TREE AND SHRUB ENRICHMENT AS PART OF THE MUNICIPAL RECLAMATION PROGRAM IN SUDBURY, ONTARIO[1]

P. J. Beckett[2,3], W. Lautenbach[2], J. Miller[2], Negusanti[2], T. Peters[2], J. Vining[2],

Abstract: The Sudbury Land Reclamation Program treats the hilly acid metal-contaminated landscape that has been affected through historic anthropogenic effects, including emissions from nickel and copper smelting. Phase one of the program is to add dolomitic limestone (10 t/ha), fertilizer and a grass-legume seed mixture. To enhance natural colonization over 2.0 million trees and shrubs have been planted since 1979 into 3100 ha previously limed and grassed or into open birch woodland. Survival and growth rates of the twenty (mostly native) species used are similar to non-contaminated areas outside Sudbury. In 15 years of monitoring metal levels in pines there is no evidence of accumulation of toxic amounts of nickel, copper or aluminium.

Additional Key Words: Sudbury, reclamation, trees, shrubs, tree growth, nickel, copper

Introduction

Sudbury, Ontario (46º 30" N, 81º 00" W) is 400 km north of Toronto and 75 km from Lake Huron. It lies on the Pre-Cambrian Shield with undulating topography in a glaciated landscape characterized by a mosaic of rock outcrops, glacial till deposits and numerous lakes. The oval shaped Sudbury Basin, which was a post-glacial lake, lies northwest of the city of Sudbury. Surrounding the basin is the Sudbury Irruptive Formation, 1.5 - 3.0 km thick. Associated with the outer rim of the Irruptive are the Sudbury ore bodies, composed of pentlandite and pyrrhodite.

The area is under the influence of a continental climate. There is an annual average of 840 mm of precipitation with snow on the ground from early December to mid-April. The average monthly temperature ranges from -12°C in January to 20°C in July. The natural vegetation is the Great Lakes - St. Lawrence mixed hardwood forest (Rowe 1959) once characterized by extensive stands of Red and White Pine (*Pinus resinosa* & *P. strobus*) and tolerant hardwoods such as the Sugar Maple (*Acer saccharum*) and Yellow Birch (*Betula alleghaniensis*).

However, the Sudbury region has a history over the past 100 years of logging, forest fires, mining and sulphide ore smelting (Wallace and Thomson 1993). The factors have caused loss of vegetation, acidification and metal contamination of the landscape (Winterhalder 1984). Before 1972 between 1.5 and 2.7 x 10^6 tonnes per year of sulphur dioxide were emitted from the three Sudbury smelters. Nickel and copper emissions were over 1000 tonnes per year. In the early 1970s approximately 17 500 ha of land lacked vegetation (DeLestard 1967; Amiro and Courtin 1981). Another 72 000 ha were semi-barren with stunted Paper Birch (*Betula papyrifera*) and Red Maple (*Acer rubrum)* as the major constituent. Depressions contained highly modified wetlands or denuded peatlands (Gignac and Beckett 1986).

---

[1]Paper presented at the 1995 National Meeting of the American Society for Surface Mining and Reclamation, Gillette, Wyoming, June 5-8, 1995.

[2]Tree and Shrub Management Subcommittee, Vegetation Enhancement Technical Advisory Committee (VETAC), Regional Municipality of Sudbury.

[3]Contact person - Department of Biology and CIMMER, Laurentian University, Sudbury, Ontario, Canada. P3E 2C6. Tel: 705-675-1151, Fax: 705-675-4859, email: pbeckett@admin.laurentian.ca

Proceedings America Society of Mining and Reclamation, 1995 pp 801-810
DOI: 10.21000/JASMR95010801

https://doi.org/10.21000/JASMR95010801

Recent Environmental Recovery

In 1972 pollution controls resulted in the closure of one smelter and the installation of a 381 m 'super stack'. Severity of fumigation has decreased as well as metal deposition in the region (Ministry of Environment (1990, 1992). Following the improvement in atmospheric quality there has been substantial improvement iof water quality in lakes (less acid) and recovery of planktonic communities, bentihc invertebrates and some fish populations (Gunn and Keller 1990; Keller *et al.*, 1992). Epiphytic and ground lichens have also re-invaded the Sudbury area with the elimination of the pre-1972 lichen desert (Beckett 1995). In 1968, no lichen species occurred within a radius of seven kilometres from the three smelters (Leblanc *et al.* 1972). By 1990, no trees were found to be devoid of lichen epiphytes, and sulphur-dioxide tolerant species were found to within two kilometres of the two existing smelters.

