parameters such as nutrient levels and pH may indicate site conditions and may partially explain the presence or abundance of ground cover; ground cover species can be used as partial indicators of site conditions such as soil moisture and nutrient levels as well as the success of habitat amelioration (Bradshaw and Chadwick 1980, Bradshaw 1983). Moreover, the greater the species diversity the higher the probability of the site being self-sustaining and able to support wildlife (Vogel and Curtis 1978).

Three different management options (henceforth called 'treatments') were chosen for study: 1) red pine, because it is the preferred tree species for the Minto area, 2) black locust, because it is leguminous and hence a natural source of N fertilizer, can survive on the spoil overburden and has been used extensively in the United States, and 3) a control which was left to recolonize naturally and therefore provided a comparison for the other two species.

Given that red pine is the preferred species for revegetation, the following questions are considered:

1) if planted without fertilizer and regular site maintenance, is the red pine a successful reclamation species in terms of providing ground cover and improved soil conditions;

2) if the red pine is not a successful reclamation species are there measures which can be taken to improve conditions in an economic manner.

However, the foci of this thesis are the linked processes of the establishment of vegetation and the creation of 'soil' from spoil material.

2.0 Site Selection and Methods

2.1 Site selection

Study sites were chosen for maximal inherent similarity in genesis, surface material and age of revegetation tree species (Table 2). Two discrete sites were selected from each management treatment for detailed evaluation (Fig. 2).

Table 2. Age of black locust, red pine and control sites.

Site	Age of vegetation	No. years since creation of spoil
1 and 2 (Black locust)	11 years	~ 15
3 and 4 (Red pine)	13 years	~ 15
5 and 6 (Control)	~12 years (aged by tree core samples)	~ 17

2.2 Site description

All sites selected had gently rolling, parallel slopes. Site 1 (black locust) and site 6 (control) contained the steepest slopes averaging 30 degrees. Ridges in black locust and control areas ran in an east west direction while in red pine areas they ran in a north-east south-west pattern.

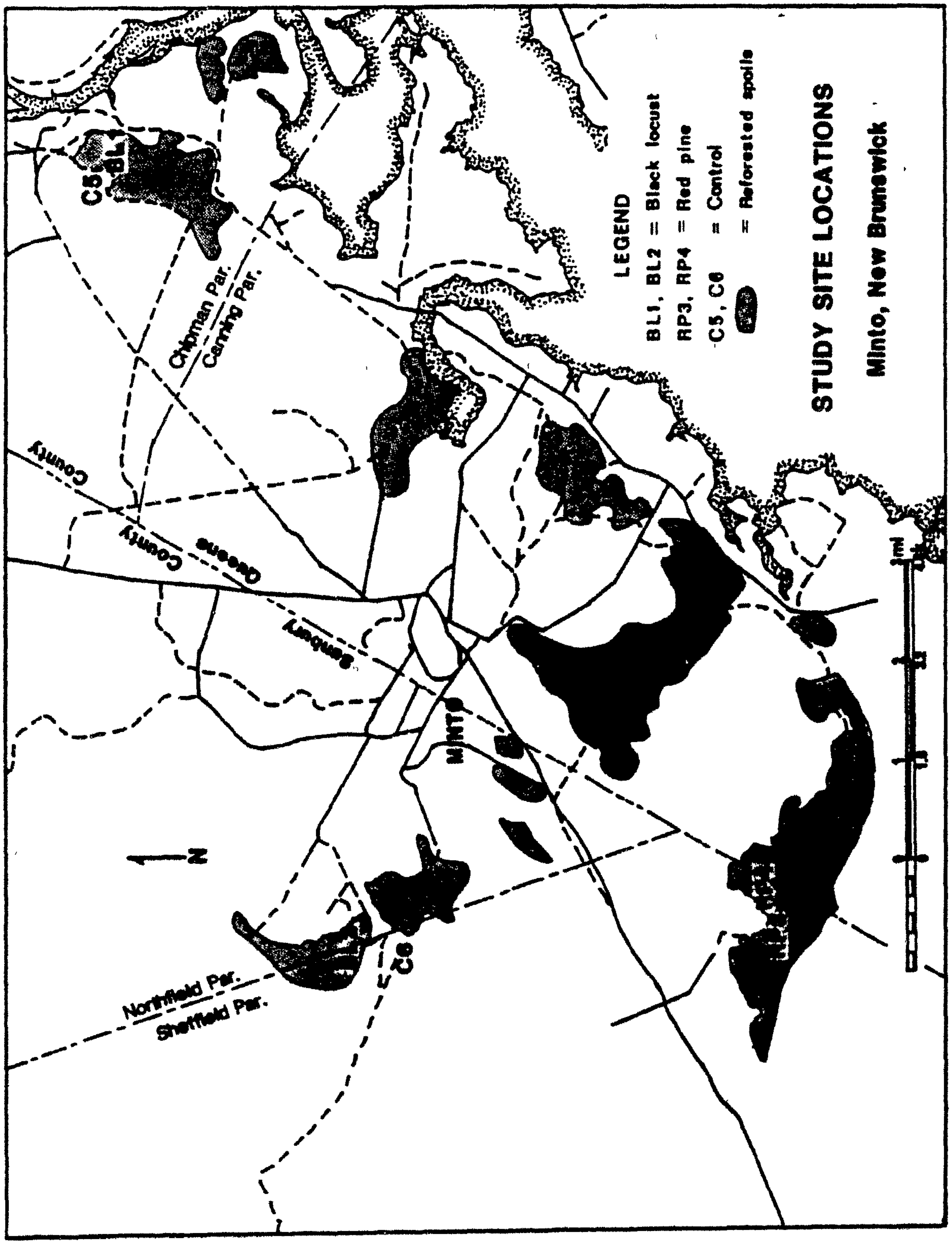


Fig. 2. Study site locations of red pine, black locust and control sites.

There was natural vegetation within 600 m of each site. Sites 2,3 5 and 6 contained ponds. None of the sites was levelled or fertilized in the preliminary preparation for revegetation.

2.3 Sampling techniques

Site size varied according to the number of hectares planted for each species (Table 3), with the result that the larger sites were sampled less intensively per unit area than the smaller sites. A simple closed traverse was used to set up the boundaries for each site which were then partitioned by a dot grid pattern at the spacing indicated in Table 3. Buffer zones of 9 percent and 7 percent for the larger and smaller plots respectively were established around each of the sites to reduce the edge effect. Twenty points were randomly selected from the dots resulting in a total of 40 points for each treatment and 120 points for the study. Soil cores, 15 cm deep by 10 cm wide were extracted and bagged for analysis. Position on the slope and aspect were also recorded. All sampling was done within a two week period from July 31 to August 11, 1982. At each sampling point a $1m^2$ grid was used to study herbaceous species occurrence, diversity and frequency; frequency was determined by noting those species appearing directly under grid points which were at 20 x 20 cm spacing.

TABLE 3 . Site dimensions including buffer zones for all sites of black locust, red pine and control.

Species	Site	Dimensions	Grid spacing	% No. points sampled (n = 20)
Black locust	1	225 x 250m	25 x 25m	31
	2	150 x 200m	12.5 x 12.5m	28
Red pine	3	150 x 200m	12.5 x 12.5m	28
	4	225 x 250m	25 x 25m	31
Control	5	150 x 150m	12.5 x 12.5m	28
	6	150 x 150m	12.5 x 12.5m	28

2.4 Laboratory analyses

Soil cores were air dried and passed through a 2 mm sieve. The following analyses were then performed on subsamples:

1)Particle size distribution was determined by the pipette method and converted to soil texture (Day 1965).

2)Organic matter was determined by weight loss after oven drying for 24 hours at 105'C and igniting at 850'C for one-half hour. A value of 2% was subtracted from results to account for water loss during ignition. (Ball 1964).

3)A 1:1 ratio of soil/water paste was used for pH analysis (Peech 1965).

4)Exchangeable Ca, Mg, K, Na and H were extracted with neutral 1N ammonium acetate, the bases being determined by atomic absorption spectrophotometry and H by pH change (Chapman 1965).

5)Available P was extracted with a NH4F-HCl solution and determined by the ammonium molybdate-ascorbic acid method (Olsen and Dean 1965, Hesse 1971).

All soil analyses were duplicated and where discrepancies appeared, analyses were repeated. Results appear as the means of the duplicates.

Because planting black locust is equivalent to nitrogen fertilization, it was felt that chemical analysis of N would be redundant since neither the red pine nor the control had received this treatment, and would consequently be lower in available N. Thus, emphasis was placed on the ability of each of the three treatments to affect soil, ground cover and microclimate. However, the availability of N is considered in the discussion of the results.

2.5 Ground cover analysis

All herbaceous species from within the 1 m^2 quadrats were removed, bagged and subsequently identified.

