USING LAND RECLAMATION PRACTICES TO IMPROVE TREE CONDITION IN THE SUDBURY SMELTING AREA,ONTARIO, CANADA[1].

by

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Abstract. Extensive areas of Great Lakes-St. Lawrence mixed forest in the Sudbury area have declined over the past 100 years through a history of logging, fire, soil erosion, sulphur dioxide fumigation, acidification, particulate nickel and copper contamination and frost action. Pollution controls enacted since 1972 have not resulted in widespread recolonization and tree invasion as expected in the barren and depauperate White Birch-Red Maple (*Betula papyrifera* - *Acer rubrum*) communities. Birch growing in the toxic soils shows marginal leaf chlorosis during the mid summer while the maple exhibits regressive dieback. Since 1978, approximately 3000 hectares have been revegetated by the Sudbury Land Reclamation Programme. Dolomitic limestone, fertilizer and a grass-legume mixture were applied in the first year and in subsequent years a total of 1 million bare root and paper pot tree stock have been planted into the reclaimed sites. Trees introduced include Red Pine (*Pinus resinosa*), White Pine (*P. strobus*), Jack Pine (*P. banksiana*), White Spruce (*Picea glauca*), Red Oak (*Quercus rubra*), and Black Locust (*Robinia pseudoacacia*). Amounts of macro-elements in the foliage are below normal, except for nitrogen levels in Black Locust. Nickel and Al concentrations are high in tree tissue but not at toxic concentrations, whereas, Cu is average and Zn is present in low amounts. There is little evidence of chlorosis in the needles or in birch or maple leaves in the treated areas. Growth rates of the conifers are typical for trees found on acid, nutrient poor sites of northern Ontario. Trees lost due to insect or fungal disease have been minimal.

additional key words: rehabilitation, metals, conifers, hardwoods, landscape ecology.

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Introduction

Background to the programme.

Sudbury, Ontario, Canada (46° 30' N 81° 00' W) is situated on the southern edge of the Canadian Precambrian Shield, in a glaciated landscape characterized by a mosaic of rock outcrops, glacial till deposits and lakes. The area supported a transitional forest of boreal and hardwood elements; the Great Lakes-St. Lawrence Forest (Rowe, 1959). There were extensive stands of Red (*Pinus resinosa*) and White Pine (*P. strobus*) which were extensively logged from 1872 onwards, together with Yellow Birch (*Betula lutea*), Sugar Maple (*Acer saccharum*) and Red Oak (*Quercus rubra*). Regrowth supported stands of White Birch (*Betula papyrifera*) and Trembling Aspen (*Populus tremuloides*).

The mining and smelting of sulphide ores began in 1882, and smaller trees were used as mine timbers and as fuel for the open roast beds. Fires were started by sparks from the wood-burning locomotives of the Canadian Pacific Railway, and prospectors often burned the vegetation and duff to reveal the bedrock below. Sulphur dioxide from the ground-level roast yards also killed vegetation in their vicinity between 1888 and 1929, while smoke from the smelters, containing not only sulphur dioxide, but also copper, nickel and iron particulates, leached and acidified the soil, contaminating it with copper and nickel. Acidification caused aluminum from the soil minerals to be solubilized. The soil, having lost its protective vegetation cover, suffered extensive erosion, exacerbated by the intense frost-heaving and needle ice formation (Amiro and Courtin 1981; Winterhalder 1984)

The net result was the creation of 10,000 ha of completely barren land, as well as 36,000 ha of open woodland dominated by stunted and coppiced *Betula papyrifera* (White Birch), *Acer rubrum* (Red Maple) and *Quercus borealis* (Red Oak) (DeLestard 1967). Peatlands have also been affected by the industrial operations (Gignac and Beckett 1986).

In 1972, one of the three existing smelters, as well as an iron ore sintering plant, were closed. In addition, the three smokestacks at another smelter were replaced by a 381 metre stack, and emissions reduced. Following the improvement in atmospheric quality, some of the barren areas were colonized by metal-tolerant grasses such as *Deschampsia caespitosa* (Tufted Hairgrass), *Agrostis gigantea* (Redtop) and *A. scabra* (Tickle Grass) and the moss, *Pohlia nutans*.

On a few stony hillsides germination and re-establishment of scattered White Birch seedlings began approximately ten years following smelter closure. Near poor fens, *Betula pumila* var. *glandulifera* (Dwarf Birch) began, uncharacteristically, to move up the slopes.

