TRIGGER FACTORS INITIATING NATURAL REVEGETATION PROCESSES ON BARREN, ACID, METAL-TOXIC SOILS NEAR SUDBURY, ONTARIO SMELTERS[1]

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Abstract.--A century of sulphur-dioxide fumigation, copper and nickel particulate deposition, fire, soil erosion, and enhanced frost action has created 10,000 ha of barren land and 36,000 ha of stunted, open birch-maple woodland in the Sudbury area. Following environmental improvement, several species including tufted hairgrass (Deschampsia caespitosa (L.) Beauv.), tickle grass (Agrostis scabra Willd.), redtop (A. gigantea Roth), and dwarf birch (Betula pumila L. var. glandulifera Regel) have colonized barren sites, but extensive areas remain barren. Manual surface application of limestone, with or without an accompanying grass-seed/legume-seed/fertilizer application, leads to immediate colonization by woody species, including white birch (Betula papyrifera Marsh.), trembling aspen (Populus tremuloides Michx.), and willows (Salix spp.), with stunted relict individuals on the barren land providing the seed source. Nevertheless, red maple (Acer rubrum L.), a prominent relic, is unable to regenerate from seed on untreated or limestone-treated land. Since conifers have not so far colonized spontaneously, red pine (Pinus resinosa Ait.), jack pine (P. banksiana Lamb.), white pine (P. strobus L.), and white spruce (Picea glauca (Moench) Voss) - normal components of the climax vegetation of the region - have been planted in simulated natural groupings to improve species diversity and to provide a seed source for future colonization.

INTRODUCTION

For approximately 100 years, the Sudbury landscape has been ravaged by logging, fire, soil erosion, enhanced frost action, sulphur dioxide fumigation, and copper, nickel and iron particulate fallout from the region's three smelters (Winterhalder 1984). This complex of interacting factors has given rise to zones of barren land around the three smelters totalling 10,000 ha. Predominantly a mosaic of stony slopes interspersed with rock outcrops and fine sand or silty valley bottom soils, the barrens also include occasional gully-eroded clay at the margins of the valleys as well as expanses of barren peat that were originally bogs and cedar swamps. Surrounding the barrens is a 36,000 ha zone of stunted, semibarren woodland, characterized by patches of bare soil between the relict, coppiced trees (Watson & Richardson 1972; Amiro & Courtin 1981). Following smelter closures and cutbacks as well as the construction of a 381-m smokestack in 1972, it was expected that vegetation would gradually return to the barrens. Recolonization was confined, however, to relatively favourable sites and to specific species, some of which have been shown to have evolved a metal tolerance (Cox & Hutchinson 1980). Soils in the Sudbury region were shown (Winterhalder 1975) to display a pattern of decreasing pH and increasing copper and nickel content as the three smelters are approached, the vegetation pattern conforming with the soil zones. Table 1 shows mean soil chemical parameters (as measured in 1969) in relation to fumigation zones established by the Ontario Department of Energy & Resources (Dreisinger & McGovern 1971).

Since the closure of one of the three smelters, at Coniston, in 1972, there has been a distinct rise in mean soil pH in that area. By 1975, the mean pH of Coniston soils had risen from the 3.0 - 3.5 range measured in 1969 to a 4.0 - 4.5 range (Winterhalder 1976).

Early revegetation research showed that limestone application is an essential prerequisite to revegetation

[1]Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

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Proceedings America Society of Mining and Reclamation, 1988 pp 117-124
DOI: 10.21000/JASMR88020117

Table 1.-- Soil chemical parameters in relation to fumigation history (n = 10).

Fumigation zone	Mean pH ± s.d.	Mean total copper mg/kg±s.d.	Mean total nickel mg/kg±s.d.
None	5.0 ± 0.2	100 ± 20	200 ± 30
Perceptible	5.0 ± 0.2	200 ± 30	420 ± 120
Light	4.7 ± 0.1	320 ± 80	400 ± 120
Moderate	4.3 ± 0.1	900 ± 300	750 ± 300
Heavy	3.8 ± 0.3	1,250 ± 500	1,930 ± 900

(Winterhalder 1974). At first, revegetation was confined to flat, sandy sites accessible to agricultural machinery, where shallow cultivation of the soil surface was carried out (Winterhalder 1975) in the belief that it was necessary to bring less metal-contaminated soil to the surface. Later it was shown that not only was it possible to establish a grass-legume mixture on barren, stony slopes by manual surface application of limestone, fertilizer, and seeds (Winterhalder 1983a), but that limestone application in itself was an effective trigger-factor in initiating "natural revegetation" (i.e., spontaneous colonization) by a wide variety of species (Winterhalder 1983b).

COLONIZATION OF BARREN LAND WITHOUT TREATMENT

In the late 1960's, the only plants found in "barren" sites were relict woody plants that had survived the complex of environmental factors responsible for the loss of the original vegetation. Trees falling into this category were mostly white birch, red maple, and red oak (Quercus borealis Michx.f.) in drier sites and trembling aspen in moister areas. While the three former species took on a coppiced form, with suckers arising from the base of a stool, the aspens existed as clonal patches arising from root suckers. Relict woody shrubs included the common blueberry (Vaccinium angustifolium Ait.) and larger shrubs such as wild currant (Viburnum cassinoides L.) and red elderberry (Sambucus pubens Michx.).

