Effects of Pollutants a the Ecosystem Level
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CASE 7.8
Rehabilitation of Mine Tailings: A Case of Complete Ecosystem Reconstruction and Revegetation of Industrially Stressed Lands in the Sudbury Area, Ontario, Canada

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7.8.1 INTRODUCTION

Mining, agriculture, forestry and fisheries, the four basic resource industries, on which all wealth is built, are extractive processes from the planet earth. They all have had and will continue to have an impact on the earth's surface. Modification of the future impact and amelioration of the past impact of extractive techniques on the earth's environment are a major concern of citizens, industries and governments in many areas of the world today.

Mining, and the subsequent ore beneficiating processes associated with extractive metallurgical techniques, impinge on the earth's surface in various ways which are specific to the ore being mined, the site and the waste products from the metallurgical processes. This case study will deal with the field solution of some of the problems which arise in hard rock mining and with sulphide ores in particular.

In the Sudbury area of Ontario, Canada, Inco Limited, is involved in a progressively expanding programme initiated some 70 years ago, to modify the physical effects of mining, concentrating, smelting and refining, on the local environment.

This region is one of the most ecologically disturbed in Canada. It is of interest to note that Hooker, in the report of a geological survey dated November 1886, described the appearance of the area as follows:

> The streams are small and sluggish, impeded by beaver dams, and the water rendered impure by decayed vegetation. The timber has almost been entirely destroyed by forest fires, and the charred trunks still standing, tottering, or thrown to the ground, impart a dismal aspect to the scenery, and together with the thick underbrush which prevail render passage beyond the beaten trails very difficult. There appears to be little land suitable for cultivation. The thin layer of earth covering the hills has likewise in places, suffered from the fires, permitting it to be readily washed away and exposing the bare rock underneath.

The region's importance, as an example of man's impact upon the environment, is reflected by the many more recent investigations which have been carried out in the area (Gorham and Gordon, 1960a, b; Whitby *et al.*, 1976; Hutchinson and Whitby, 1977; Freedman and Hutchinson, 1980).

7.8.2 HISTORICAL ECOLOGY

The original topography of the area now occupied by tailings was undulating, with small valleys in between rounded rock hill tops. The Wisconsin glaciation in the late Pleistocene era was responsible for many of the geomorphic formations and soil types in the area. The land was heavily scoured and much of the soil was removed, with the result that numerous rock outcrops were and remain exposed.

Soils of the region are humo-ferric podzols with glacial surface deposits of water-modified tills, lacustrine silts, and sands located in the valleys. The most common soils are those developed on stony, sand tills. These soils are usually no more than 1 m over bedrock and in many cases, bedrock appears at the surface. Organic soils occupy many of the depressions in the area. Very little of the soil in the area is suitable for agriculture, however, certain parts of the area are moderately high producers of agricultural crops (such as potatoes, spring grain and hardier market garden crops). Soil pH values are 6.0 or less (Heale, 1980).

In the valleys are lakes, swamps and, in some cases, areas of land sufficiently well drained to permit the establishment of native species of trees and shrubs. The vertical difference in elevation between hill tops and valley bottoms is generally less than 60 m. Drainage in lower areas is often very poor and as a consequence soils in specific areas warm very slowly in the spring. The lack of drainage in these soils adversely affects their chemical and physical structure, nutrient capacity, aeration and porosity. These factors significantly influenced the climax vegetation found in the different localized areas.

Braun (1950) included the climax vegetation of the immediate Sudbury area in the Laurentian Upland section of the Great Lakes—St. Lawrence Division of the Hemlock – White Pine–Northern Hardwoods Forest. Due to the close proximity of the Boreal Forest Region, intrusions of this forest type do occur in the Sudbury area.

The natural ecosystem in the area was a pine forest. Three species, eastern white pine (*Pinus strobus L.*), red pine (*Pinus resinosa* Ait.) and jack pine (*Pinus banksiana* Lamb.), grew on the soil types which were suitable to the particular species. Eastern hemlock (*Tsuga canadensis* Carr.) and white spruce (*Picea glauca* Voss) were the other main coniferous species in the climax forest. Extensive logging of the virgin forest commenced around 1872 (de Lestard, 1967) with the white pine (*Pinus strobus* L.) being the most valuable economic species. Although some of the pine are returning naturally, the principal forest cover is that of a succession forest composed of American white birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michz.) and large tooth aspen (*Populus grandidentata* Michx.) (Rowe, 1972).

Mean annual temperature for the Sudbury Climatic Region of Northern Ontario is 4.4 °C (Chapman and Thomas, 1968). The area has an average frost free period of 112 days and an average annual growing period of 183 days. Mean annual precipitation is 0.84 m.