On barren sites, soil pH ranged from 2.0 to 4.5, while copper and nickel levels frequently reached 1,000 $\mu g\ g^{-1}$. Root growth was so inhibited that seedlings quickly dried out and died. Bioassay experiments showed that barren soils could be detoxified by addition of ground limestone. Field trials showed that a grass-legume cover could be achieved on the stony slopes by the manual application of ground dolomitic limestone, fertilizer and a seed mixture. The stones acted as a mulch, trapping the seeds and cutting down moisture loss. The surface application of limestone was sufficient to "promote" colonization by woody plants, even in the absence of fertilizer and seed (Winterhalder 1985).

Early rehabilitation attempts in 1969 and 1970 using trees (both bare root and container stock) on unamended barren soils had little success. (summarized by Winterhalder 1984). However, trials with bare root Jack (*Pinus banksiana*) and Red Pine in 1975 and 1976 using lime and fertilizer and in 1978 using the same species in Japanese Paper Pots (Negusanti 1978) showed excellent growth. Subsequently, as reported by Lautenbach (1985,1987, 1988) the Sudbury Land Reclamation Programme was initiated (1978) under the direction of the Vegetation Enhancement Technical Advisory Committee (VETAC) that reports to the Regional Municipality of Sudbury. In addition, both mining companies have been operating their own reclamation projects.

<u>Philosophy governing tree planting</u>

Before tree planting could be successful on a large scale, a herbaceous cover together with proper soil treatment was necessary. The grass-legume mixture must not be too dense so that it chokes the woody species. Nor must the herbaceous cover be sufficient to support a large population of small mammals that may damage the small trees. The grass legume mixture provides a mulch and, before the trees are fully established, acts as a nutrient reservoir. However, the nutrients must become available to the trees to avoid permanent stunting. The 10 - 30% herbaceous cover achieved in the programme appears suitable for adequate tree growth.

The presence of legumes should be of longterm benefit to the trees as a source of nitrogen. Indeed some of the more successful treeplots contain Birdsfoot Trefoil (*Lotus corniculatus*) as a dense understory. However, the creation of woodland with an understory of agronomic species may seem unusual. Long-term monitoring has shown that the agronomic species decrease in importance over time and woody species through colonization increase in importance (see Winterhalder 1988).

The establishment of an open grass cover initiated colonization by seedlings of White Birch, *Salix* spp. (Willows) Trembling Aspen and in some localities, Dwarf Birch. Since natural colonization of woody species is occuring so rapidly, one might question the cost and expense of artificially introducing herbaceous and tree species on these sites. In time, one might expect a slow colonization by climax trees including the pines, spruces and oaks. However, the monocultural problems and the visual appearance of uniform stands of these colonizers is not very appealing.

By directly introducing trees into the grassed areas, total diversity could be quickly increased and a large number of niches can be available for other components of the ecosystem. In addition, one of the aims of the programme is the partial restoration of the mixed forest that was characteristic of Sudbury one hundred years ago. Once established, the introduced trees should act as a local source of seeds.

Mature trees in the landscape are much more intruding than a herbaceous cover. Thus it has been the intention of the Programme to create semi-natural, attractive, diverse and stable bio-ecosystems. Hence, the use of extensive "plantation" planting and very high stocking rates is opposed. Before planting, evaluating the site aids in the determination of a harmonious grouping of trees with the landscape, helps create openings in the arrangement, maintains sight lines, and makes the landscape appealing upon maturation of the trees. This aim is helped by the rocky terrain with small and large pockets of soil that make it difficult to completely cover the terrain with trees. Pines and spruces have been extensively used to provide year-round greenery (Beckett 1988)

Since one of the aims is to recreate, at least partially, the appearance of the original forest cover, the use of exotics is minimized. Black Locust has, however, been used because of its ability to fix nitrogen and to withstand windy locations. It is often mixed with pines or Red Oak to act as a nurse tree. For autumn colour, European and Japanese Larch has been used in well-drained localities. There is evidence that the native Tamarack (*Larix larcina*) will grow satisfactory in these locations and creating trials with this species are in progress.