Species diversity was calculated using the Shannon-Weiner diversity index (Remmert 1980, Ricklefs 1980, Farmer et al. 1982), such that:

$$H' = -\sum \frac{\text{No. plants for individual spp.}}{\text{Total No. plants}} \log \frac{\text{No. plants for individual spp.}}{\text{Total No. plants}}$$

Percent relative frequency was calculated by the formula:

$$F = \frac{\text{Frequency of a species}}{\text{Sum of frequency values for all species}} \times 100$$

(Curtis and McIntosh 1950, Kershaw 1973) where frequency was determined for each site and for each species. The selection of these formulae was based on the need for a common measure of species diversity and frequency so that results could be compared with studies reviewed in the literature. Percent ground cover was determined by the number of segments in the 1 m^2 grid which contained vegetation, where: $\% C = x/25 \times 100$. Allowances were made for semi-vegetated segments.

2.7 Statistical Analysis

Normal distribution was determined using the Shapiro-Wilk statistic 'W' (data were similar to a normal distribution). Analysis of variance (ANOVA) was done on the soil laboratory results and the percent ground cover. The Duncan Multiple Range test (Alpha = 0.05) was used to establish significantly different means among sites and between species. A correlation matrix and stepwise regression were used to determine any relationship existing between the soil parameters and ground cover.

3.0 Results

3.1 Results by treatment

The spoils beneath treatments of black locust, red pine, and control sites ranged from strongly acidic (pH 3.0) to neutral (7.4 pH). The soil texture was predominantly loam although clay ranged from 13 to 46 %, silt ranged from 16 to 59 %, and sand ranged from 12 to 65 %.

Available phosphorus ranged from 63 to 400 ppm while exchangeable bases of potassium, sodium, magnesium, and calcium ranged from 0.10 to 0.45, 0.13 to 0.21, 0.10 to 2.78, and 0.05 to 10.75 m.e./100g respectively.

Ground cover ranged from 0 to 100 %, while litter depth ranged from 0 to 4 cm.

Analysis of variance gave the following results (Table 4):

pH was significantly higher ($P < 0.05$) on black locust and red pine than on the control but there was no significant difference in percent organic matter between the three treatments at $P < 0.05$.

Soil texture contained significantly more ($P < 0.05$) silt and significantly less sand ($P < 0.05$) on black locust and red pine than on the control; there was no significant difference in the percent clay between the three treatments.

Available phosphorus was significantly higher ($P < 0.05$) on the black locust treatment than on either red pine or control

TABLE 4. Treatment means and standard errors for soil parameters and ground cover for black locust, red pine and control

VARIABLE	TREATMENT		
	Black locust (n=40)	Red pine (n=40)	Control (n=40)
pH	5.0 ±0.12 a	5.2 ±0.12 a	4.5 ±0.10 b
Organic matter (%)	5.2 ±0.22 a	4.7 ±0.24 a	4.8 ±0.23 a
Soil texture (%)			
Clay	22.6 ±0.09 a	22.9 ±0.07 a	23.2 ±0.07 a
Silt	41.0 ±0.15 a	43.0 ±0.10 a	34.0 ±0.10 b
Sand	37.0 ±0.16 b	34.0 ±0.10 b	43.0 ±0.10 a
Available P (ppm)	250.0 ±1.83 a	187.5 ±8.02 b	200.0 ±11.30 b
Exchangeable bases (me/100 g soil)			
K	0.24 ±0.01 a	0.19 ±0.01 b	0.18 ±0.006 b
Na	0.16 ±0.002 a	0.15 ±0.001 b	0.14 ±0.001 c
Mg	1.37 ±0.10 a	1.18 ±0.07 a	0.89 ±0.11 b
Ca	5.21 ±0.45 a	5.34 ±0.41 a	3.07 ±0.53 b
Base saturation (%)	88.7 ±1.82 a	94.4 ±2.27 a	73.1 ±3.53 b
CEC (me/100 g soil)	7.6 ±0.49 a	7.0 ±0.43 a	4.9 ±0.59 b
Ground cover (%)	65.0 ±5.59 a	13.1 ±3.61 b	5.9 ±2.58 b
Litter layer (cm)	1.3 ±0.26 a	0.08 ±0.05 b	0.18 ±0.10 b

N.B. values with the same letter are not significantly different at α=0.05

as was sodium; sodium was significantly higher ($P<0.05$) on the red pine treatment than on the control.

Both black locust and red pine contained significantly more ($P<0.05$) calcium and magnesium than the control.

Base saturation and cation exchange capacity were significantly greater ($P<0.05$) on the black locust and red pine treatments than on the control treatment.

Ground cover and litter layer depth were significantly ($P<0.05$) greater on the black locust treatment than on either the red pine or control treatments.

Species diversity and frequency (Table 5) were greater on the black locust treatment than on the other two treatments. Frequency of shrubs was greatest on the control decreasing from red pine to black locust. Although young seedlings of the invading pioneer species were present on both the control and black locust treatments, there were none within the 1 m^2 quadrat on the red pine. Grass and sedge species present on the black locust decreased in frequency from red pine to control so that the latter was devoid of these vegetation types.

Correlation matrices suggested no significant relationships ($P<0.05$) between ground cover and soil characteristics.

TABLE 5. Diversity and percent relative frequency of species found beneath the three treatments of black locust, red pine and control.

$$H' = -\sum_{i=1}^{s} p_i \ln p_i \qquad \% F = \frac{F(x)}{\sum F(X)} \times 100$$

Species	% F Black locust	Red pine	Control
Carex umbellata	0.59		
C. cumulatus	0.29		
C. debilis	1.19		
Danthonia spicata	0.29	9.86	
Poa compressa	2.99		
P. palustris	5.37		
Anaphalis margaritacea	2.39		
Aralia hispida	1.49		
Aster lateriflorus	7.46	2.82	
A. umbellatus	1.79		
Comptonia peregrina	1.79	26.76	18.42
Cornus canadensis		4.20	
Diervilla lonicera			15.78
Epilobium watsonii	0.59	4.20	
Equisitum arvense		4.22	
Hieracium aurantacium	12.84	4.20	
H. kalmii	2.99		
H. pilosella	11.04	21.12	
Pyrola elliptica	5.67	2.82	
Rubus allegheniensis	2.09		
R. setosus	9.85	5.60	
Senecio viscosus	2.08		
Solidago graminifolia	9.25		
Spirea latifolia	7.16		5.26
Trifolium spp.		11.26	
Betula papyrifera	0.29		31.56
Populus tremuloides	1.46		7.89
Prunus pennsylvanica	0.29		15.78
Robinia pseudoacacia	11.34		
Salix discolor			21.05
H'	2.35	1.25	0.76

n.b. all tree species listed here appeared as seedlings.

4.0 Discussion

4.1 Edaphic features

4.1.1 Nutrient availability

Surface materials resulting from strip mining are dissimilar to the former soils of the area and are assumed to be heterogenous in nature because of the mixing of the various layers of substrate (Cornwell 1971, Plass and Vogel 1973, Johnson et al. 1982).

Native undisturbed soils in the Minto area revealed pH values of 4.4 (Stobbe 1940) which were lower than those of the three treatments.

Heterogeneity, as expected, was evident within treatments, but was limited to nutrient availability and proportion of sand (red pine) and silt (black locust). The control sites had the greatest amount of variation in soil parameters although this had no effect on the percent ground cover.

Between treatment variability of nutrients was shown by the higher amounts of available phosphorus and exchangeable potassium and sodium found beneath the black locust. Further, black locust and red pine were consistently higher in exchangeable calcium, magnesium as well as base saturation and cation exchange capacity when compared to the control. This is probably due to the large number of control samples which were devoid of any vegetation and emphasizes the need for revegetating spoil material.

Although available nitrogen was not analysed, the high correlation between black locust and the presence of nitrogen in soils has been constantly documented as previously shown. On minespoils in southern Illinois, black locust soil was inherently richer in nitrogen than soils beneath shortleaf pines (Ashby and Baker 1968). Total nitrogen in West Virginia mine soils beneath black locust plantations was comparable to and sometimes greater than surrounding native soils and Jencks et al. (1982) felt it to be sufficient to permit invasion by other vegetation to an over burden otherwise devoid of nitrogen. Elsewhere, Carpenter and Eigel (1979) found that soil nutrient accumulation did not vary between the species on minespoils in Kentucky excepting nitrogen which was significantly higher under black locust as compared to cottonwood and Virginia pine. Hence it was assumed that nitrogen was more abundant under the black locust than under the other treatments.

The high annual turnover of nitrogen beneath black locust due to the rapid decomposition of its leaf litter found by Auten (1945) could be applied to the high amounts of leaf litter found beneath the black locust treatment on the Minto spoils. In this study depths of up to 4 cm of leaf litter were often observed beneath the locust as compared to the meagre scattering of pine needles on the red pine sites. In fact, the majority of the leaf litter available beneath the pines was from the aspen, birch and cherry successional tree species. Since the leaf litter was not included in the determination of organic matter/organic carbon, values obtained were not significantly different between the three treatments. The low values obtained are usually associated with low nitrogen availability (Brady 1974), but are only pertinent to the soil analysis. Since the decomposition of locust litter is the main source of plant available nitrogen (Ike and Stone 1958), there should be no deficiency of nitrogen beneath the black locust plots. This would not be the case with the other species. The low nitrogen content associated with pine needles as well as the trace amounts of litter found on both the red pine and control sites would result in poor nitrogen return through the decomposition of that leaf litter.