7.8.3 MINE TAILINGS PROBLEM

The discovery of deposits of nickel and copper sulphide ores in the Sudbury District occurred in 1883 during the building of Canada's first transcontinental railway. The International Nickel Company was formed by the merger of several smaller companies in 1902. Over the years, the Company has grown. At the present time, Inco Limited is the largest mining, milling, smelting and refining complex in the non communist world. In the Sudbury area, the Company operates eight mines, two mills, a smelter, a sulphuric acid plant, a copper refinery and a nickel refinery. At Shebandowan, in Northwestern Ontario, a mine and mill are operational, and a nickel refinery is located at Port Colborne in Southern Ontario. A total work force of approximately 12200 is employed in these operations. Altogether 15 elements are extracted from the ores mined. The list includes nickel, copper, iron, sulphur, gold, silver, cobalt, platinum, osmium, iridium, selenium, tellurium, palladium, rhodium and ruthenium.

In the Sudbury area, the rated capacity of the two mills, Clarabelle and Frood-Stobie, is 53 524 tonnes per day. This figure will give an indication of the size of the daily milling operation. At full production, the milling and concentrating is a continuous process operating 24 hours per day, 7 days per week. Production operations vary with market requirements.

Replacement of the roast yard system of smelting by the Herreschoff Roaster and the reverberatory furnace in the new smelter in 1930, necessitated the development of a finely ground concentrate. Finding disposal sites for the tailings, produced as a waste by-product of the new system, became a necessity. Nearby valleys located between the rock hills provided these areas and the rock outcrops were used to act as buttresses for the tailings dams and as dams themselves.

Currently the dams are built by first constructing a starting dam, using waste

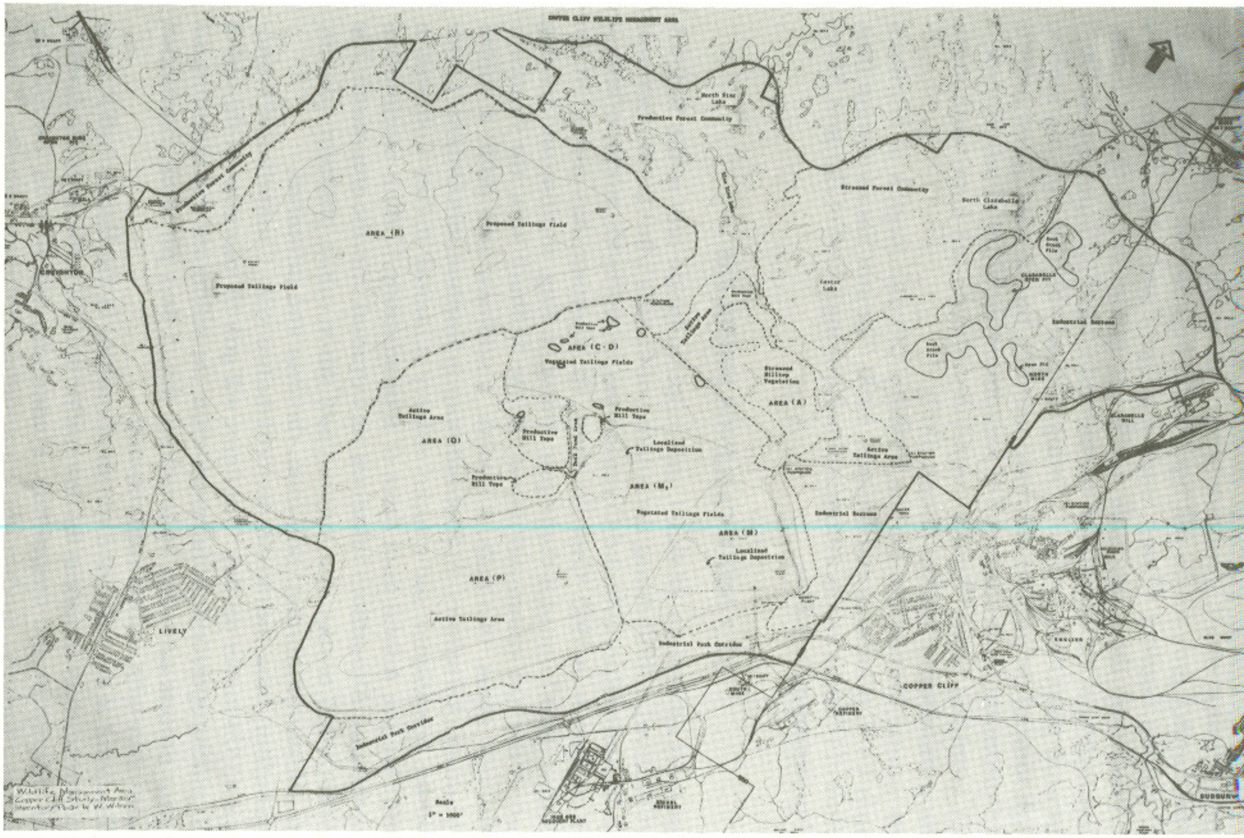

Figure 7.8.1 Map of the Copper Cliff mine tailings area showing the site of the revegetation study