Materials and Methods

The Regional Land Reclamation Program - the Process

The major activities of the programme are summarized in Table 1.

a) Establishment of Grass Cover. Depending on the soil pH and colloid content, between 4.5 and 11 t ha^{-1} of ground limestone were applied. The limestone was allowed to react with the soil for a few weeks before the addition of a N-P-K fertilizer having a high P:N ratio (usually 4:1). Sudbury soils are more deficient in phosphorus than nitrogen and phosphorus can decrease the amount of toxic metals, (especially Al) available to roots. Fertilizer in 50 kg bags was hand-spread at a rate of approximately 390 kg ha^{-1} The fertilizer application usually occurred late in the summer to coincide with the seeding operation.

Seeding began in mid-August and continued through September to coincide with the autumn rains. A blended mixture of five agronomic grasses and two legume species was spread using Cyclone-seeders at a rate of 30 - 45 kg ha^{-1}

During the period 1978-89 approximately 3,000 ha have been treated, with the ten-year old areas showing a good cover of volunteer birchs and poplars, often up to 2.5 m in height and a diverse assemblage of herbs.

b) Tree Planting Programme. In spite of occasional relict Jack Pines (*Pinus banksiana*) and Red Pines, there is little evidence so far of volunteer pine establishment. For this reason, a tree-planting programme has been in effect for almost as long as the grassing programme. Both bare-root nursery stock and paperpot stock have been used, and over one million tree seedlings have been planted. Apart from some early test plots, seedlings are not planted in rows, but in groups that conform with topography and appear relatively natural. It is hoped that these trees will form a seed-source for later spread, as has began to occur in the ten year old Jack Pine stands.

The Tree Planting Subcommitee of VETAC is responsible for the selection of planting sites and tree allocation. Although a proposed tree planting plan has been drawn up (Regional Municipality of Sudbury, 1986) each site is visually inspected by the Sub-

TABLE 1. LAND RECLAMATION PROGRAMME ACHIEVEMENTS 1978-89

YEAR	AMOUNT LIMED (hectares)	AMOUNT FERTILIZED (hectares)	AMOUNT SEEDED (hectares)	AMOUNT SITE IMPROVED (hectares)	NUMBER OF TREES PLANTED	OTHER ACHIEVEMENTS
1978	114.8	114.8	114.8	206.3		30,000 pH and nutrient samples. 365 kg of native seed collected. 11,000 trees, shrubs and plants transplanted. 122 composting test plots.
1979	478.6	466.6	420.2	295.9	4,250	420 hectares sampled for pH. 425 kilograms of native seed collected. 20,000 trees, shrubs and plants transplanted. Monitoring and assessment begun.
1980	331.0	299.3	299.3	258.7	1,300	Land reclamation data assembled and computer coded. 2,000 pH samples taken. 5 Year Land Reclamation Plan developed.
1981	208.0	173.4	173.4	9.8	4,600	5 Year Plan updated. Monitoring and assessment records processed. 29 research plots established.
1982	362.4	342.4	305.2	199.2	-	Dismantled 2.4 km of abandoned trestle and improved tailings wildlife area.
1983	1,084.0	934.6	935.4	-	228,080	Established 10 wildflower experimental test plots.
1984	57.7	188.4	215.9	7.5	149,350	Timber cruised 3,213 hectares. Transplanted 400 trees. Updated all mapping records. Compiled second 5 year grassing plan.
1985	112.0	106.0	106.0	-	154,600	Native shrub seed sources identified. Land Reclamation Summary Report 1978-84 published.
1986	24.0	30.0	30.0	-	80,300	5 Year Tree Planting Plan developed. Monitoring survey of trees planted 1978-1985 completed. Forest management report prepared.
1987	59.5	64.7	64.7	-	264,880	Seeds of 15 species of trees or shrubs collected for diversity and future outplanting. Seed collection report prepared.
1988	34.8	34.8	34.8	-	118,885	Planted 8,300 shrubs. Monitored and assessed past work. Wildlife habitat improvement report prepared.
1989	7.5	12.2	12.2	-	65,740	
Totals	2,874.3	2,767.2	2711.9	977.4	1,071,985	

Table 2. Type and number of tree seedling planted (l979-89)