Soil acidity, which is so often a hindering factor to plant growth on coal mine spoils (Croxton 1928) had no significant effect on the presence of ground cover on any of the treatments.

Comparisons with other studies revealed some differences between soil parameters (Table 6).

The black locust treatment was slightly higher in available potassium, exchangeable magnesium and calcium than spoils beneath the seven and ten year old jack pine plantations studied by Rivard and Smith (1978). Available phosphorus was much higher under all treatments in this study than results obtained by either Abbott (1976) or Rivard and Smith (1978) on unfertilized sites at Minto. This may be partially due to the aging of the sites but is more likely due to the extracting

TABLE 6. A comparison of the three treatments with other coal mine spoil sites using soil parameters.

Soil parameter	Site I	II	III	IV	V	VI	VII
pH	5.0	5.2	4.5	4.7	4.8	5.5	2.9
Organic matter %	5.2	4.7	4.8	N.A.	N.A.	N.A.	N.A.
Organic carbon %	1.4	1.3	1.3	N.A.	N.A.	0.7	N.A.
Soil texture %							
Clay	22.6	22.9	23.2	N.A.	N.A.	34.6	N.A.
Silt	41.0	43.0	34.0	N.A.	N.A.	53.0	N.A.
Sand	37.0	34.0	43.0	N.A.	N.A.	12.4	N.A.
Available P (ppm)	250	188	200	139	trace	N.A.	N.A.
Exchangeable bases (me/100g soil)							
K	0.24	0.19	0.18	0.19	N.A.	N.A.	0.4
Na	0.16	0.15	0.14	N.A.	N.A.	0.89	N.A.
Mg	1.37	1.18	0.89	1.25	N.A.	5.64	0.3
Ca	5.21	5.34	3.07	4.72	N.A.	12.74	3.2
Base saturation %	88.7	94.4	73.1	N.A.	N.A.	N.A.	125
CEC (me/100g soil)	7.6	7.0	4.9	N.A.	9.6	N.A.	3.4
Age	11	13	12	7&9	N.A.	2	new

I= black locust (Minto, 1982)
II= red pine (Minto, 1982)
III= control (Minto, 1982)
IV = Rivard and Smith (Minto, 1978)
V = Abbott (Minto, 1977)
VI= Indorante and Jansen (Ohio, 1981)
VII = Czapowskyj (1973)

solution used in the chemical analysis. The method employed in this study, based on Olsen and Dean (1965), using carbon black as an organic matter decolorizer, has been shown to be satisfactory for P determination (Berg 1973, 1978). Although Abbott (1976) does not cite the method for his P determination; Rivard and Smith (1978) used the Truog method of determination which may have given slightly lower results than the method used here.

Studies in the United States were dissimilar due either to the age of the spoil material and/or the varying composition of the overburden. The spoils analysed by Czapowskyj (1973) were very new and thus strongly acidic, the low pH prohibiting the release of plant available nutrients and thus producing the low values seen in Table 6. On the other hand, soil texture and a higher pH appeared to improve the nutrient availability in the silty clay loam spoils studied by Indorante and Jansen (1981) in Ohio. Since clay provides a greater effective surface area and number of possible exchange sites than sandy soil thereby increasing the adsorption and retention of nutrients (Brady 1974), this may explain the higher overall available bases on that site. Some authors (Indorante and Jansen 1981) have shown a considerably higher concentration of available nutrients in mine spoils as compared with local forest soils. However, this may be due to the nutrient removal by plants growing in the forest soils rather than particularly fertile minespoils. It should be noted that standard nutrient requirements for red pine and trembling aspen survival were comparable to levels found on the spoils (Table 7).

Development of vegetation on the spoils was probably affected by the presence/absence of available nitrogen, but other factors such as physical and microclimate conditions can influence plant establishment. Once established, they in turn, affect edaphic and microclimate conditions

4.1.2 Physical and microclimate factors

The loose shale conditions encountered on the control have been shown to prohibit plant establishment elsewhere. Bramble and Ashley (1955) found that banks having loose shale slopes may achieve only 15 percent coverage over a period of 30 years. Bramble (1952) noted that the crust formed by loose shale may serve to reduce runoff and evaporation from underlying layers hence conserving moisture but will also serve as a barrier to natural reseeding of herbaceous species. The fact that the aspen, birch and cherry association was able to colonize first was probably due to the seeds' ability to sift through the surface layers and then spread vegetatively. The soil texture on the control sites was close to the optimum range required for aspen. Stoeckler (1948) found that a silt plus clay content of around 50 to 55 percent improved productivity of quaking aspen.

Bramble (1952) and Abbott (1976) describe a mulching effect which is caused by loose shale surface conditions. This was noticeable on the control plots where soil was moist despite the

Table 7. Nutrient requirements for red pine and quaking aspen

	Red Pine 1	Red Pine 2	Red Pine 3	Aspen 4
pH	5.3	6.3	5.2-6.5	4.7
Organic matter %	4.68	3.9	1.3	0.96
Available P (ppm)	N.A.	114	N.A.	6.0 (H layer=184)
Exchangeable bases (me/100g soil)				
Ca	3.2	4.24	0.8	0.6
Mg	0.9	1.26	0.2	0.28
C.E.C. (me/100g soil)	8.3	9.8	3.5	3.2
Base saturation %	52.0	N.A	N.A.	N.A.

Red Pine

1 = Wilde (1938) for Wisconsin, Michigan Minnesota, Ohio

2 = Leaf and Keller (1956) for Wisconsin

3 = Wilde (1966) for Wisconsin

Aspen

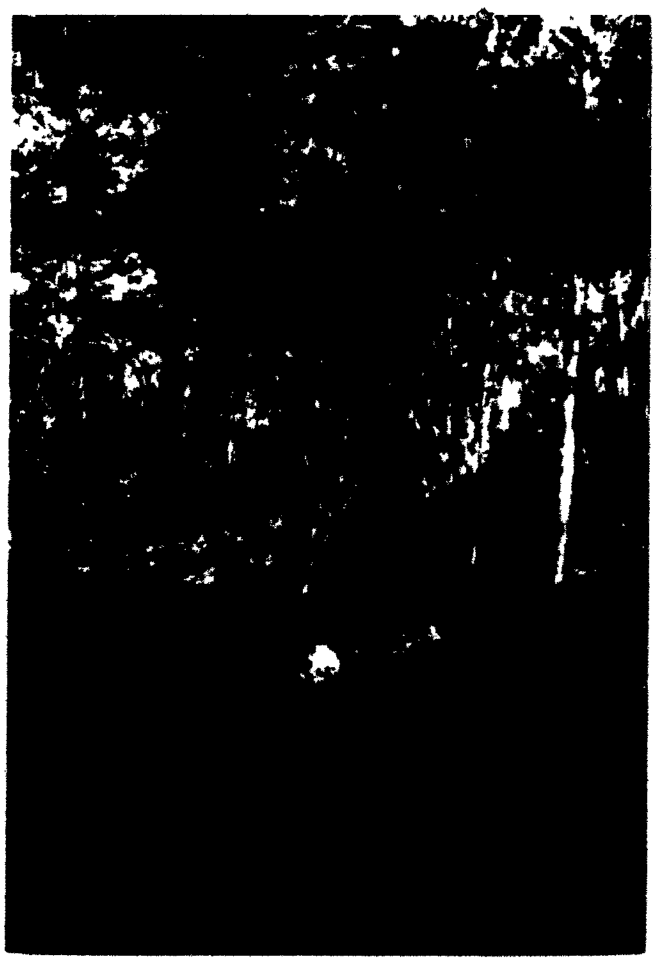
4= Stoeckler (1948) for Wisconsin and Minnesota high temperatures and greater evaporation rates associated with barren spoils (Smith 1968). However, the crust was effective in discouraging vegetation as was the lack of protection from high surface winds and temperatures.

In some areas of the red pine sites where the crust was lacking, soil moisture was observed to be low. The open areas were likely subject to high winds and temperatures and the resultant loss of moisture through high evaporation. Herbaceous species had established deep root systems (in comparison to the black locust sites) and were located in hollows or at the bases of the spoil piles where moisture and leaf litter were more likely to collect. A lack of suitable soil medium was also a hindrance to plant establishment on some sites on the black locust plots where most barren areas were typified by unweathered shale below the surface few centimeters or sandstone outcroppings. Here again it is possible to see the benefits of planting to improve spoil conditions; spoil on the locust and pine sites contained less coarse material than the control suggesting advanced weathering of the spoil.