rock of a suitable size. The height of the dams is then increased by raises of 3 m to 5 m using the tailings on site and by stepping in towards the centre with each raise. Dam heights vary with local requirements but are currently built to a height of approximately 50 m in the Copper Cliff Tailings Disposal Area at Sudbury. At present, the 'A', 'CD' and 'M' areas (Fig. 7.8.1) are at their final elevation and are at various stages in their reclamation and revegetation programmes. Their total area is approximately 485 ha. The 'P' and 'O' areas are nearing completion, and in areas where they have reached their final elevation, grass has been established. These two areas cover approximately 600 ha in total. The 'R' area, of approximately 1120 ha, is in the development stage. It will bring the total tailings area at Copper Cliff to approximately 2226 ha. Two smaller tailings areas totalling approximately 80 ha, are located adjacent to the mill at Levack Mine and at the Frood–Stobie complex.

Although it is difficult to come up with an average composition of tailings, since the composition will vary with the source and nature of the ores being mined at any given time, the following general figures may be utilized (Montreal Engineering Company, 1975; Wilson, 1976).

Mineralogical composition of copper cliff tailings
Sample size not reported

Feldspar	+50%
Amphiboles (chlorite)	20%
Quartz	10%
Pyroxenes	7%
Biotite	7%
Pyrrhotite	5.6%
Magnetite	0.6%
Pentlandite	0.5%
Chalcopyrite	0.3%

Trace element analysis of tailings soils (available concentrations). Range found in 12 sampling sites. Single sample taken at each site.

pH	3.7–6.2
Cu	1–81
Ni	1–87
Fe	59–441

Expressed in ppm on a dry weight basis.
Technique: 2.5 per cent acetic acid leach for 30 minutes.

In the early stages, when the elevation of the tailings is low, the surrounding hills minimize the effect of winds and thus limit the amount of dust generated from the tailings beaches. As the elevation of the disposal area increases, the wind protection afforded by the surrounding hills decreases, until a point is reached where this protection becomes non-existent.

The necessity of controlling dust from these sources became apparent to the Company in the late 1930s. In addition to being a nuisance to the residents of Copper Cliff, the dust contaminated certain electro-metallurgical refining processes and reduced the effectiveness of lubricants used to minimize normal wear in operating machinery.

Therefore, the immediate concern was to stabilize the surface of the tailings. At first, various stabilizers such as chemical sprays, limestone chips, bituminous sprays and timed water sprays pumped through an irrigation system were tried. These methods either proved to be ineffective or uneconomical. In the mid 1940s some experimental seedings of grasses were made but were unsuccessful, largely due to the unavailability of agricultural and ecological expertise at that time and the consequent failure to consider such factors as species selection and adjustment of the substrate pH.

7.8.4 REVEGETATION

In 1957 an experimental programme of revegetation plots was established on the tailings area. The successful stabilization of mine tailings with vegetation was the first step in developing new ecosystems. These systems were designed and developed to complement, as far as possible, the stage of development of the ecosystems in the surrounding area. With the knowledge gained from this and subsequent experiments over the years the present programme for establishing vegetation on tailings has evolved as follows:

1. The seeding should be established on that portion of the area which is closest to the source of the prevailing wind during the growing season to minimize covering or damaging of young plants by the drifting tailings.
2. Agricultural limestone, as required, should be applied at least 6 weeks prior to seeding; this permits sufficient time for reaction to raise the tailings pH to approximately 4.5–5.5.
3. In the Sudbury area late summer is the best time to seed grasses; after July 21, rates of success of seed germination and seedling establishment are enhanced due to more suitable temperatures and the increased availability of moisture.
4. Although this is the optimum time for seeding grasses, the short period which is left of the growing season is insufficient for legume seedlings to establish a sufficiently deep and strong root system to withstand the heaving effects of the repeated surface freezing and thawing the following spring.
5. The use of a companion crop, to reduce surface winds and provide some shade, is beneficial.
6. Nitrogenous fertilizer should be applied several times, as required during the establishment period, to ensure maximum uptake.

7. Slopes with southerly and southwesterly exposures should be mulched to provide shade for seedlings and to reduce evaporation of moisture from the soil during the critical period of seedling establishment.

As the preceding facts became obvious from experimental data and field programmes, it appeared essential to review the entire project from an ecological point of view in order to establish new project procedures.