On land some of the barrens have been colonized by metal-tolerant grasses such as *Deschampsia caespitosa* (Tufted Hairgrass), *Agrostis gigantea* (Redtop) and *A. scabra* (Tickle Grass) (Winterhalder 1993a), the moss *Pohlia nutans* (Beckett 1986) and more recently by scattered White Birch seedlings and *Betula pumila* var. *glandulifera* (Dwarf Birch). Nevertheless, many barren sites remained bare with soil pH values less than 4, nickel and copper up to 2000 mg km^{-1} dry wt (Dudka *et al.* 1995), and those that were invaded by plants showed low species diversity. Thus it seemed that natural recovery was not going to happen quickly. A large scale reclamation program was needed to substantially alter the psychological impression of Sudbury and to provide an impetus for change. A full review is provided by Gunn (1995).

The Regional Land Reclamation Program

Reclamation Program Beginnings

In 1978, the Regional Municipality of Sudbury embarked upon its Land Reclamation Program, basing its approach on research carried out at Laurentian University (Lautenbach 1985, 1987, 1988). In addition, both mining companies (INCO Ltd and Falconbridge Ltd) have been operating their own reclamation projects to cover tailings with vegetation and to rehabilitate land around their operations (Heale 1991).

The major goal is to make the approaches to Sudbury green and visually attractive through the re-establishment of a forest similar to the original forest cover of the hills. The landscape or "raw material", on which rehabilitation was applied, still possessed many of the characteristics of the original landscape. Initial field trials had demonstrated that liming was needed to detoxify the soils and that a herbaceous cover was essential before trees and shrubs could be successfully established (Winterhalder 1984).

Program organization

The Vegetation Enhancement Technical Advisory Committee (VETAC), a Regional Government Advisory Committee of 33 members, directs the program through the Land Reclamation Co-ordinator. The program operates in two phases. Initially a grass-legume cover is established on sites selected by the Site Selection Subcommittee of VETAC. Trees and sometimes shrubs are introduced into the grassed sites following the recommendations of the Tree and Shrub Management Subcommittee of VETAC.

The process

1. Establishment of Grass Cover.

Depending on the soil pH and colloid content, between 4.5 and 11 t ha^{-1} of ground dolomitic limestone are applied at the normal rate of about 10 t ha^{-1}. The limestone is allowed to react with the soil for a few weeks (decreases soil acidity) before the addition of a N-P-K fertilizer (6-24-24) at a rate of approximately 390 kg ha^{-1}. The fertilizer application usually occurs late in the summer to coincide with the seeding operation (Lautenbach *et al.* 1995). Seeding begins in mid-August and continues through September to coincide with the autumn rains. A blended mixture of four agronomic grasses and two legume species is spread using Cyclone-seeders at a rate of 30 - 45 kg ha^{-1}(Table 1).

Table 1 : Typical seed mixture (by weight.) used in the Sudbury Program

15% Canada Blue Grass (*Poa compressa*)
15% Kentucky Blue Grass (*Poa pratensis*)
20% Timothy (*Phleum pratense*)
20% Red Top (*Agrostis gigantea*)
10% Alsike Clover (*Trifolium hybridum*)
10% Bird's Foot Trefoil (*Lotus corniculatus*)

Within a couple of years the typical grass legume cover is around 25-40% which gives a green appearance from a distance. Major woody invaders (in order of importance) include Trembling Aspen, (*Populus tremuloides*) and willow (*Salix pyrifolia*), White Birch (*Betula papyrifera*) and Balsam Poplar (*Populus balsamifera*) often up to 2.5 m in height ,together with a diverse assemblage of herbs (Winterhalder 1993a &b). Mosses and lichens (especially *Cladonia*) can become abundant.