4.2 Ground cover

The most significant distinguishing feature among the three treatments was the amount of ground cover present: black locust supported the greatest number and density of species, with red pine and the control plots having considerably fewer. (See Fig. 3 - 5). Many of the species found are reported in other studies

Black locust site 1



Black locust site 2

Fig. 3. Black locust sites 1 & 2

COLOURED PICTURES
Images en couleur

Red pine site 3

Red pine site 4

Fig. 4. **Red pine sites 3 & 4**

COLOURED PICTURES
Images en couleur

Control site 5

Control site 6

Fig. 5. Control sites 5 & 6

of the Minto spoils. Nightingale (1972b) studied the natural succession occurring around surface mine ponds, listing terrestrial ground cover such as *Hieracium* spp. (hawkweeds), *Comptonia peregrina* (sweetfern), *Epilobium angustifolium* (fireweed), *Solidago* spp. (goldenrod), *Aster* spp. (asters), *Equisitem arvense* (horsetail), *Senecio* spp. (groundsel), and *Aralia* spp. (sarsaparillas). Abbott (1976) included a list of approximately 130 species sighted on old spoils which had revegetated naturally. His list of dominants included *Hieracium* spp., *Oenothera biennis* (evening primrose), *Rubus* spp. (raspberry, blackberry), *Comptonia peregrina*, *Equisitem arvense*, *Epilobium angustifolium*, and various grasses and sedges. Rivard and Smith (1978) recorded the ground cover appearing on jack pine plots as *C. peregrina*, *Hieracium* spp. and *Aster* spp.

The dominants beneath the black locust in this study were *Poa palustris* (fowl meadow grass), *Hieracium aurantacium* (devils paintbrush), *H. pilosella* (mouse-ear hawkweed), *Aster lateriflorus* (calico aster), *Rubus setosus* (red raspberry), *Pyrola elliptica* (shinleaf), *Solidago graminifolia* (goldenrod), *Spirea latifolia* (meadowsweet), and black locust seedlings. Beneath the red pine the dominants were *Danthonia spikata* (poverty grass), *H. pilosella*, *R. setosus*, *C. peregrina*, and *Trifolium* spp. (clover). The control plots, representative of natural recolonization, showed that the hardwoods aspen, birch and cherry were the first to colonize followed in most cases by *C. peregrina*, a local, early successional species. These and other species found within the 1 m^2 grid are listed in Table 8 along with their locations and characteristics.

The dense ground cover noted beneath the locust, particularly on site 2, was comparable to other studies. Bramble (1952) and Bramble and Ashley (1964), showed the locust to be an aggressive native pioneer species in Pennsylvania, resulting in adequate ground cover on spoils ten years and older. Similarly, Riley (1957) noted that heavy undergrowth had developed after 10 years and by 15 years was very dense.

Casual observation in the field showed that black locust had a positive effect on the surrounding vegetation. Percent ground cover and species diversity appeared to decrease with distance from the plots. Particularly noticeable was the absence of herbaceous and grass species. This effect was not seen on either the red pine or control plots. Pine plantations in Ohio were found to have little undergrowth probably because crown closure was achieved in nine years at 1.2 x 1.2 m. spacing (Riley 1957).

Distribution of ground cover also varied between treatments. Cover on the black locust was fairly uniform except for sandstone outcrops which hindered the establishment of vegetation because of slower weathering and unsuitable medium for root growth. However colonizing species on red pine and control treatments were concentrated at the bases of the spoil piles and in the hollows on the slopes, usually appearing beneath the invading aspen, birch and cherry, all early

TABLE 8. Location and characteristics of species found on black locust (B.L.), red pine (R.P.), and control (C.) sites.

Sedges & grasses	Location	Characteristics
Carex cumulatus	B.L.	Open, dry to fairly moist sandy loams with low pH; drought resistant; full sunlight to light shade; dispersal = wind.
C. debilis	B.L.	Poor, dry to moist loams; also in part shade of richer soils.
C. umbellata	B.L.	Dryish, sandy loams; full sun; drought resistant; dispersal= wind & gravity & water.
Poa compressa	B.L.	Open, sandy or rocky soils, but is adaptable to many soils; drought resistant; full sunlight; dispersal= wind & gravity.
P. palustris	B.L.	Dry to wet habitats, in sandy to rich organic soils; partly shaded woods to open areas.
Danthonia spicata	B.L. R.P.	Open, dry sandy/loamy sites; drought resistant; full sunlight to light shade

Herbs & shrubs	Location	Characteristics
Cornus canadensis	R.P.	Dry to moist sandy loams; shaded or partly shades woods; low pH; high organic content.
Hieracium kalmii	B.L.	Dry, sandy or rocky open areas; full sunlight; drought resistant.
H. aurantacium	B.L. R.P.	Dry to moist sandy/gravel and sandy loam soils; full sunlight; drought resistant.
H. pilosella	B.L. R.P.	Dry, sandy or rocky open areas; full sunlight; drought resistant;
Aster lateriflorus	B.L. R.P.	Dry to wet sandy loam; organic and sphagnum loam; full sunlight to medium shade.
A. umbellatus	B.L.	Moist to wet sandy loams, organic and sphagnum soils; full sunlight to light shade.
Pyrola elliptica	B.L. R.P.	Moist to wet leaf covered soils; light to medium shade; low pH.
Epilobium watsonii	B.L. R.P.	Open areas; dry to fairly moist sandy and sandy loam soils.

Herbs & shrubs	Location	Characteristics
Solidago graminifolia	B.L.	Open, dry to wet sandy loams; drought resistant; dispersal= wind.
Senecio viscosus	B.L.	Open sandy or rocky soils; drought resistant; dispersal= wind.
Anaphalis margaritacea	B.L.	Dry to moist sandy and sandy loams; full sunlight to light shade; drought resistant; dispersal= wind.
Equisitem arvense	R.P.	Very sandy soils; full sunlight; dispersal= wind;
Trifolium spp.	R.P.	Open soils, high pH; somewhat drought resistant;
Diervilla lonicera	C.	Dry to moist well drained sandy and sandy loams; full sunlight to light shade; drought resistant; dispersal= bird.
Comptonia peregrina	B.L. R.P. C.	Open , dry sandy loams; full sunlight N fixing; dispersal= wind & gravity.
Aralia hispida	B.L.	Dry gravel and sandy loams; full sun-light; dispersal= bird.
Spirea latifolia	B.L. C.	Open, fairly moist sandy loams; low pH.

Herbs & shrubs	Location	Characteristics
Rubus allegheniensis	B.L.	Fairly dry soils; relatively high pH; full sunlight to light shade; dispersal= bird;
R. setosus	B.L. R.P.	Damp thickets and swampy areas; colonizing species.
Trees		
Salix discolor	C.	Open moist soils with fairly low pH; dispersal= wind.
Populus tremuloides	B.L. C. R.P.	Open mineral soils; not drought resistant; dispersal= wind.
Prunus pensylvanica	B.L. R.P. C.	Open mineral soils; nurse tree for other successional spp.; dispersal= bird.
Betula papyrifera	B.L. R.P. C.	Open mineral soils; not very drought resistant; dispersal= wind;

colonizers of waste sites in the area.

The combination of aspen, birch and cherry as the first successional tree species has been noted by other authors. Cornwell (1971) studied spoil vegetation in Pennsylvania and found that the first colonizers were invariably small trees, specifically birch, aspen and cherry, with traditional first colonizers of lichens and moss occurring infrequently. Bramble (1952) and Bramble and Ashley (1964) also studying natural succession in Pennsylvania reported the pioneer community developing on the spoil banks to be an aspen-fire (pin) cherry association, which was followed by shrubs and herbaceous species. Johnson et al. (1982) noted a similar pioneering community on mine spoils in Oklahoma in which small trees, woody shrubs and vines provided the majority of cover with only a sparse scattering of herbaceous species beneath. Paper birch, trembling aspen and pin cherry have also been noted to colonize talus slopes and glacial till resulting from land slides herbaceous cover being slow to follow (Flaccus 1959). Other authors such as Croxton (1928), who studied natural succession in the mid-west, found a much different process in which lichens and grass-herb associations were the first to colonize the spoils, tree species only occuring on the peripheries. This difference was probably due to a disparity in location and spoil type.

Aspen is known to colonize waste areas rapidly either by vegetative growth or seed; it is also intolerant to shade and a rapid grower. Alban (1982) showed that nutrient accumulation beneath aspen on the forest floor was in some cases two to three times higher than that for red pine. Fowells (1975) stated that aspen is a soil improver, particularly because it redistributes nitrogen to the surface layers through its leaf litter. However, it is not a leguminous species and does not fix nitrogen as is the case with black locust.

Paper birch is another early successional species, also intolerant to shade, whose reproduction is mostly by seed which can grow in acidic to calcareous, well drained sandy loams (Fowells 1975). It also restores exchangeable potassium in K deficient soils (Hepting 1971).

Pin cherry, which has a short life span, is known for its ability to rapidly recolonize disturbed areas, being a fast growing pioneer species with an intolerance to shade (Hosie 1969, Hepting 1971). Marks and Bormann (1972) found that pin cherry helped to minimize nutrient losses in disturbed areas because of its rapid growth. The high rate of biomass accumulation meant an increase in nutrient cycling which might otherwise have been lost through leaching.