Our review indicated that in order to establish a self-sustaining system, several ecological considerations should be taken into account:

1. Establishing initial plant communities using available species that are tolerant of drought, low soil pH, poor soil texture, the lack of organic materials and nutrients, and other factors characteristic of metal-extracted tailings.
2. Modifying the localized microclimates to benefit plant establishment.
3. Re-establishing soil invertebrate and microbial communities to ensure natural organic decomposition, essential to the rebuilding of soils.
4. Re-establishing essential nutrient cycles and conservation.
5. Establishing a vegetative habitat suitable for wildlife colonization.
6. Establishing the climax plant communities for the area by manipulating species competition.

Similar considerations have been outlined in other studies dealing with the problems of land restoration (e.g. Bradshaw *et al.*, 1978).

Since the start of the tailings rehabilitation programme, the grass mixture used has been changed from time to time to increase the percentage content of the species that show hardiness and ability to persist under local conditions. The mixture currently used is:

25% Canada blue grass (*Poa compressa* L.)
25% Red top (*Agrostis gigantea* Roth.)
15% Timothy (*Phleum pratense* L.)
15% Park Kentucky blue grass (*Poa pratensis* L.)
10% Tall fescue (*Festuca arundinacea* Schreb.)
10% Creeping red fescue (*Festuca rubra* L.).

Other grasses which have been tried and are no longer used include crested wheat grass (*Agropyron cristatum* Gaertn.) and some varieties of fescue including sheep fescue (*Festuca ovina* L.). They have not shown comparable persistence over the years under the local conditions.

The practice of late summer seedings has made it difficult to establish good stands of legumes for reasons previously explained. Various methods to overcome this problem have been and continue to be researched. One alternative method which has yielded positive results is to seed the tailings with legumes in the spring. Alfalfa (*Medicago sativa* L.) has persisted for over twenty years from an original spring planting. Other legumes with which successful stands have been established experimentally include white blossom sweet clover (*Melilotus* *alba* Desr.), yellow blossom sweet clover (*Melilotus officinalis* Desr.), alsike (*Trifolium hybridum* L.) and bird's-foot trefoil (*Lotus corniculatus* L.).

The current revegetation programme follows an orderly sequence starting early in the summer. Agricultural limestone is spread at the rate of 4.4 tonnes per hectare in late May or the month of June whenever possible. The limestone is then disced into the tailings' surface. The major portion of our seedings is carried out during the last week of July and early August. Recent experience has taught us the necessity of waiting to seed until after the first heavy rain following July 20. This rainfall provides moisture for a sufficient period for germination and encourages the companion crop, fall rye (*Secale cereale* L.), to grow rapidly to a height providing early shade and reducing the velocity of surface winds. These two factors make a significant contribution to the successful establishment of the slower growing grasses.

At seeding time, an additional 4.4 tonnes per hectare of limestone are spread and the area disced, and then, 450 kg ha^{-1} of 5–20–20 fertilizer (5 per cent nitrogen, 20 per cent phosphate, 20 per cent potash) are broadcast over the area and harrowed into the top 5–8 cm of the surface. A conventional farm seed drill follows, seeding 94 kg ha^{-1} of fall rye (*Secale cereale* L.), 22 kg ha^{-1} of grass seed mixture and an additional 392 kg ha^{-1} of 5–20–20 fertilizer. Then, 9–11 kg ha^{-1} of brome grass (*Bromus inermis* Leyss.) are broadcast and a Brillon seeder is used to plant an additional 22 kg ha^{-1} of grass seed mixture. This machine compacts the soil and presses both the brome grass seed and the final seeding into the surface of the tailings where it germinates best.

After the grass germinates, light top dressings of nitrogen are applied, as required, during the balance of the season. Limestone and fertilizer are applied in subsequent seasons, on the basis of soil tests, to maintain and encourage growth.

In an effort to introduce legumes into the resultant sward, the inoculated, desired legume is seeded as early as possible in the following spring using a powertill seeder. Bird's-foot trefoil (*Lotus corniculatus* L.) is the legume currently being used.

These seeding practices generally provide the best germination and establishment, and are used whenever contours permit the use of standard agricultural machinery. Outside tailings berm slopes, and other slopes (sand pit, clay pit, or roadside) encountered in our reclamation work, do not usually permit the use of this equipment. Unique tillage implements, such as Klod-Busters, are utilized and a hydroseeder is necessary for fertilizing and seeding. It has been our experience that a mulch is very beneficial, if not essential, in promoting early germination and survival of seedlings on southerly and southwesterly facing slopes. Mulches and chemical stabilizers can be applied with a hydroseeder or straw mulches may be applied by using a mulcher.

It has become apparent that a new ecosystem, with an altered substrate was being established. The rock materials were finely ground but had not had sufficient time to weather. The physical sizing of the particles was in a smaller range, the drainage was different and organic matter was completely absent. The site had been raised up to 46 m and had become a flat saucer-shaped basin in contrast to the original topography of undulating rocky hills interspersed with small valleys.