2. Tree and Shrub Planting Programme.

To increase diversity, add year round greenery to the landscape, and to speed up natural successional changes phase 2 of the land reclamation program is tree planting. Trees are introduced 1 to 3 years after initial treatment. Both bare-root nursery stock, paperpot stock and more recently container stock have been used. 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 begun to occur in sixteen year old Jack Pine stands.

Table 2. Type and approximate number of tree and shrub seedling planted (1979-94)

Species		Number planted (1979-94)	1995
conifers			
Jack Pine	*Pinus banksiana*	600 000	102 000
Red Pine	*Pinus resinosa*	600 000	114 000
White Pine	*Pinus strobus*	333 000	61 500
White Spruce	*Picea glauca*	137 300	25 000
Black Spruce	*Picea mariana*	40 000	13 000
Norway Spruce*	*Picea abies*	25 000	
White Cedar	*Thuja occidentalis*	20 000	
Japanese Larch*	*Larix leptolepis*	2 000	
European Larch*	*Larix decidua*	3 000	
Tamarack	*Larix laricina*	32 000	
Mugo Pine*	*Pinus mugho*	1 100	
	subtotal	1 793 400	315 500
hardwoods			
Black Locust*	*Robinia pseudoacacia*	130 500	
Red Oak	*Quercus rubra*	78 000	1200
Silver Maple*	*Acer saccharinum*	30 000	
Sugar Maple	*Acer saccharum*	4 600	
White Ash	*Fraxinus americana*	6 000	
Yellow Birch	*Betula alleghaniensis*	4 000	
	subtotal	249 100	1200
	TOTAL	2 042 500	
shrubs		40 000	

Include Bush Honeysuckle (*Diervilla lonicera*); Red-Osier Dogwood (*Cornus stolonifera*); Nannyberry (*Viburnum lentago*)*; *Caragana sp.**; Russian Olive (*Elaeagnus angustifolia*)*

* Not native to the Sudbury area

In total, over twenty species have been used: eleven conifer species and six hardwood species and a mixture of shrubs (see Table 2). The majority of the tree stock before 1993 was bareroot (2-3 y old) and obtained from the Ontario Ministry of Natural Resources' tree nurseries. Bareroot stock is stored in a reefer van at 4°C until planted. Most planting has occurred between early May and the beginning of June. Since 1987, paper pot Red, White and Jack Pine have been planted in addition to the bare root stock. By 1993 most of the planted stock was container class. Between 100000-350000 trees are planted each year (Beckett 1988; Beckett and Negusanti 1990). By September 1994 over 2.0 million trees had been planted, together with several thousand shrubs (Table 2). Ceremonial plaques have been erected to mark the planting of the first and second millionth tree in the program. It is anticipated that over 300 000 trees will be planted in 1995 (Table 2) and another 1.25 m in the 5 year plan from 1996-2000.

The majority of the shrub seed was collected from local sources. Seed was cleaned through co-operation of the Ministry of Natural Resources and stored at 4°C. Seedlings were grown for 3-4 months in greenhouses by Environmental Horticulture students at the local Community College (Cambrian College). The shrubs were given at least one month outdoors to harden off before transplanting into reclaimed sites.

Red and Jack Pines have been used most extensively because of their suitability to open dry habitats. White Pine is planted where invading Trembling Aspen and White Birch provide some cover. Spruces are planted in areas with deeper soils and cover from the spruce budworm. *Robinia pseudo-acacia* (Black Locust) is used on eroded clay areas on which it is difficult to establish vegetation or as a nurse tree to slower growing trees such as Red Oak, and for its ability to fix nitrogen. Tamarack and other larches are mixed with pines to provide colour. Areas may be planted at several different times as ecological conditions change with the aim of improving species richness. Shrubs are used for their ability to attract birds and other wildlife.

Assessment of the planting program

Survival rates after three years are 50-80% with pines having the highest success rates. Annual growth rates are little different from trees planted on other nutrient poor sites in northern Ontario (Lautenbach *et al.* 1995). Shrubs show survival rates below 50% (Figure 1) due mainly to competition from grasses and Bird's Foot Trefoil.