Although some of these species have a wide range of tolerance to moisture regimes such as <u>Poa compressa</u>* (wire grass), which can tolerate high moisture levels (Rapp and Rapp 1946), most species are usually restricted to their optimum regime as pointed out by Rowe(1956). The presence of certain herbaceous species indicated that moisture levels were good on

*N.B. Descriptions of ground cover were taken from Scoggan, 1979 &/or Peterson and McKenny 1968, unless otherwise indicated.

selected areas. *Aster umbellatus* (flat topped white aster), *Rubus setosus*, *Solidago graminifolia*, *Poa palustris*, *Epilobium angustifolium*, *Pyrola elliptica* and *Spirea latifolia* all require medium to high moisture regimes. The shallow root system of *Fragaria virginiana* (strawberry) makes it intolerant to drought (Weaver and Albertson 1939) and both *S. latifolia* and *Salix discolor* (pussy willow) are common moist forest species (Rowe 1956). Other ground cover species indicated dry conditions, and like *Poa compressa* and *Anaphalis margaritacea* (pearly everlasting), which have large underground rootstocks, can survive extended drought (Young 1936, Partridge 1941). *Equisitem arvense* is also deeply rooted (Kurskii 1941) and can withstand up to three feet of silt and sand covering(Dunklee and Midgley 1939) making it an excellent natural species for stabalizing slopes subject to erosion. Other dry site colonizers included *Danthonia spikata*, *Hieracium canadensis* (Canada hawkweed), *Diervilla lonicera* (bush honeysuckle), and *Aralia hispida* (bristly sarsaparilla).

The only species which did appear on all three treatments was *Comptonia peregrina* which colonizes barren sandy areas and fixes atmospheric nitrogen through root nodules (Ziegler and Huser 1963). This low woody shrub was found predominantly on the control and red pine plots and to a much lesser extent on the black locust treatment. The possible values of this species as a spoil amender have yet to be considered in relation to black locust.

The absence of pine seedlings supports the findings of Aharrah and Hartman (1972) that red pine is not a self sustaining species on the spoils. Since viable seed production generally begins at 20 to 25 years (Fowells 1975) and the condition of the present species is generally poor, there is little chance that the red pine will reproduce to form a continuing community. Conversely , black locust sprouts were prolific and probably the result of vegetative reproduction since natural reproduction is largely by this method (Fowells 1975).

Species diversity beneath the three treatments, was comparable to other studies (Table 9). Farmer et al. (1982) studied the diversity of plants emerging from forest topsoil of mixed deciduous stands which was placed on mine spoils in Tennessee and found that a diverse community developed, well within the range for deciduous woodlands in eastern North America. Similar values were found by Monk et al. (1969) and Bazzaz (1975) who studied species diversity of a stratified oak-hickory forest community and species diversity in old field successional ecosystems respectively.

Diversity tends to increase with age until shade intolerant species are excluded by shade tolerant species which have become the dominants. High diversity is therefore maintained by environmental perturbations such as windfalls. This was noticeable on the black locust treatment where shaded and non-shaded areas displayed varied herbaceous species. Open

Table 9. Species diversity beneath the three treatments and on three forest soils.

Author	H'	age	Source
This study	2.35	11	Black locust
This study	1.25	13	Red pine
This study	0.76	12	Control (aspen-birch-cherry association)
Monk *et al.* (1969)	3.45	N.A.	Oak-hickory (Georgia)
Bazzaz (1975)	2.0	10	Deciduous (Illinois)
Farmer *et al.* (1982)	3.16	1	Mixed deciduous (forest topsoil on spoil banks) (Tennessee)

areas on the red pine and control tended to be generally unsuited for plant growth and therefore the contrast was not as marked.

Since the treatment plots were in various stages of recolonizing most of the plants were early successional, light demanding species as opposed to shade tolerant late succession types. For instance, with the development of a tree canopy, Anaphalis margaritacea and Spirea latifolia (Flaccus 1959) as well as Aster spp., Epilobium angustifolium and Solidago spp. (Ehrenreich and Crosby 1960) quickly disappear. Some grass species such as Poa compressa and Danthonia spikata are tolerant to shade (Watkins et al. 1940, Ehrenreich and Crosby 1960) and may increase with a growth of crown cover. However, light tolerance is only part of the successional process, physiographic adaptation to poor site conditions being just as important as the lack of competition from other less hardy species.

Brenchley and Heintze (1933) noted that colonization by Epilobium angustifolium was due to competition rather than the ability to withstand acidic conditions and this species quickly died out as other vegetation became established. It is also capable of vegetative reproduction and tends to allocate most of its mineral accumulation to root production, thus enabling it to spread to adjacent barren areas (Van Andel and Vera 1977). Poa compressa can outcompete Anaphalis margaritacea because of a larger number of individual plants which can grow from one root system as compared to the few individuals supported by A. margaritacea (Young 1936). Further, P. compressa does well on nitrogen poor soils which have a low organic matter content (1.3%) (Watkins et al. 1940). Similarly, Danthonia spikata has been shown to produce the densest growth and greatest yield on poor unfertilized sites (Johnstone-Wallace et al. 1942), as have Hieracium aurtantacium and H. pilosella (Hay and Ouellette 1959). However, the presence of these species does not necessarily mean that the spoils are lacking in plant available nutrients, as evidenced by the comparable amounts required for optimum growth by both red pine and aspen (Table 7) and lack of correlation with percent ground cover. Further, Van Andel and Nelissen (1979) found that Epilobium angustifolium showed good growth patterns on soils containing less available calcium, magnesium, sodium and potassium than available on the three treatments studied here (Table 10). Thus, herbaceous species with higher nutrient requirements should be able to survive on the spoils.

It is apparent that many of the indigenous species of the Minto area are capable of rapid colonization on the spoils given the right conditions of lowered temperatures and wind speeds, and the availability of moisture, nutrients and a rooting medium New ideas on trial elsewhere involve the use of hardy native species adapted to the climate of the area (Kuga and Hutchison 1979, Fedkenheuer and Heacock 1979) or plant communities originating from topsoil placed on the spoils (Farmer et al.

1982, Iverson and Wali 1982). Both of these methods might prove uneconomical in the Minto area because of the poor quality of the forest soil (MEC 1978) and the time and labour required to set up a local seedbank. Thus, it is apparent that black locust, as an alternative has the ability to speed up the process of natural succession both in the percent ground cover and diversity of species far above that of the red pine or untouched control plots.

Based on the results found from analysis of the black locust, red pine and control plots, it is possible to describe models of succession for each of these management measures. Approximations of the succession on each of the three treatments provides a description of the natural processes involved in the the recolonization of the coal spoils.

Table 10. Mean soil results from 17 plots of *Epilobium watsonnii*.

pH	3.9
Exchangeable bases (me/100g soil)	
K	0.13
Na	0.38
Ca	2.15
Mg	0.44

(VanAndel and Nelissen 1979)

5.0 Models of Succession

The purpose of the following models of succession is to compile the results of this study and to extend them into the future based on field observations and information found in the literature. Although they are hypothetical from approximately 15 years onward, they are, I feel an accurate representation of the processes of succession up to 50 years.

5.1 Model 1: Natural recolonization

Natural succession on untreated spoils is dominated by the invasion of birch, cherry and aspen approximately 5 years after the creation of the spoils (Fig. 6). The ability to achieve deep rooting not only provides moisture for these tree species during drought conditions, but also forms an anchor against high winds. Conversely, the arrival of pioneer shrub and herbaceous species is hindered by the high temperatures, winds, and crusty surface conditions. Without the rooting depth of the tree species, germinating seeds usually have little chance of surviving on the barren spoils.

Litter accumulation from the hardwood species provides an important rooting medium for plant establishment. Similar to a mulch, litter not only supplies nutrients for the developing seeds but protects them from surface winds and high temperatures. Once roots have penetrated this layer, the spoil pH and available bases, although low, are within acceptable

TABLE 11. Legend for the pictorial diagrams of Models 1, 2, and 3.