Species		Number	Symbol
conifers			
Jack Pine	*Pinus banksiana*	345 000	Pj
Red Pine	*Pinus resinosa*	350 000	Pr
White Pine	*Pinus strobus*	100 000	Pw
White Spruce	*Picea glauca*	25 000	Sw
Black Spruce	*Picea mariana*	10 000	Sb
Norway Spruce*	*Picea abies*	5 000	Sn
White Cedar	*Thuja occidentalis*	15 000	Ce
Japanese Larch*	*Larix leptolepis*	2 000	Lj
European Larch*	*Larix decidua*	3 000	Le
Tamarack	*Larix laricina*	7 000	Ta
hardwoods			
Black Locust*	*Robinia pseudoacacia*	90 000	Lb
Red Oak	*Quercus rubra*	78 000	Or
Silver Maple*	*Acer saccharinum*	30 000	Ms
Sugar Maple	*Acer saccharum*	4 600	Mh
White Ash	*Fraxinus americana*	6 000	Aw

* Not native to the Sudbury area

committee and the numbers of each species deliminated on 1: 2000 maps for use by the planting crews.

In total, fifteen species have been used: ten conifer species and seven hardwood species (see Table 2). The majority of the stock has been bareroot, obtained through the Ontario Ministry of Natural Resources' tree nurseries. Trees are stored in a reefer van at 4 ^{0}C until planted. All planting has occurred between early May and the beginning of June. Unfortunately hot and dry weather has been experienced in some years during or immediately after the planting period. In 1987, approximately 70 000 paper pot Red, White and Jack Pine were planted in addition to the bare root stock.

c) Evaluation of Tree Planting Programme. Monitoring of trees at selected sites is performed to evaluate survival, growth, performance and chemical composition. The results are used to refine the tree planting programme. Each monitoring site contains approximately 100 trees and each species planted is replicated at several locations across the Region of Sudbury. During the year of planting, trees are assessed for survival and general health only. In subsequent years trees are individually identified and survival, growth by height, diameter of trunk and general health are monitored. At a few sites tree parts are sampled for chemical analysis. Full details of monitoring sites, method and results may be found in a series of tree monitoring reports produced for the Vegetation Enhancement Technical Advisory Committee (1985 - 1989). The monitoring has been assisted through the use of students and their help is much appreciated.

Results and Discussion

Tree monitoring and assessment

a) Tree Survival Figure 1 reports the mean survival of the major tree species three years after planting. In general, the pines show the best survival rates. Black Locust is planted on difficult sites but showed good survival rates. The more sensitive hardwoods, maples and ash, are used in a few restricted sites with the most favourable conditions, but their survival is poor. The generally shallow and dry soils of the reclaimed lands are best suited to pines and this is reflected in their best overall survival rates. The high survival of Red and Jack Pine has led to the extensive use of these two species (see Table 2). The development of monocultures of these 2 species is not ideal and efforts are made to diversify the mixture of trees planted with or near the pines. Despite the low tolerance of White Pine to pollution stress,

Fig. 1. Percentage Survival Rate of Major Tree Species after 3 Years. (Legend for species is in Table 2.)