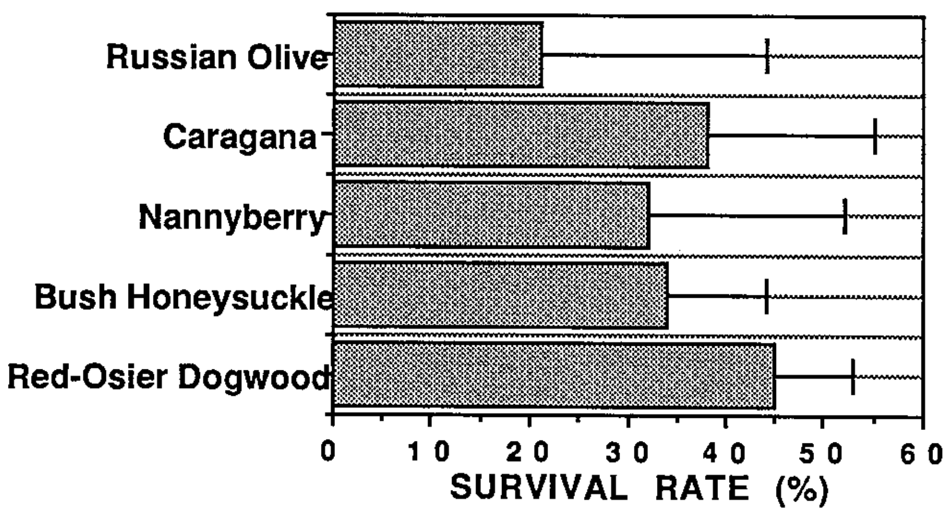

Figure 1. % Survival rate (+ standard deviation) of shrubs after 5 years based on a sample size of 100

Jack pine has a fast growth rate (see Figure 2) and is therefore a useful tree for quickly providing cover and winter greenery. However, the visual appearance of Red Pine is more appealing and grows almost as fast as Jack Pine (Figure 2). There is little difference between height increases in Sudbury compared to a control with a similar pH, low nutrients but low metal levels (Figure 2). Other species (Figure 3) are growing at adequate rates, appear generally healthy, and are adding to the visual changes in the landscape. Black locust was set back by the unusually long and intensively cold winter of 1993-1994 that killed many trees or severely pruned the living branches.