Life form		Species name			
Trees:	Black locust 	A	Aspen	Pe	Pyrola elliptica
		B	Birch	Ew	Epilobium watsonii
	Pine spp. 	C	Cherry	Sg	Solidago graminfolia
		Wp	White pine	Sv	Senecio viscosus
	Pioneer spp. 	Rp	Red pine	Am	Anaphalis margaritacea
		Cp	Comptonia peregrina	Ah	Aralia hispida
		Dl	Diervilla lonicera	Ea	Equisitem arvense
Shrubs: 		Sd	Salix discolor	T	Trifolium spp.
		Sl	Spirea latifolia		
		Rs	Rubus setosus		
Herbs/grasses: 		Ra	R. allegheniensis		
		Cc	Carex cumulatus		
		Cd	C. debilis		
		Cu	C. cumulatus		
		Ds	Danthonia spicata		
		Pc	Poa compressa		
		Pp	Poa palustris		
		Cca	Cornus canadensis		
		Hk	Hieracium kalmii		
		Ha	Hieracium aurantacium		
		Hp	H. pilosella		
		Al	Aster lateriflorus		
		Au	A. umbellatus		

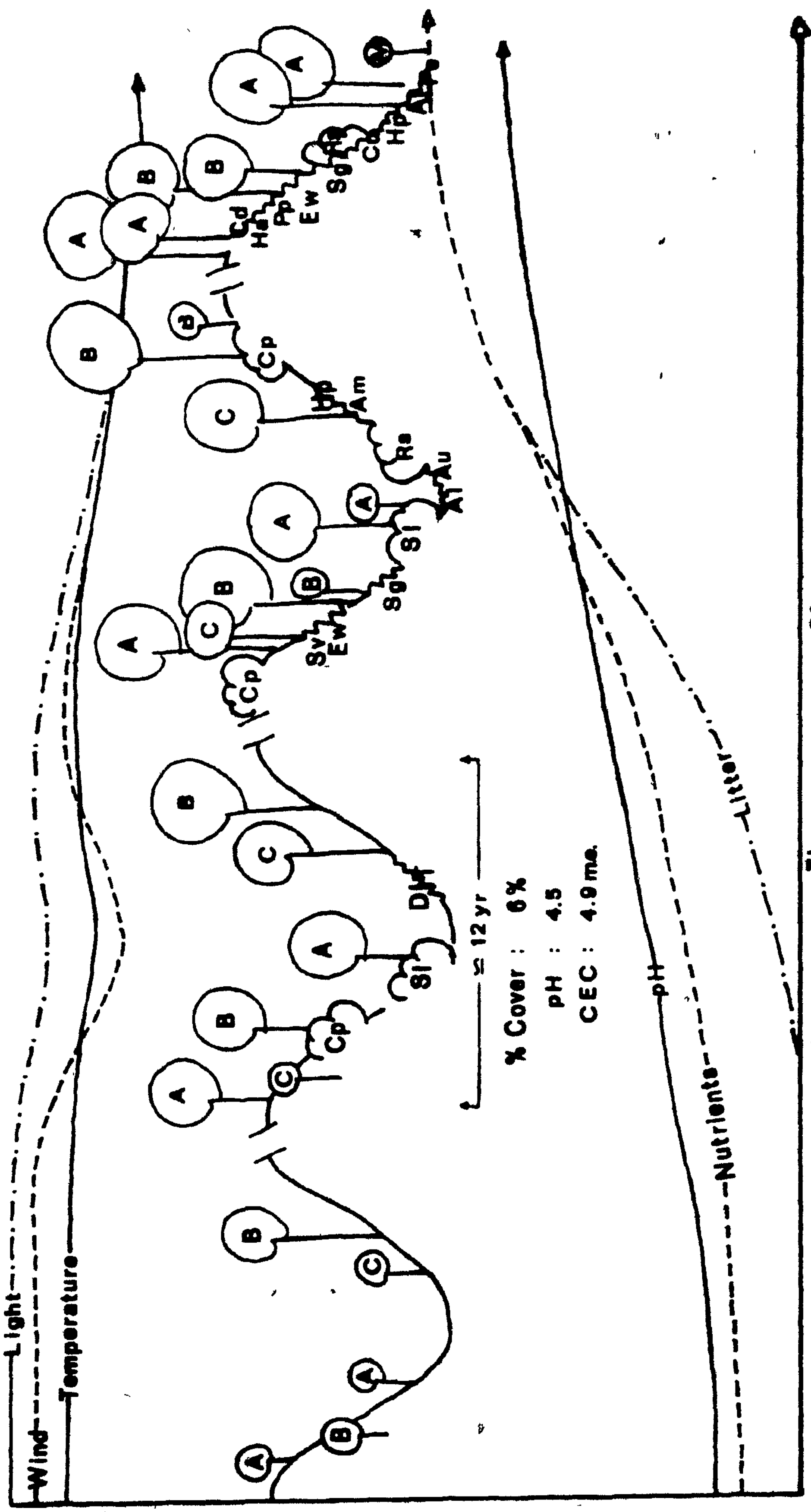


Fig. 6. Successional Model 1.

range for continued plant growth. Soil texture beneath the crust is also acceptable for many of the hardier species which are adapted to sandy loams.

The general downslope movement of litter by gravity, wind and water, means an increased accumulation at the slope bases. This, along with greater moisture and less wind results in a greater abundance of species. Although diversity is low and confined to mostly woody shrubs (Spirea latifolia, Comptonia peregrina, Diervilla lonicera, Salix discolor), there is more between tree cover than can be found on the spoil tops.

New growth on the spoil ridges is limited to the hardwood seedlings with some C. peregrina locating in windbreaks; otherwise the area is devoid of any shrubs.

Further colonization should progress from the spoil bases to the slopes and slope tops as species become strongly established and branch out. Increased competition from successional species would would lead to the colonization of the open slopes and ridges by such early pioneers as Comptonia peregrina.

The aspen, birch and cherry association will remain the dominant hardwood species since individuals are so widely scattered and therefore have little effect on the microclimate or the overall accumulation of litter. Crown closure and colonization by later successional species such as maple will be slow as will the overall improvement of spoil physical and chemical conditions. Horizon formation will take years although the crusty surface conditions will disappear as the shale is weathered, increased root action breaks up the soil, and leaf litter accumulates.

5.2 Model 2: Red pine

Ammending spoils with red pine results in areas of sparse ground cover and low species diversity at 13 years (Fig. 7). The slow accumulation of pine needle litter does little to enhance rooting medium for ground cover, especially on spoil tops. However, the present low bushy nature of most of the pines acts as a windbreak, enabling herbaceous species to colonize in hollows as well as protected slopes in limited numbers. Further, the litter layers formed by the interspersed cherry, aspen and birch improve site conditions for incoming species especially at spoil bases.

Although the most frequently occuring species were Comptonia peregrina and Hieracium pilosella, both early colonizers of dry waste sites, some moist woodland species such as Pyrola elliptica and Cornus canadensis occured at the spoil bases. The increase in species number on the red pine areas over naturally colonized sites is probably a result of improved microclimate conditions. The reduction in wind and surface temperatures is due to the greater density and number of tree species.

Casual observation on site suggests that survival of the red pine is poor. Red pine seedlings require mineral soils to become established and do not survive in heavy litter layers associated with deciduous species. However, without the

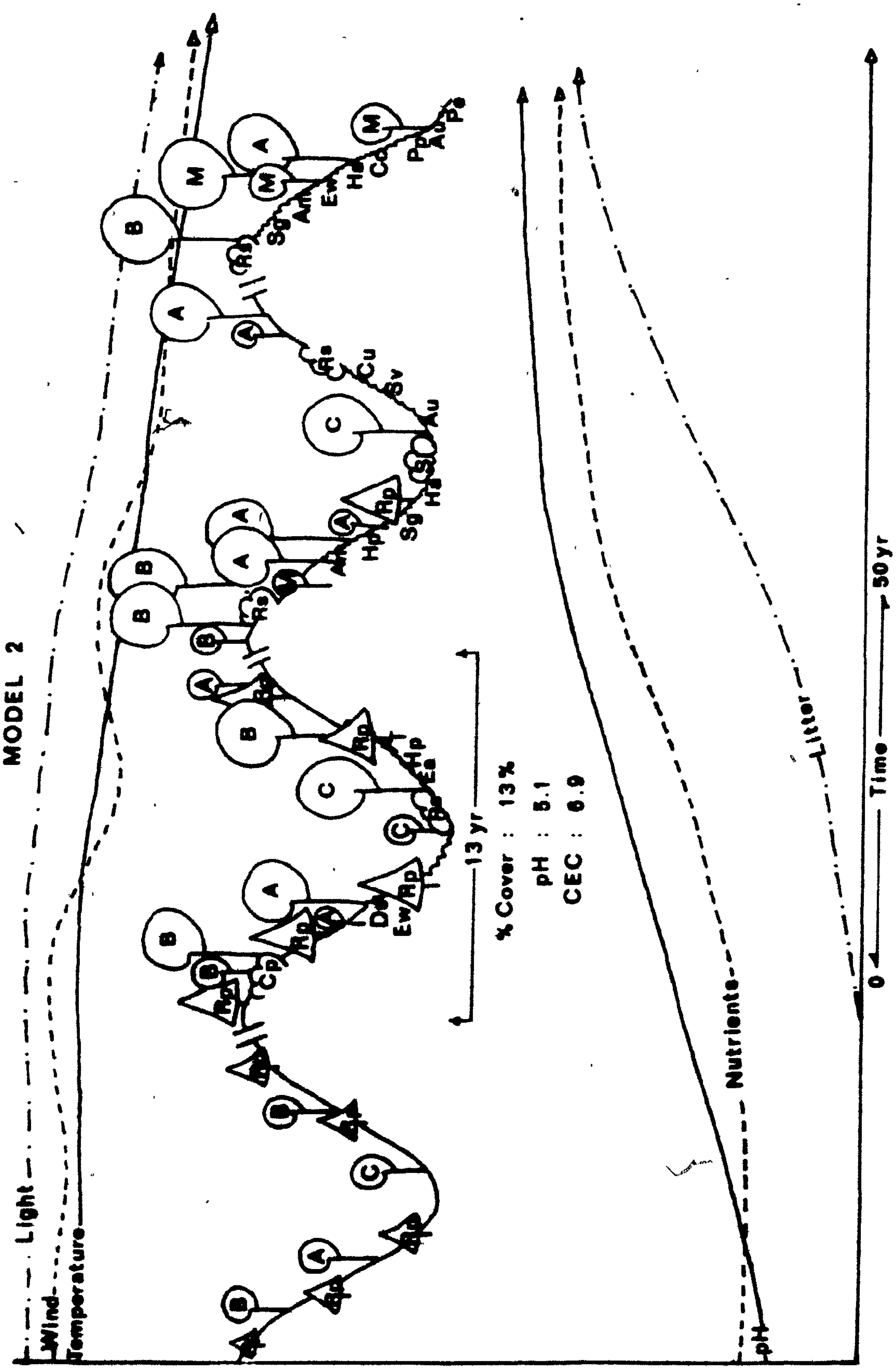


Fig. 7 . Successional Model 2.

addition of fertilizer to improve growth and yield, the red pine will continue to be overtopped by the colonizing birch, aspen and cherry species, which create both shade and litter sufficient to kill pine. Thus, the probability of red pine becoming a self-sustaining community or growing to economic value seems low, given the present condition of the trees and the time required for regeneration.