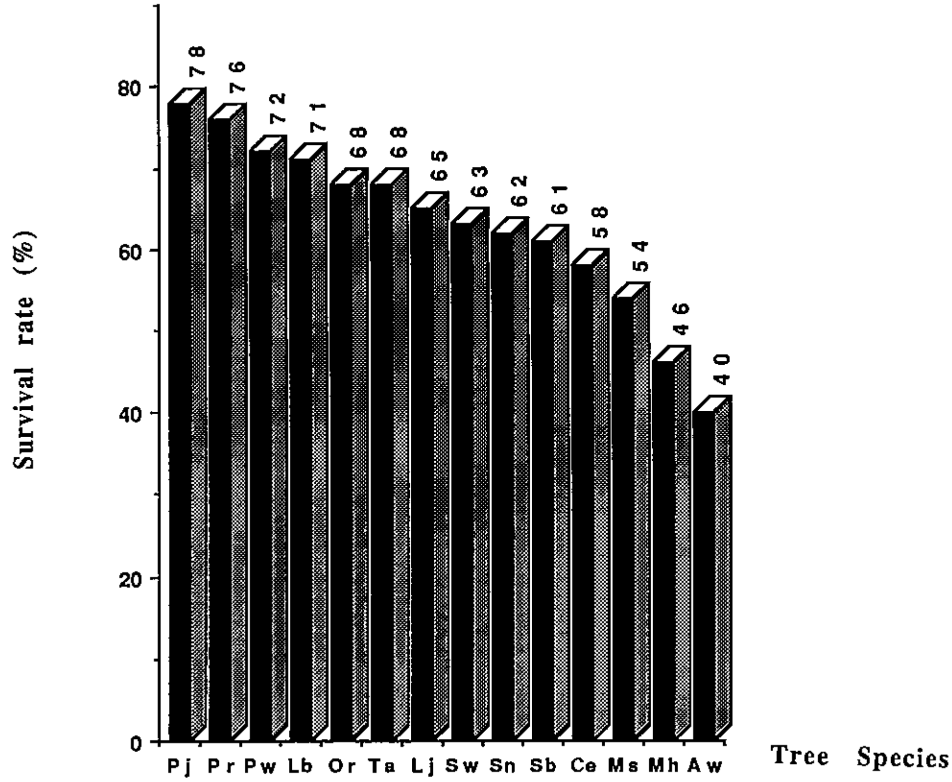
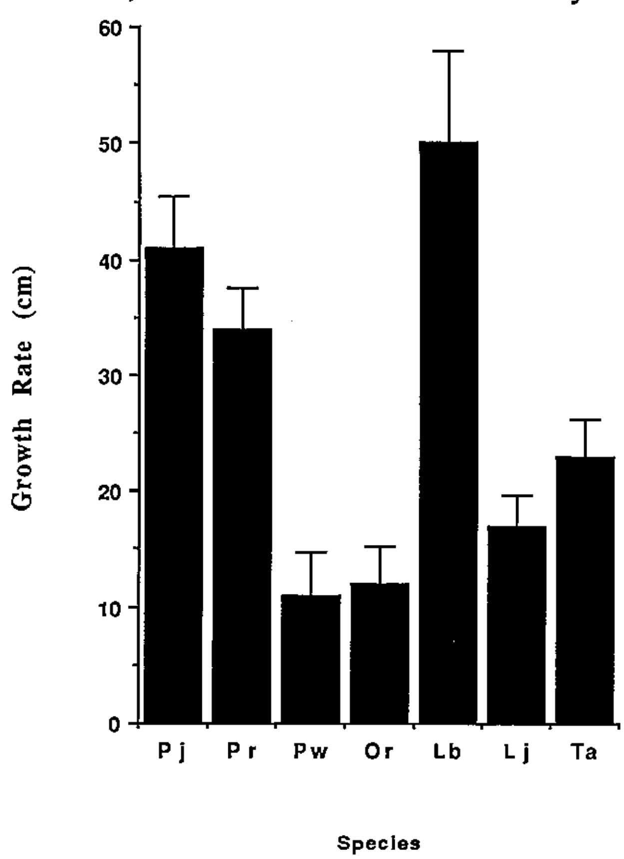


Fig. 2. Mean Annual Growth of Trees on Reclaimed Land (+ standard) error). Measurements were made 3 years after planting.



especially sulphur dioxide, the species has a respectable survival rate. White Cedar has a low rate of survival. In part this is due to its planting in wetland sites that are not always limed. On slopes where the reclamation treatment has been applied, the survival rate of cedar increases dramatically.

b. Tree Growth. The annual growth rates for a selection of the major species are reported in Figure 2. Jack Pine and Red Pine are the fastest growing conifers The growth of Black Locust in the Sudbury area is reduced each year by hard winter frosts killing the youngest extension growth

The experimental sites of Red and Jack Pine set up in 1979 have allowed growth patterns to be followed over the longer term. The cumulative growth of these species on reclaimed sites is compared to control sites (see Fig. 3 and Fig. 4). The control sites are outside Sudbury and have similar soil properties and soil acidity but not the elevated metal levels of the Sudbury area. There is no statistical difference ($p>0.05$ for slope comparison) between growth rates at the Sudbury reclaimed and control reforestation sites for either species. Jack pine has the faster growth rate and is therefore a useful tree for quickly providing cover and winter greenery. However, the visual appearance of Red Pine is more appealing. These results indicate that the trees in Sudbury are performing satisfactorily but need several years of growth before they can be visually appreciated.

c. Chemical composition. Metal content in the needles increases with age. Nickel and aluminium levels are high but do not appear toxic (Table 3), whereas, copper levels are about normal and zinc amounts are less than normal. Similar patterns have been observed in both Red and White Pine, although the metal levels are lower. Aerial deposition of metal particulates may contribute to the metal concentrations associated with the needles.