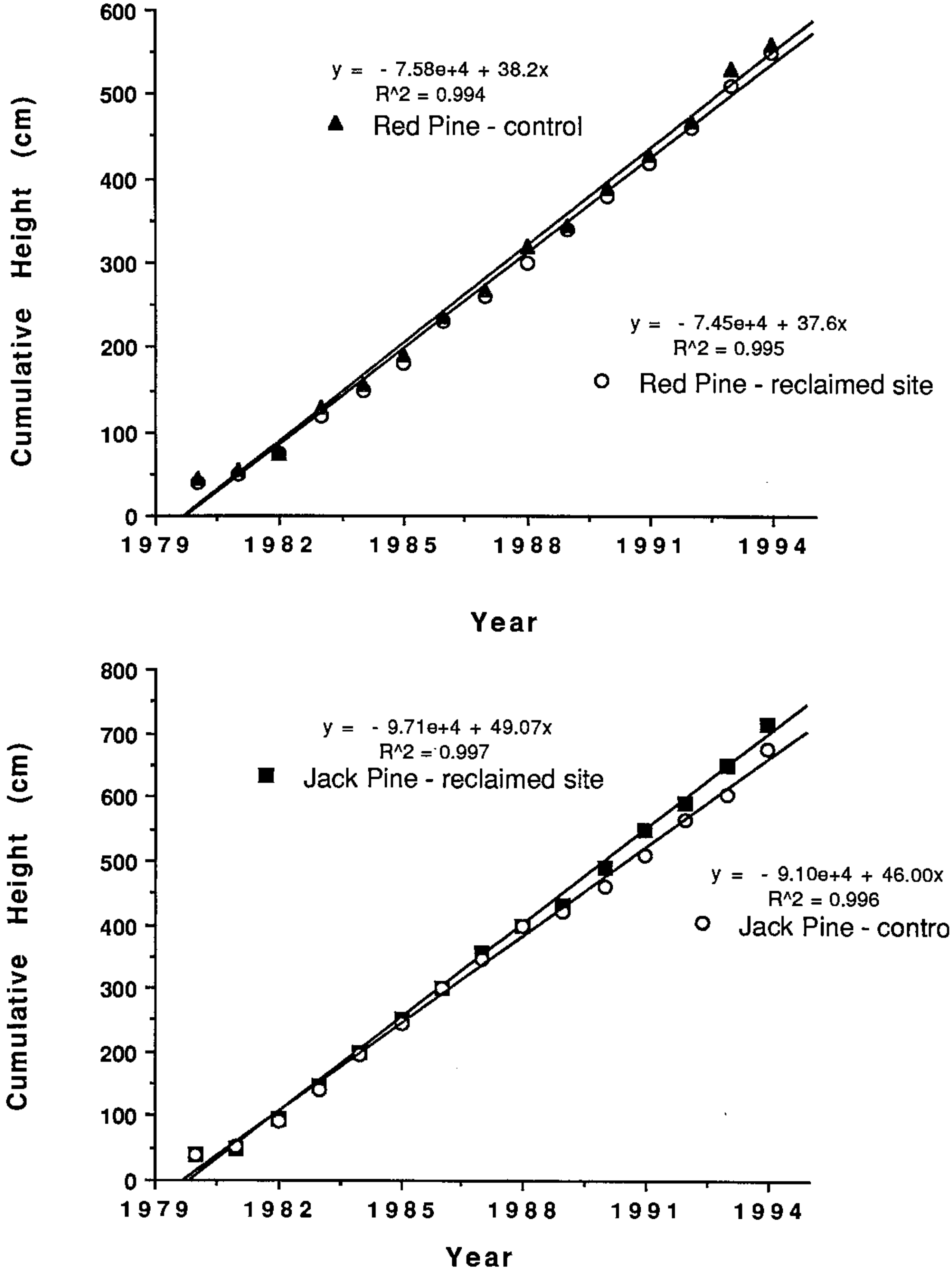

Figure 2. Cumulative growth and fitted linear regression for Red and Jack Pine planted in 1979 from a reclaimed and control site 75 km west of Sudbury (n = 100)