Given the improved microclimatic conditions provided by the increased number of tree species, succession on red pine sites should occur at an increased rate compared with Model 1. Cover established in the valleys and hollows will extend up the slopes to the ridges. A more diverse community will evolve as conditions such as shade, improved availability of nutrients from decomposition of litter and increased pH, and changes in the microclimate are created. Physical properties will also improve as root action and various soil biota weather the soil, although, as with Model 1, horizon development will be extremely slow.

5.3 Model 3: Black locust

The areas planted to black locust reveal the most rapid colonization by herb,grass and shrub species of all three treatments. Following 11 years, black locust sites have the highest density and the most diverse and complete ground cover on both spoil tops and bases (Fig. 8).

Although early harsh site colonizers such as Comptonia

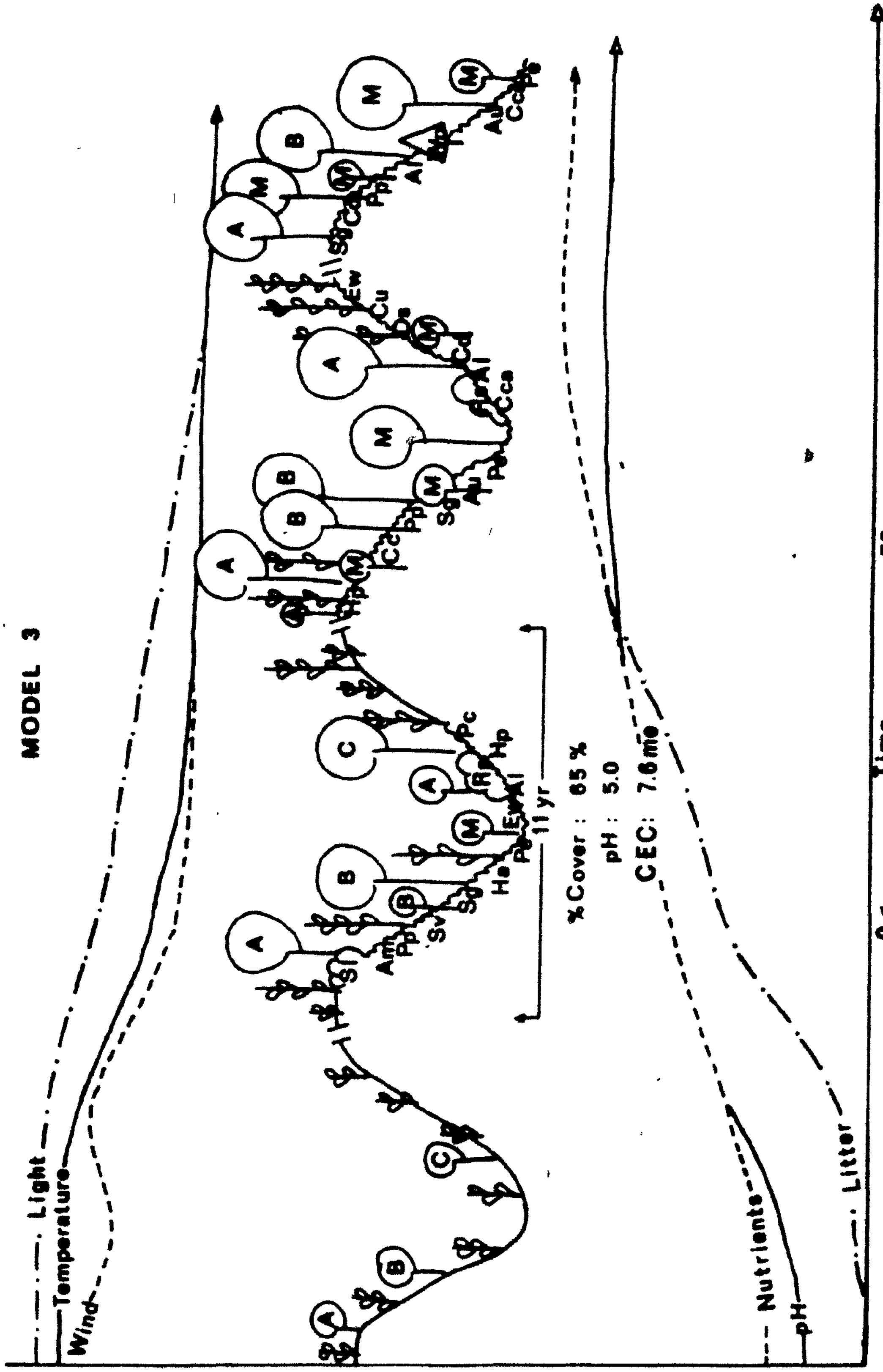


Fig. 8. Successional Model 3.

peregrina are still present, they are not the major species as in Models 1 and 2. Similarily Spirea latifolia shrubs found only at the bases in Model 1 are located on spoil tops in Model 3. The abundant fruit on both Rubus allegheniensis and R. setosus suggest that there is reduced stress from environmental conditions.

The crusty surface conditions so prevalent on the other two treatments has evolved, in many areas into a brown forest soil, easily penetrated by rooting seeds. However, in open sections, the abundant litter from the black locust provides the necessary rooting medium for germinating seeds with further protection given by black locust saplings and offspring of the birch, cherry and aspen association.

Later successional tree species such as the red maple are beginning to colonize by the 11th year. However, the existing hardwood species will remain the dominants for some time since they have no serious competition and are approximately the same age and height. Once they begin to die, later successional species will respond to release, replacing the pioneers. The short life span associated with those black locust affected by nectria canker will keep the locust from overtopping incoming native hardwoods, especially on site 1,and will permit competition from herbs and grasses in the new openings created by dead trunks. However, since regeneration by the locust is strong, especially for those trees affected by the canker, it will be a while before the locust disappears. The healthy locust prevalent on site 2 are similar in height to the surrounding hardwoods.

The sequence for succession for Model 3 will involve the continued growth of the black locust and the birch, cherry, aspen community, and the eventual colonization of open areas by herbaceous,grass or shrub species. There should be little change in the composition of the present ground cover except in the general frequency of species occurence, depending on shade and competition. Creation of 'soil' from weathered spoil material will continue as the shale is broken down and litter decomposes. Since the black locust sites have the greatest amount of ground cover and litter, the development of a soil horizon will occur at a faster rate than either of the other two models. Return to a 'natural' state is therefore hastened by the planting of black locust.

In summary, it is the time required to establish soil material and continuous ground cover which links the three models. Hypothetically, Model 1 is slower than Model 2 which is slower than Model 3 in achieving a forested ecosystem, although eventually they will all contain the same climax vegetation. The important consideration here however, is the necessity of rapid colonization to ensure stability and recovery of the spoil piles.

To this end, black locust is shown to be the most successful reclamation species, and if planted with red pine, may result in successful commercial yields of the latter species.

6.0 Conclusions

6.1 Summary

The analysis of ground cover and edaphic factors beneath similarly aged treatments revealed that black locust supported the highest amount and greatest diversity of ground cover in comparison to red pine and control treatments. Available plant nutrients of phosphorus, sodium, potassium, calcium and magnesium, and pH were sufficient for plant growth and were comparable to other studies done both on these spoils and elsewhere. Available nitrogen was assumed to be adequate beneath the locust but lacking on the other two sites due to the absence of litter layer present and the likely correlation with releasable nitrates through decompostion. This led, in part, to early growth of ground cover.

Crusty surface conditions as well as high surface winds and temperatures were probably the major hindrance to the establishment of herbaceous species on the control sites. Poor moisture conditions brought about by a lack of crust and therefore increased evaporation through high winds and temperatures may have affected the establishment of ground cover on the red pine plots. Unweathered sandstone and shale were responsible for uncolonized areas on the black locust sites.