The 'CD' area, the first area to be revegetated, has been the subject of many studies related to soil and plant development. Watson (1970) commented on the high surface and reflected temperatures in artificial waste areas. This reflected heat from the tailings' surface necessitates the use of a fast growing companion crop and shows the necessity of getting some vegetation on the surface to permit natural forest regeneration. Labine (1971), in his study of monoliths of the 'CD' area soils, found the development of an organic horizon (A°) of 2–3 cm and the beginning of a podzolic soil profile. It was found that drainage at different slope elevations quantitatively affected soil profile development and the formation of an iron pan at varying depths (Swanson, 1977). Root penetration of the pan was through cracks. However, single hair roots penetrated into the iron pan from thick tangles at root stop.

The physical ability of soil to retain moisture and nutrients is essentially a function of particle size. Tailings, which are generally deficient in clay-sized particles, behave much like a sandy loam and may be prone to moisture deficiency (Dimma, 1981). Lacking colloidal moisture adsorption, it would appear that the water which is retained in tailings has resulted from capillary action, which is most pronounced in the silt-sized particles (Pitty, 1979).

Under the above conditions, the rate of leaching of plant nutrients is high. Thus, in the early years' continuous nitrogenous fertilizer applications have been necessary to ensure that sufficient nitrogen was available for the successful growth of grasses.

Also, due to the fixation of phosphates by the high level of iron oxides found in the tailings, the amout of phosphorus which is actually available for plant growth may be significantly lower than analytical results indicate (Dimma, 1981).

Light annual applications of general fertilizers were made to supplement the availability of phosphorus and other nutrients.

We have found that the establishment of grass is only the first step in the return of a reclaimed area to the climax vegetation which is to exist for each site. Our early thoughts had been agriculturally oriented, the first step being the cutting of grass for hay. However, before long, seedling trees were observed voluntarily establishing themselves in the grassed areas. By the mid-1960s, a programme to gradually reduce the area being mowed, in order not to cut the seedlings, was initiated.

The voluntary invasion of birch trees (*Betula papyrifera* Marsh.) which started in the mid-1960s continues in all areas. Trembling aspen (*Populus tremuloides* Michx.) and willow (*Salix spp.*) constituted less than 10 per cent of the total voluntary tree seedlings in the early stages of forest invasion. The Trembling aspen, due to their vegetative method of propagation, are spreading in the established 'CD' site where they are becoming the numerically dominant species in localized areas. A few oak (*Quercus rubra* L.) have begun to appear, probably due to rodents or birds transporting acorns from the adjacent hills. Experimental plots of hybrid poplar and black locust (*Robinia pseudo-acacia* L.) have been established.

Replicated plots, to study the potential for the introduction of coniferous species, were established in 1972 with the following species: jack pine (*Pinus banksiana* Lamb.), red pine (*Pinus resinosa* Ait.), scots pine (*Pinus sylvestris* L.), white spruce (*Picea glauca* Voss) and black spruce (*Picea mariana* Mill.) The jack pine (*Pinus banksiana* Lamb.) has proven to be the most adaptable to date. Seven years after planting, as forestry seedlings, they have reached a height of 3–3.6 m and produced seed cones.

These plots indicated that in specific locations red pine (*Pinus resinosa* Ait). and white spruce (*Picea glauca* Voss) are the next most adaptable. Since 1976, 5000–15 000 forestry seedlings of these particular species have been planted annually. Although these seedlings must compete with the grasses for water and nutrients, a 60 per cent success rate for planting has been achieved.

A recent (1980) study of the plant species found growing in the 'CD' area showed the slow rate of volunteer introductions and the gradual development of dominant species (McLaughlin *et al.*, 1982) (see Table 7.8.1).

Along with the invasion of flora, various insects, grasshoppers, spittle bugs, ants and small mammals (deer-mice and voles) have colonized the new ecosystem. Meadow birds attracted by the small insects became resident, and sparrow hawks, marsh hawks and owls, along with foxes, began to provide predatory control of the small mammals. Waterfowl and shorebirds began making stops during their spring and fall migration and some even began to raise their broods in the area.

In 1974, after consultation with local Rod and Gun Clubs, a decision was made to develop the tailings and adjacent land as a Wildlife Management Area. A wildlife biologist was then hired to design a plan of development for the Wildlife Management Area and negotiations were started with the Ontario Ministry of Natural Resources to have the area so designated. The plan was completed in May 1976, and since that time investigations of various components of the plan have been carried out to determine the final route which will be taken. At present, we are investigating whether or not heavy metals accumulate in plants and small mammals which inhabit the area. Studies are also being conducted on birds in the area, including tests for heavy-metal levels in the blood, feathers and muscles of waterfowl. A general bird species census and a kestrel nesting and banding programme are also in progress (see Table 7.8.2).