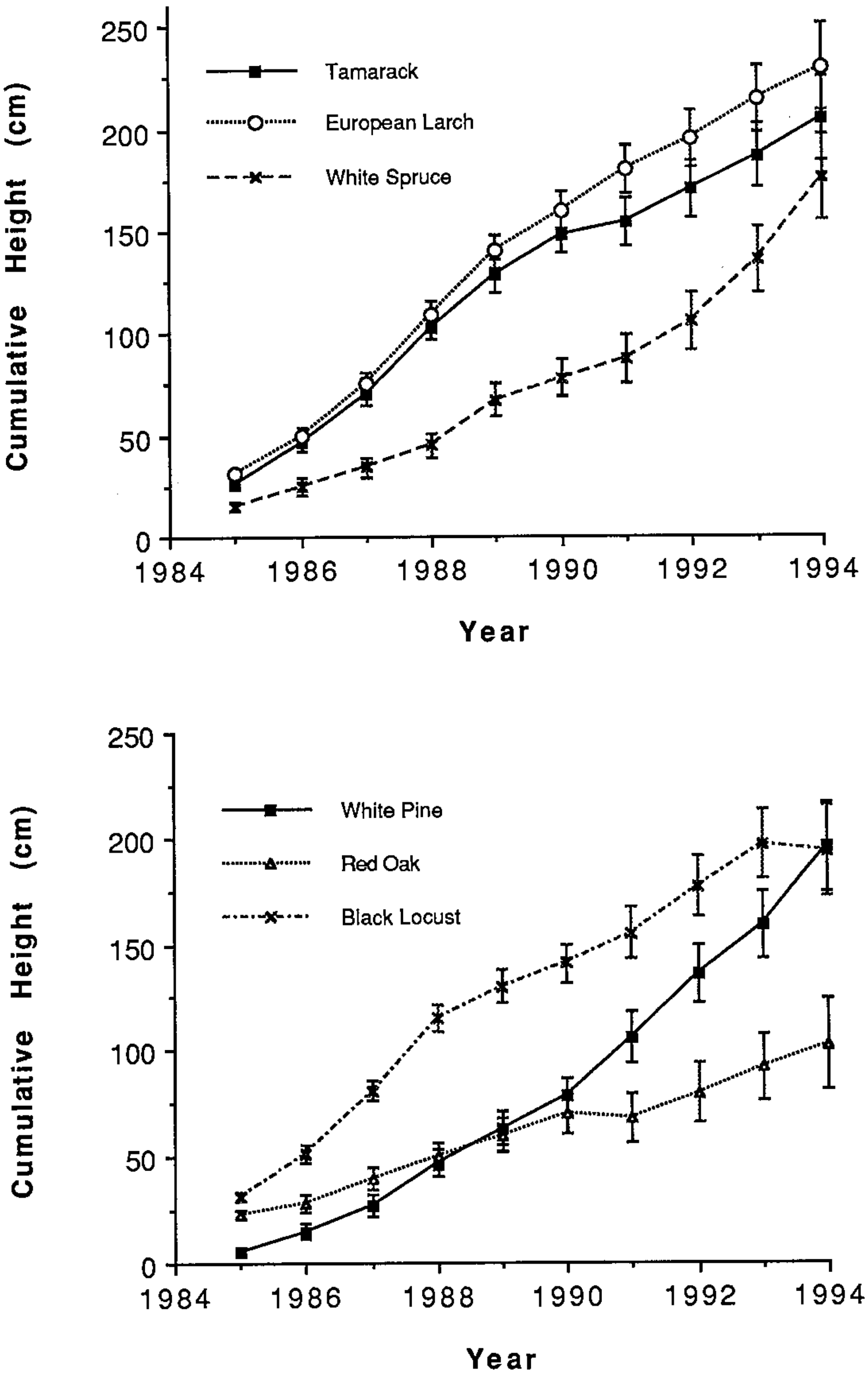

Figure 3. Cumulative height (± se) of several tree species from plots established in 1984 (sample size = 100)

Early efforts at tree planting suggested that a vegetation cover was necessary in order for trees to survive. Recent improvements in air quality and soil conditions may allow for soil amendment and tree planting to take place together rather than the two stage procedure now in use. This would be of great benefit in using volunteer labour in land reclamation activities. In a trial about 1 kg of limestone and 100 g fertilizer were mixed with the substrate in the rooting zone immediately before planting. After 1 year there has been a high survival rate of White Pine (Gunn, personal communication) or Jack Pine (>85%). However, the summer of 1994 was cool and wet with few drought periods so a longer assessment period is needed before the technique is adopted.

Metal content in the needles increases with age of Red Pine. 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 Jack Pine (Table 4), although the metal levels are lower than in non-reclaimed area. Aerial deposition of metal particulates may contribute to the metal concentrations associated with the needles.

Table 3. Metal levels (90% percentiles) in Red Pine (*Pinus resinosa*) Needles of 3 ages collected over a ten year period (1984-1993) from a reclaimed site in Sudbury (planted 1979) and a control, 50 km away (n = 20 samples per year).

SITE	NEEDLE AGE (year)	METAL CONCENTRATION ($\mu g\ g^{-1}$) Al	Cu	Ni	Zn	Sud
bury	1	289-365	4.2-9.9	11.2-21.6	109-142	
Sudbury	2	324-374	6.5-10.7	10.4-24.6	132-156	
Sudbury	3	420-748	7.3-12.6	22.4-35.8	147-188	
Control	1	204-243	1.0-3.5	2.5-5.8	221-258	
Control	2	221-265	2.4-5.6	1.7-5.8	231-284	
Control	3	414-547	2.3-7.8	3.6-7.8	275-365	

Table 4. Median elemental content of 2 year old Jack Pine (*Pinus banksiana*)needles (trees 15 years old, needles from top of canopy) from a reclaimed site and an adjacent area with no reclamation treatment

Element ($\mu g/g$)	Reclaimed	No Treatment
Cu	8	42
Ni	21	32
Pb	3	5
Zn	27	65
Fe	85	170
Al	276	560
Ca	2500	1300
Mg	950	350
S (%)	0.1	0.21

Revegetated land fixes carbon dioxide from the air. With the concern over the possible contribution of increasing carbon dioxide to global warming there is the possibility of using reclaimed land as a sink for carbon sequestration. Over time as biomass increases, especially in the trees more carbon is removed from the atmosphere. Figure 4 shows the progressive change in carbon in the total biomass of areas that have received typical land reclamation treatments with only scattered trees. It is estimated that 100 tonnes per hectare could be sequestered over a 30 year period if the density of trees were increased to that of forestry practices. For sustainability each person requires the equivalent of about 1 ha mature reclaimed land to balance carbon dioxide output. Thus the complete reclamation of disturbed lands in the Sudbury area would make a major contribution to local carbon sustainability.