Amounts of macro-nutrients in the foliage are below normal. However, White Birch. Red Maple and Red Oak growing in the reclaimed areas have significantly higher levels of calcium and magnesium and do show the marginal chlorosis of leaves from untreated areas. Black Locust appears to be fixing nitrogen since the leaves are a dark green and contain 2-4% nitrogen; similar to nitrogen values for trees where nitrogen fixation has been demonstrated.

Conclusions

1. The tree planting programme has stressed diversity, but uses a minimum number of exotic

Fig. 3. Cumulative Growth of Jack pine planted in 1979 compared with a non-polluted reforestation stand planted in the same year. (n = 100 at each site)

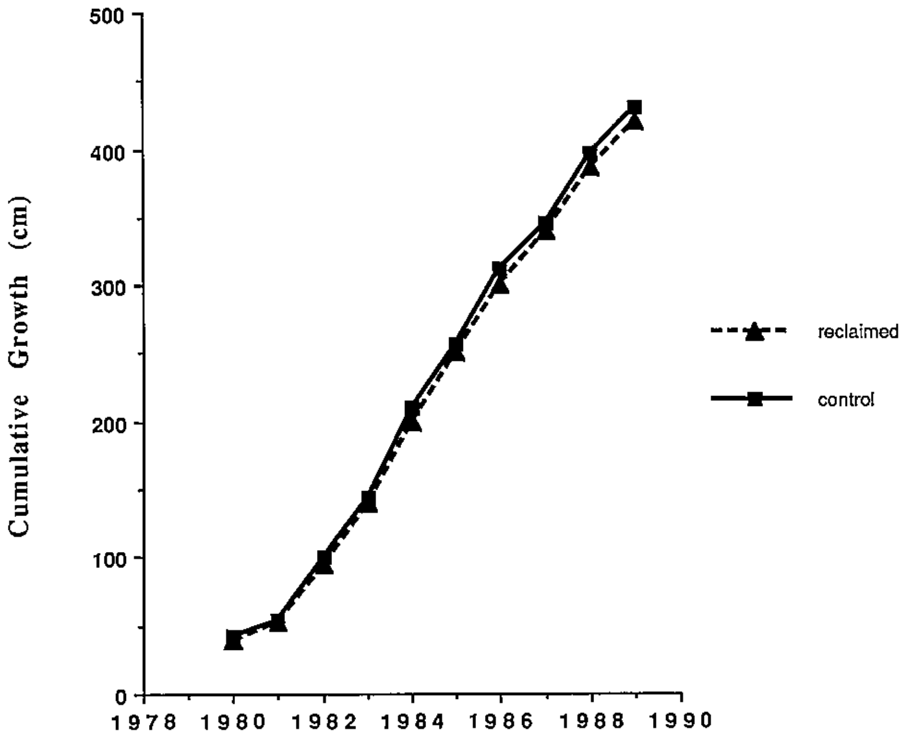


Fig. 4. Cumulative Growth of Red pine planted in 1979 compared with a non-polluted reforestation stand planted in the same year. (n = 100 at each site)