The period from 1976 to the present (1981) is relatively short, and this makes the measurement of recognizably significant differences almost impossible. However, if these measurements are examined as being indicative of developing trends, they are of interest to researchers observing the broad spectrum of ecosystem development.

Table 7.8.1 Checklist of plants found on the 'CD' area in 1979–1980

			1	2	3	4
Trees and Shrubs	Red Maple	*Acer rubrum*		+	+	+
	Paper Birch	*Betula papyrifera*	+	+	+	+
	Honeysuckle	*Diervilla lonicera*			+	+
	Jack Pine	*Pinus banksiana*	+		+	+
	Trembling Aspen	*Populus tremuloides*		+	+	+
	Red Oak	*Quercus rubra*		+	+	+
	Black Locust	*Robinia pseudo-acacia*	+		+	+
	Long-beaked Willow	*Salix bebbiana*		+	+	+
	Common Elder	*Sambucus canadensis*			+	+
	Blueberry	*Vaccinium angustifolium*		+	3.4	1.2
Grasses	Redtop	*Agrostis alba* (= *A. stolonifera L.*, *A. gigantea Roth*)	13	+	50.	30.
	Hairgrass, Ticklegrass	*Agrostis scabra* (= *A. hyemalis Walt*)			2.7	0.7
	Crested Wheat Grass	*Agropyron cristatum*	6	+	+	+
	Witch Grass, Couch Grass	*Agropyron repens*		+	+	+
	Awnless Brome	*Bromus inermis*	24	+	17.	6.9
	Red Fescue	*Festuca rubra*	6		+	+
	Timothy	*Phleum pratense*	6	+	2.7	0.1
	Reed Canary Grass	*Phalaris arundinacea*		+	+	+
	Wiregrass	*Poa compressa*	38	+	2.1	0.3
	Kentucky Bluegrass	*Poa pratensis*	6	+	50.	34.
	Alkali-grass	*Puccinellia distans*			3.4	1.8
	Rye	*Secale cereale*	+		+	+

Table 7.8.1 (*cont.*)

			1	2	3	4
Sedges, Rushes and Cat-Tails	Sedge	*Carex siccata*		+	0.7	0.2
	Rush	*Juncus filiformis*		+	+	+
	Bulrush	*Scirpus lacustris*	+	+	+	+
	Cat-tail	*Typha latifolia*	+	+	+	+
Horsetails	Meadow Horsetail	*Equisetum pratense*		+	+	+
Legumes	Bird's-foot Trefoil	*Lotus corniculatus*	+	+	2.1	1.7
	Alfalfa, Lucerne	*Medicago sativa*	+	+	2.7	0.6
	White Melilot	*Melilotus alba*	+		+	+
	Yellow Sweet Clover	*Melilotus officinalis*	+		+	+
	Alsike Clover	*Trifolium hybridum*	+		+	+
Field Weeds	Pearly Everlasting	*Anaphalis margaritacea*		+	+	+
	Milfoil	*Achillea millefolium*		+	+	+
	Lamb's-quarters	*Chenopodium album*		+	+	+
	Sheep Sorrel	*Rumex acetosella*		+	+	+
	Goldenrod	*Solidago graminifolia*		+	+	+
	Spiny-leaved Sowthistle	*Sonchus asper*		+	+	+
Mosses		*Pohlia nutans*			2.1	0.9
		Leptodictyum riparium			+	+

1: Plants seeded; numbers are per cent composition of the original seed mixture (rate of seeding = 38 kg ha^{-1}).
2: Species found by Wilson in 1975.
3 and 4: Species found in this study; per cent frequency and per cent cover, along the transects, respectively (McLaughlin *et al.*, 1982).

Table 7.8.2 Record of bird species sited, 1973–1981 (no records available for 1978–79)

			1973	74	75	76	77	80	81[1]
Loons	Common Loon	*Gavia immer*						+	+
Herons	Great Blue Heron	*Ardea herodias*						+	
aterfowl	Whistling Swan	*Cygnus columbianus*					+		
	Canada Goose	*Branta canadensis*		+	+	+	+	+	
	Snow Goose	*Chen caerulescens*	+	+				+	
	Mallard	*Anas platyrhynchos*	+					+	+
	Black Duck	*Anas rubripes*	+	+				+	+
	American Widgeon	*Mareca americana*		+					
	Pintail	*Anas acuta tzitzihoa*	+	+	+	+			
	Green-winged Teal	*Anas carolinensis*	+	+			+	+	+
	Redhead	*Aythya americana*	+	+			+	+	
	Ringed-neck Duck	*Aythya collaris*	+				+		
	Lesser Scaup Duck	*Aythya affinis*	+	+	+		+	+	
	Golden-eye	*Bucephala clangula*	+	+	+			+	
	Bufflehead	*Glaucionetta albeola*	+	+	+	+			
	Old-squaw	*Clangula hyemalis*	+	+		+			
	White-winged Scoter	*Melanitta fusca*		+					
	Surf Scoter	*Melanitta perspicillata*	+	+	+				
	Hooded Merganser	*Lophodytes cucullatus*	+						
Hawks	Red-tailed Hawk	*Buteo jamaicensis*							+
	Sparrow Hawk	*Falco sparverius*							+
	Marsh Hawk	*Circus cyaneus*		+		+		+	+
	American Kestrel	*Falco sparverius*	+					+	
	Merlin	*Falco columbarius*	+	+			+		
Cranes	Sandhill Crane	*Grus canadensis*						+	+
Rails, Gallinules, Coots	Coot	*Fulica americana*			+				