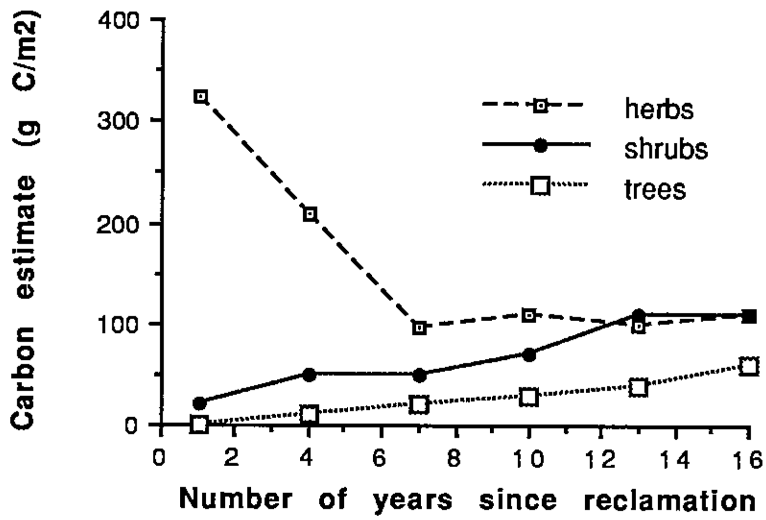

Figure 4. Changes over time in estimated carbon in above and below ground components

Program achievements

Approximately 3100 hectares of barren and semi-barren land have been reclaimed, 980 hectares of damaged land have been visually improved by removing dead trees or branches, and 2.0 million tree seedlings have been planted. 3150 students and unemployed individuals have been employed for 3-9 month periods. Total expenditures exceed 15 million dollars Canadian of which wages accounted for $11 million and capital costs $4.0 million.

The greening of the environment has slowly changed the attitudes of local residents from ignoring the bleak environment to taking an active interest in the health and appropriate development of the local community. The awarding of six major international awards for reclamation efforts has also instilled a new pride for the local environment.

Acknowledgements

Funding for assessment has been provided through Environmental Youth Corps, Ontario Ministry of Northern Development and Mines, Regional Municipality of Sudbury, and Laurentian University Research Fund. Chemical analysis were performed through co-operation of the Ontario Ministry of Environment and Energy. The contributions of numerous summer employees and students are appreciated.

References

Amiro, B. D. and G.M. Courtin 1981. Patterns of Vegetation in the Vicinity of an Industrially Disturbed Ecosystem, Sudbury. Canadian Journal of Botany. 59: 1623-1639.
http://dx.doi.org/10.1139/b81-221

Beckett, P.J. 1995 Lichens: Sensitive Indicators of Improving Air Quality. In Environmental Restoration and Recovery of an Industrial Region, Chapter 6. Ed. J. Gunn, Springer-Verlag, New York p. 81-91.

Beckett, P.J. and J. Negusanti 1990. Using Land Reclamation Practices to Improve Tree Condition in the Sudbury Smelting Area, Ontario, Canada. In Skousen, J, Scencidiver and D, Samuel (Eds), Proceedings of the 1990 Mining and Reclamation Conference and Exhibition. 2 vols. West Virginia University, Morgantown, WV.
http://dx.doi.org/10.21000/JASMR90010307

Beckett, P.J. 1988. Tree Planting Activities of the Sudbury Regional Land Reclamation Programme - An Evaluation. In Proc. 12th Annual Meeting, Canadian Land Reclamation Association, 32-41.

Beckett, Peter J. 1986. Pohlia moss tolerance to the acidic, metal-contaminated substrate of the Sudbury, Ontario, Canada, mining and smelting region. Environmental Contamination - 2nd International Conference. CEP Consultants, Edinburgh. pp. 30-32.