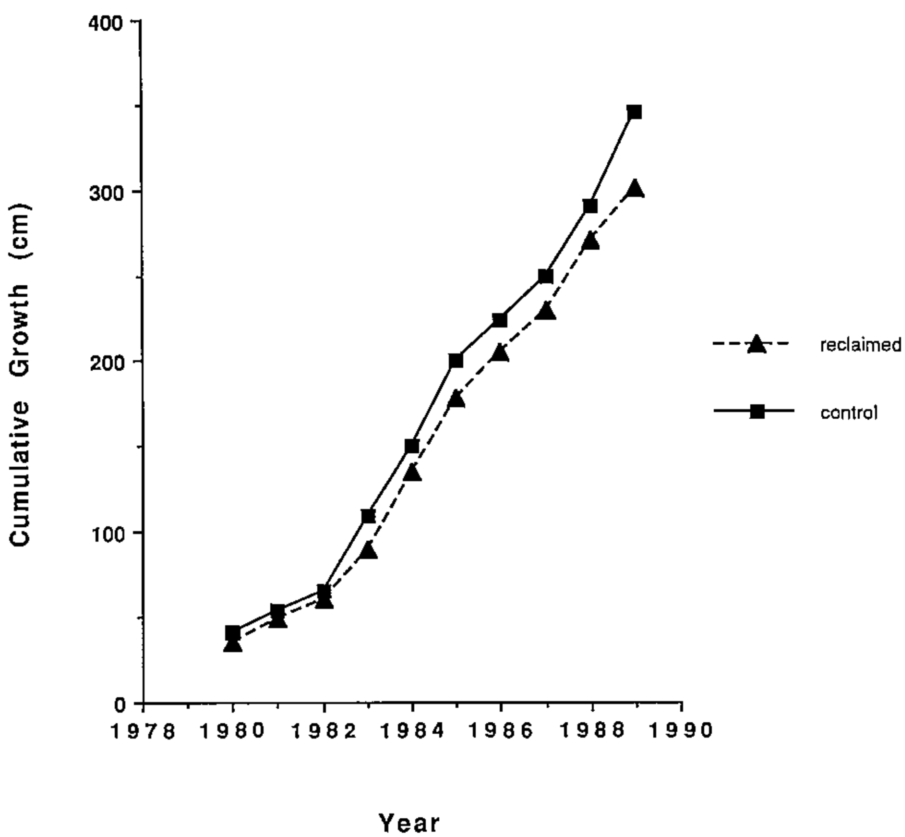


Table 3 Metal levels in Jack Pine Needles of 3 ages from a reclaimed site in Sudbury (planted l979) and a control, 50 km away. (Values are means +/- standard error based on a sample size of 20.)

SITE	NEEDLE AGE (year)	METAL CONCENTRATION ($\mu g\ g^{-1}$) Al	Cu	Ni	Zn
Sudbury	1	324 +/- 5	8.9 +/- 1.3	16.0 +/- 1.3	123 +/- 23
Sudbury	2	345 +/- 6	8.5 +/- 1.4	19.0 +/- 2.1	134 +/- 34
Sudbury	3	620 +/- 11	8.1 +/- 1.9	30.0 +/- 3.3	178 +/- 45
Control	1	234 +/- 6	2.0 +/- 0.9	3.5 +/- 0.8	235 +/- 34
Control	2	244 +/- 9	2.4 +/- 0.8	3.8 +/- 1.0	256 +/- 35
Control	3	439 +/- 7	2.7 +/- 1.3	6.3 +/- 1.3	310 +/- 32

species. However based on survival and growth information, a large number of Red and Jack Pine have been used.

2. The use of White Pine, despite its alleged sensitivity to sulphur dioxide, has allowed some diversity in the use of pines. Survival of White Pine indicates that pollution control measures in the Sudbury area have been beneficial.

3. The majority of the stock planted has been bare root. This has restricted the length of the planting season. Paper pot stock could be used with advantage to extend the planting period.

4. Other species of tree and shrubs have potential use in the Sudbury Programme. The present source of trees has been Ontario Ministry of Natural Resources' nurseries and thus only a restricted list of species is available. In addition, the plant materials may not have originated from NE Ontario. Other species of local origin could increase the diversity and be more characteristic of the original forest ecosystem of Sudbury. A programme to collect and grow material of local origin is in progress.

5. With respect to landscape creation, there has been an emphasis on making use of the natural topography. The micro-environmental pattern has imposed its mark upon the resulting vegetative cover. Grasses and other plants vary, with respect both to species and to density, in response to differences in soil depth, soil moisture and the shelter factor. The seeds of colonizing woody plants have been deposited and have germinated in a non-random fashion, presumably dependant on topographical factors such as soil moisture, aspect and turbulent wind-flow. Overall, the spatial heterogeneity of the vegetation, overlaid on the already diverse topography, has given rise to an attractive and natural-appearing landscape.

Superimposed on the topographic-vegetational pattern is one created by tree-planting. Apart from early trials, the plantation effect has been avoided, and trees are planted in groupings that conform to the topography. An extra dimension is added by the response of the trees themselves. Where even-aged tree seedlings are planted, the micro-environmental pattern is reflected in the varied stature and vigour of their growth, helping to blend them into the landscape.

6. At present the major land use of the reclaimed areas is rural passive, recreation and wildlife habitat. To futher wildlife enhancement, several species of shrubs have been

planted in and around areas with introduced trees. If the feasibility of growing shrubs from locally collected seed is economical, it is anticipated that more use of shrubs and other species useful for wildlife will be utilized.

7. The reclamation effort in Sudbury has played a role in improving the national image of Sudbury and has helped in economic diversification in the region. The less bleak landscape is contributing to the concept that Sudbury can be a "healthy place" for "healthy people".

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