Table 7.8.2 (*cont.*)

			1973	74	75	76	77	80	81[1]
Shorebirds	Semi-palmated Plover	*Charadrius semipalmatus*	+	+	+	+	+	+	
	Killdeer	*Charadrius vociferus*	+	+				+	+
	Golden Plover	*Pluvialis dominica*	+	+	+	+	+		
	Black-bellied Plover	*Squatarola squatarola*	+	+	+	+	+		
	Ruddy Turnstone	*Arenaria interpres*	+	+		+		+	+
	Spotted Sandpiper	*Actitis macularia*	+	+				+	+
	Solitary Sandpiper	*Tringa solitaria*		+				+	
	Greater Yellowlegs	*Totanus melanoleucus*	+	+	+			+	+
	Lesser Yellowlegs	*Totanus flavipes*	+	+	+	+	+	+	+
	Redknot	*Calidris canutus*	+	+			+		
	Pectoral Sandpiper	*Erolia melanotos*	+	+	+		+		
	White-rumped Sandpiper	*Erolia fuscicollis*		+	+	+			
	Baird's Sandpiper	*Erolia bairdii*	+	+	+	+	+		
	Least Sandpiper	*Erolia minutilla*	+	+	+	+	+		+
	Dunlin	*Erolia melanotos*	+	+	+			+	+
	Dowitcher	*Limnodromus griseus*	+	+			+		+
	Stilt Sandpiper	*Micropalama himantopus*	+	+	+				
	Semi-palmated Sandpiper	*Ereunetes pusillus*	+	+	+	+	+	+	+
	Western Sandpiper	*Ereunetes mauri*		+				+	+
	Buff-breasted Sandpiper	*Tryngites subruficollis*	+	+			+		
	Hudsonian Godwit	*Limosa hoemastica*			+	+			
	Sanderling	*Crocethia alba*	+	+	+		+	+	+
	Wilson's Phalarope	*Steganopus tricoler*		+					
	Northern Phalarope	*Lobipes lobatus*	+	+		+			
Gulls, Terns	Herring Gull	*Larus argentatus*							+
	Ringed-billed Gull	*Larus delawarensis*				+		+	+
	Caspian Tern	*Hydroprogne caspia*				+			
Woodpeckers	Common Flicker	*Colaptes auratus*						+	
	Hairy Woodpecker	*Dendrocopus villosus*							+

			1973	74	75	76	77	80	81[1]
Tyrant Flycatchers	Eastern Kingbird	*Tyrannus tyrannus*						+	+
	Eastern Phoebe	*Sayomis phoebe*						+	
	Horned Lark	*Eremophila alpestris*	+		+	+	+		
Swallows	Tree Swallow	*Iricloprocne bicolor*				+		+	
	Bank Swalow	*Riparia riparia*			+	+	+	+	+
Jays, Crows	Blue Jay	*Cyanocitta cristata*						+	
	Common Raven	*Corous coxax*						+	+
	Common Crow	*Corous brachyrhynchos*						+	+
Titmice, Wrens Thrushes	Black-capped Chickadee	*Parus atricapilla*						+	
	House Wren	*Troglodytes aeclon*						+	
	Brown Thrasher	*Toxostonia rufrum*						+	
	American Robin	*Turclus migratorius*						+	
	Hermit Thrush	*Hylocichla guttata*						+	
Pipits, Waxlings, Starlings	Water Pipit	*Anthus spinoletta*	+		+	+	+	+	
	Starling	*Sturnus vulgaris*						+	+
Vireos, Woodwarblers	Philadelphia Vireo	*Vireo philadelphius*						+	+
	Solitary Vireo	*Vireo solitarius*						+	+
	Yellow-rumped Warbler	*Dendroica coronceta*						+	+
	Bay-breasted Warbler	*Dendroica castanea*						+	
	Palm Warbler	*Dendroica plamarum*						+	

Table 7.8.2 (*cont.*)