DeLestard, L.P.G 1967. A History of the Sudbury Forest District. Department of Lands and Forests, Ontario: District History Series No. 21. 90 pp.

Dudka, S, R. Ponce-Hernandez, T.C. Hutchinson 1995 Current Level of Total element Concentrations in the Surface Layer of Sudbury's Soils. Science of the Total Environment 162: 161-171
https://doi.org/10.1016/0048-9697(95)04447-9

Gignac, L.D. and P.J. Beckett 1986 The Effect of Smelting Operations on Peatlands near Sudbury, Ontario, Canada. Canadian Journal of Botany. 64: 1138-1147.
http://dx.doi.org/10.1139/b86-157

Gunn, J. (Ed) 1995. Environmental Restoration and Recovery of an Industrial Region. Springer-Verlag, New York

Gunn, J.M. and W. Keller. 1990. Biological Recovery of an Acid Lake after Reductions in Industrial Emissions of Sulphur. Nature, 345: 431-3.
http://dx.doi.org/10.1038/345431a0

Heale, E.L. 1991. Reclamation of Tailings and Stressed Lands at the Sudbury, Ontario Operations of INCO Limited. In Proc. 2nd International Conference on the Abatement of Acidic Drainage, Montreal.

Keller, W., J.M. Gunn and N.D. Yan. 1992. Evidence of Biological Recovery in Acid-Stressed Lakes near Sudbury, Canada. Environmental Pollution 78: 79-85.
http://dx.doi.org/10.1016/0269-7491(92)90013-Z

Lautenbach, W.E. 1985. Land Reclamation Programme 1978-1984. Regional Municipality of Sudbury. 65 pp.

Lautenbach, W.E. 1987 The Greening of Sudbury. Journal of Soil and Water Conservation 42, 228-231.

Lautenbach, W.E. 1988. The Sudbury Regional Land Reclamation Program. In Proc. 12th Annual Meeting, Canadian Land Reclamation Association, 22-31.

Lautenbach,W.,J. Miller, P.Beckett, J. Negusanti and K. Winterhalder. 1995. Municipal Land Restoration Program. In Environmental Restoration and Recovery of an Industrial Region, Chapter 8. Ed. J. Gunn, Springer-Verlag, New York pp. 109-122.

Leblanc, F., D.N. Rao and G. Comeau. 1972 The epiphytic vegetation of *Populus balsamifera* and its significance as an air pollution indicator in Sudbury, Ontario. Can. J. Bot 50: 519-528.
https://doi.org/10.1139/b72-065

Ministry of Environment (MOE) 1990. Studies of the Terrestrial Environment in the Sudbury Area 1978 to 1987. Prepared by: J.J. Negusanti and W.D. McIlveen (Eds). Northeastern Region, Ontario Ministry of the Environment. pp. 70 (17 Figures; 60 Tables).

Ministry of Environment (MOE). 1992. Air Quality Monitoring Studies in the Sudbury Area 1978 to 1988. Prepared by Dobrin,D.J. and R. Potvin, Technical Assessment Section, Northeastern Region, Ontario Ministry of the Environment. pp.128.

Rowe, J.S. 1959. Forest Regions of Canada. Bulletin 123, Canada Department of Northern Affairs and National Resources, Forestry Branch. 71 pp.

Wallace, C.M and A. Thomson. 1993. Sudbury, Rail Town to Regional Capital. Dundurn Press, Toronto, 303 p

Winterhalder, K. 1984. Environmental Degradation and Rehabilitation in the Sudbury Area. Laurentian University Review 16(2): 15-47.

Winterhalder, K. 1993a Factors Affecting Vegetation Dynamics on Acid Metal-Contaminated Soils of the Sudbury Area. in Proc.1993 Canadian Land Reclamation Association, Annual Meeting, Lindsay, Ontario, August 11-13. pp. 58-79.

Winterhalder, Keith. 1993b. The Roles of Colonization and Succesion in the Reclamation of mine sites. In Proc. 10th National Meeting of the American Society for Surface Mining and Reclamation, Spokane, Washington, May 16-19, 1993. pp. 30-53