Where litter was able to accumulate, ground cover had a better chance of becoming established. Acting as a rooting medium for germinating seeds it provided nutrients, moisture, and protection from surface winds and temperatures. Its influence was particularly noticeable on the control and red pine sites such that on the control, ground cover was located at the spoil bases; on the red pine sites, ground cover was located in protected hollows and at the spoil bases beneath the hardwood species.

The increased density of tree species on the red pine sites served to improve conditions by lowering surface winds, thereby improving chances for increased diversity and percent cover. Since the black locust sites were not lacking in either protection from wind and high temperatures or in the availability of a litter layer rich in nitrogen, ground cover was well established from spoil bases to tops.

Future revegetation of the Minto spoils does not include the use of black locust or the application of fertilizers. Thus, in answer to the first question posed in Section 1.8, the proposal of red pine plantations for commercial use seems non-viable, since commercial yields require regular maintenance through fertilization, thinning, and pest control.

The results expressed here and elsewhere indicate that black locust is a beneficial species for reclamation of coal mine spoils due to its amending properties and adaptability to numerous site conditions. Thus it is suggested that black locust be reconsidered as a revegetation species to provide the spoils with a more diverse, self sustaining community.

Section 6.2 provides detailed recommendations, thereby encompassing the second question posed in Section 1.8.

6.2 Recommendations

Of the several possible methods available to those involved in the revegetation of the Minto coal spoils, the main choice for future tree harvesting appears to be red pine (Logan 1982) and jack pine (N.B.Coal Ltd. 1982). If commercially viable products are to result, these trees will require high maintenance either in the form of fertilizer application or the addition of herbaceous legumes at the time of planting. Fertilizers are expensive and do not last while many herbaceous species are intolerant to shade and die out when crown closure begins (Logan 1978). Further, some require added nutrients to become well established and are generally only suitable on spoils with a pH of 4.5 or higher (Vogel and Berg 1968). Cost of establishment is high and since application is usually by hydroseeding relatively even topography is required.

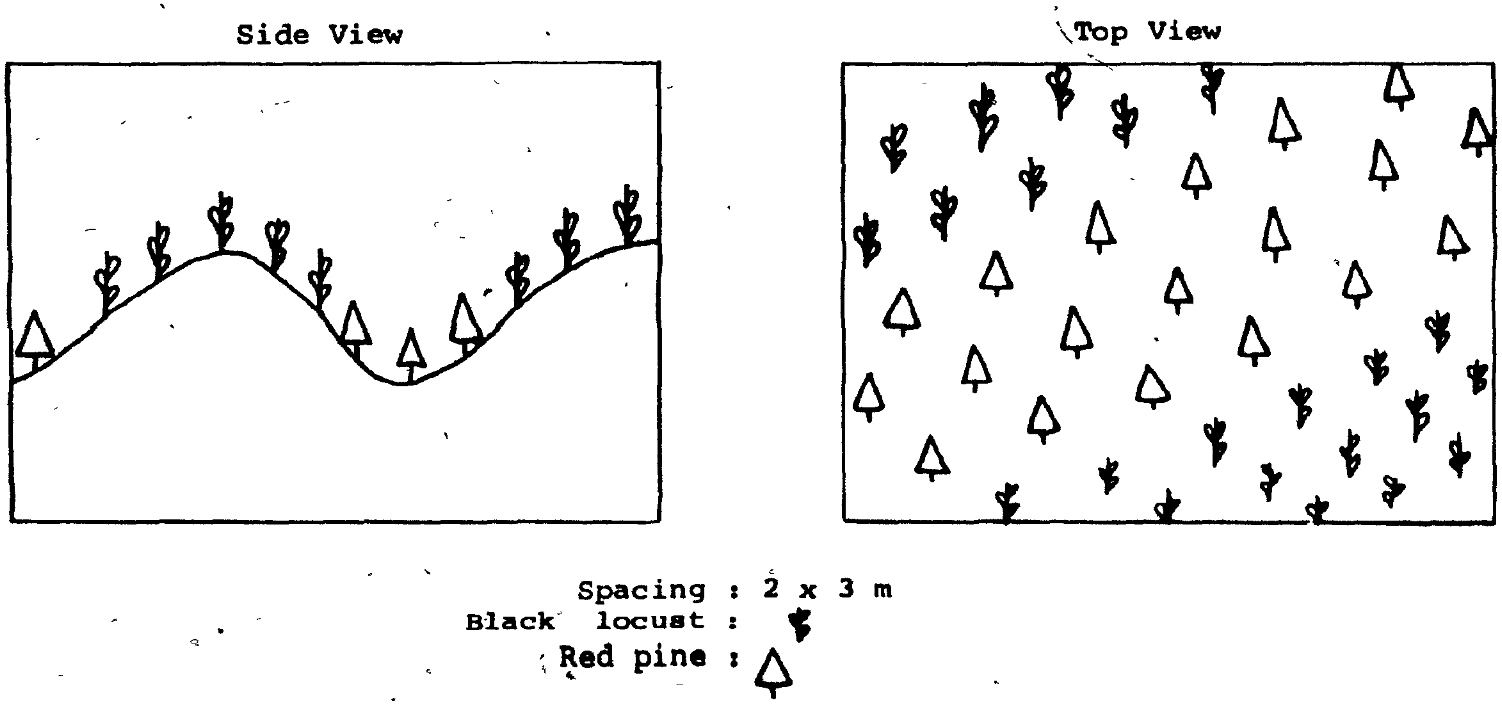
Alternatively, mixed planting using the tree legume black locust has shown excellent results. The adaptability of this species to varied nutrient pH and moisture levels, as well as its self-sustaining ability make it highly useful. Despite this, the black locust will not be planted as a site amender because of its poor economic value, thorny nature and fear that it will become a pest species. These problems can be used to advantage however. Sensible planting methods placing locust on spoil tops and upper slopes would not only reduce wind damage to young pine seedlings planted on the lower slopes but provide them with nutrients supplied through leaching processes. Further, the locust enables other tree species to colonize not only because of improved soil conditions but because of a lack of competition for light. The shrub-like appearance caused by nectria canker enables aggressive pioneer species to overtop the locust or opens new areas for incoming herbaceous layers. Normally viewed as a non-commercial species because of the poor form resulting from diseases the locust may still be marketable. Carpenter and Eigel (1979) found that since the locust has one of the highest heat equivalents on any North American woody species, it shows excellent potential as an alternative energy source. The authors found that in full bloom, black locust provides 33.1 million BTU/cord as compared to 15.8 BTU/cord for cottonwood; wood alone yields 24.6 million BTU/cord, which is comparable to 1.12 tons of anthracite coal.

The adaptability of black locust to a wide range of spoil conditions makes it an important species in areas unsuitable for red pine plantations. Further, when planted as a monoculture, it results in a much more diverse community than red pine, without the addition of fertilizers. This study and others show that black locust is quick to provide conditions suitable for rapid colonization of native species, therefore providing an acceptable habitat for wildlife. Although no detailed study of fauna was implemented here, several sitings of wildlife, particularly porcupine, were recorded. A preponderance of deer and moose tracks revealed heavy use of the spoils either as pathways or for available water sources. Although red pine is not noted for its ability to attract wildlife, black locust and its associated vegetation provide food sources for a variety of birds and mammals (Petrides 1958).

Multi-species planting reduces the chance of total crop failure in the event of disease or pest invasion, and according to Ashby et al.(1978), it increases the diversity and number of tree invaders when compared to areas planted with one or two similar species. Further, it can provide a multi-purpose land use system of easy accessibility for recreation or commercial activities when the trees are properly spaced. Figure 9 illustrates a suggested pattern of planting to maintain sufficient access while allowing rapid natural succession. The rows between the species provide access routes for human traffic and planting the locust on the spoil tops provides necessary nutrients for pines at the bases. Should the decision be made for harvesting pines in the future, spacing the trees at 2 x 3 meters would permit adequate release of all trees without the need of thinning; restricting the black locust nurse crop to less than 25% of the area would reduce the tendancy of producing dense stands from agressive root sprouting, (Ashby et al. 1978). Conversely, a self-sustaining community used for recreation but still requiring some freedom of access could have the spacing reduced and percentage of black locust increased. Mixed planting also encourages wildlife to inhabit the spoils. Black locust provides a food source while the the pines form a windbreak during the winter.

Low maintenance and cost, and high productivity and survival are important factors in the selection of revegetation species. Since black locust fits these stipulations, it should be reconsidered as a reclamation or nurse crop species for the Minto coal mine spoils.

Figure 9. Suggested planting to obtain maximum cover, diversity and growth using black locust & red pine.



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Appendix

Species planted on the coal spoils
Minto, New Brunswick.

Species	Year
Red pine	1967,1968,1969,1972
Scotch pine	1967,1968,1969,1970,1973
Jack pine	1968,1969,1970,1971,1972,1973
Blue spruce	1968,1969
White spruce	1970
European Black alder	1968,1969
Black locust	1968,1969,1970,1971,1972,1973
Sugar maple	1970,1971
Apple	1970
Red maple	1972,1973
Laurel Leaf willow	1971
Weeping willow	1972
White birch	1971
Caragana	1971