			1973	74	75	76	77	80	81[1]
Meadowlarks, Blackbirds, Orioles	Bobolink	*Dolichonyx oryzivorus*							+
	Eastern Meadowlark	*Sturnella magna*						+	+
	Western Meadowlark	*Sturnella neglecta*		+					
	Red-winged Blackbird	*Agelaius phoenicius*						+	+
	Brown-headed Cowbird	*Molothrus atu*						+	
	Baltimore Oriole	*Icterus galbula*						+	
Finches, Sparrows, Buntings	American Goldfinch	*Spinus tristis*						+	
	Savannah Sparrow	*Pasberculus sandwichensis*	+				+	+	+
	Vesper Sparrow	*Pooecetes gramineus*					+	+	+
	Chipping Sparrow	*Spizella passering*					+	+	+
	White-throated Sparrow	*Zonotrichia albicollis*						+	+
	Slate-coloured Junco	*Junco hyemalis*						+	
	Lapland Longspur	*Calcarius lapponicus*	+		+	+			
	Snow Bunting	*Plectrophenax nivalis*	+	+	+		+	+	
	Whimbrel	*Numenius phoepus*	+						

[1] July and August only (1981).

The revegetation of tailings areas, by establishing a grass cover crop as the initial step, in a region which is at the succession forest stage in the natural ecological process, effectively creates an islands of vegetation cover, contrasting with and differing from the surrounding plant communities. This is also reflected in the variety of different animal species which invade the newly revegetated stage. This difference is apparent in the species of insects, birds and mammals which invade the new area under a natural succession. Bird censuses (Nicholson, 1974–1976; Hendrick, 1980; Laing, 1981) described a collection of grassland species unusual to the surrounding climax vegetation areas. Waterfowl, shore birds, and other bird species not usually seen in the Sudbury area were observed, identified and recorded (Table 7.8.2). A study of the nesting of kestrels (*Falco sparverius* L.), over a period of several years, noted a change in the source of food for nestlings from predominantly insects to frogs in locales adjacent to the 'CD' area pond where bulrushes (*Scirpus spp.* L.) and cat-tail (*Typha spp.* L.) have successfully been established. These plant species have permitted the leopard frogs (*Rana pipiens*) to flourish (J. Lemmon, personal communications, 1980).

The investigation of heavy-metal levels has not as yet indicated the existence of a problem with these particular elements. Rutherford and Van Loon (1980) found that the mineral content of two species of grass, red top (*Agrostis alba* L.) and Canada blue grass (*Poa compressa* L.), growing on the tailings fell within the normal range for grasses, although the concentration of iron and copper appeared to be somewhat higher than the mean. Studies of duck species nesting and raising young in the area have yielded preliminary results which indicate that blood levels of nickel and copper in ducks are not significantly affected. Our findings correspond to those of Rose (1981) who in his research on ruffed grouse (*Bonasa umbellus* L.) in the Sudbury area found no significant change in body tissue metal content.

7.8.5 PRESENT AND FUTURE CONSIDERATIONS

Although the overall programme is in its early stages, with respect to the successional development of an ecosystem, research continues to further the progress of constructing new ecosystems. This is to ensure, as far as possible, that the directions taken are beneficial to the evolving wildlife communities. Current research activities include a detailed look at the soil development processes which are occurring, lime application studies, investigating methods of promoting the development of the microflora and microfauna responsible for the breakdown of organic matter and the subsequent release of nutrients, tree growth studies, monitoring nickel and copper levels in a variety of waterfowl species, and the introduction of new species of flora and fauna.

Industrial process changes are of concern, as we look to the future. The possible change in concentrating processes which may be implemented to lessen pyrrhotite content, in order to reduce sulphur dioxide emissions from the smelter to the atmosphere, will provide a challenge to be met. This change would increase the amout of pyrrhotite in the tailings, with a subsequent increase in acid generation potential. Therefore, a method to allow revegetation under this condition may have to be developed.

7.8.6 CONCLUSIONS

The development of a Wildlife Management Area on the Tailings Areas of Inco Limited at Sudbury, as the end use for this land, has been and will continue to be an attempt by man to influence the rate and direction of the development of a new ecosystem.

To date, there has been progress in the establishment of ecological processes on the tailings area as evidenced by the following:

1. The visual observations of soil horizons are clear evidence that soil development processes are occurring.
2. The stabilization of the tailings surface with the establishment of a grass cover is providing a satisfactory environment for colonization by native flora and fauna.
3. The voluntary invasion of trees into the grassed areas is a positive step in the natural vegetation succession to the climax forest state which existed before mining development.
4. The successful establishment of trees, both naturally and in plots, indicates that the environment is suitable for growth and development, and will likely support seedlings of other native tree and shrub species.
5. The number of birds nesting and being sighted on the tailings is evidence of a habitable environment and an adequate food supply.
6. Legumes are being introduced successfully and are accelerating the development of the natural nitrogen cycle.
7. To the best of our knowledge, the environment is not toxic to species living and reproducing on the Copper Cliff tailings.

7.8.7 REFERENCES

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