Following the improvement of atmospheric quality in 1972, several grasses began to invade the barrens in a limited way. These included tickle grass, which invaded moist depressions and valley bottoms, as well as forming an understory to such woody relicts as white birch and blueberry. Even more striking was invasion of moist sites by tufted hair grass (Cox & Hutchinson 1981), shown by Cox & Hutchinson (1980) to be tolerant of many metals. Other graminoid colonists have included redtop and Canada bluegrass (Poa compressa L.), shown to have evolved some metal tolerance by Hogan & Rauser (1979) and by Rauser & Winterhalder (1985), respectively.

The floodplains of creeks, as well as some wet depressions, were colonized by sedges, especially Carex aenea Fern. and wool sedge (Scirpus cyperinus (L.) Kunth). Another common colonist of such sites is the balsam willow (Salix pyrifolia Anderss.). On barren peat areas, the first colonizer is often a rush (Juncus brevicaudatus (Engelm.) Fern.), followed by tickle grass in drier areas and wool sedge in wetter sites.

Almost 10 years after the closure of the Coniston smelter, white birch seedlings began to appear on bare stony slopes within a kilometre of the plant. Presumably, during this time the free acid had been washed out of the soil leaving only exchangeable acidity, since the pH has been seen to rise as much as one unit of pH (from 3.5 - 4.0 to 4.0 - 5.0) in that area. It is also possible that some of the surface metal has been eroded or leached away, or washed deeper into the profile, while near the active smelters there is still some acid loading (Cox & Hutchinson 1981). Even during 1977-1978, Cox & Hutchinson (1981) found a higher rate of spread in tufted hairgrass near the Coniston smelter than near the active smelters.

One of the more surprising colonists of barren land has been dwarf birch, normally found in fens (John Jeglum, GLFRC, Sault Ste. Marie - personal communication), but in Sudbury moving up barren hillsides, especially in seepage areas or where the effectiveness of precipitation is enhanced by runoff from rock outcrops. The only native nitrogen-fixer found as a sporadic colonist of untreated barrens is the Sweet Fern (Myrica asplenifolia L.).

Although natural recolonization is occurring, there are several reasons why the Sudbury barrens require some "assistance" to the natural process:

1. Colonization is slow, and confined to specific areas.
2. A very limited number of species colonize, giving low diversity. There is little likelihood that the primary colonists will be followed by species that would normally form part of a succession on, say, logged and burned-over land.
3. The longer an area remains unvegetated, the more the soil will be eroded.
4. The Regional Municipality is anxious to "green" the highway view-corridor, in order to enhance the region's image.
5. Liming of land improves ground water and stream water quality. Skraba and Winterhalder (1986) have shown that ground water and stream water pH are raised by surface-liming a small watershed, while the levels of copper, nickel and aluminum in the water are depressed.
6. Liming of land reduces the amount of metal taken up and cycled by any plants that grow on the soil. Winterhalder et al. (1984) showed that copper, nickel, and aluminum levels were reduced in leaves of tufted hairgrass, red pine, and jack pine following surface limestone application.

COLONIZATION OF GRASSED, SANDY BARREN VALLEY-BOTTOMS

In August 1974, 2.5 ha of fine sandy barren soil in Coniston Creek valley, with a pH of 4.0 and a total copper and nickel content of 450 and 500 mg/kg respectively, was grassed. The area was scarified with a spike harrow, limed with 1,400 kg/ha dolomitic limestone, fertilized with 350 kg/ha 7-7-7, surface-seeded with 45 kg/ha Canada bluegrass seed, and re-scarified. Within a year, the area was invaded by redtop and Alsike clover (Trifolium hybridum L.), presumably from nearby roadsides. In later years, parts of the site were invaded by woody plants such as white birch, trembling aspen, pussy willow (Salix humilis Marsh.), and sweet fern, the latter being an actinorrhizal nitrogen-fixer. Other interesting native plants that colonized spontaneously were ground orchids known as ladies' tresses (Spiranthes cernua (L.) Rich. and S. gracilis (Bigel.) Beck.) and leather grape fern (Botrychium multifidum (Gmel.) Rupr.).

A full species list is available from the author on request.

Table 2 shows the change in percent frequency of the more important species at this site over a 10-year period following grassing, based on repeated measurement of 400 1-m^2 quadrats.

Table 2. -- Percent frequency of selected species growing on a sandy site grassed with Canada bluegrass in August, 1974.

Species	Year '75	'77	'79	'80	'81	'82	'83
MOSSES							
Pohlia nutans (Hedw.) Lindb.	0	53	57	50	77	59	50
Polytrichum commune Hedw.	0	11	24	32	42	48	48
GRASSES AND SEDGES							
Agrostis gigantea	8	26	69	75	84	82	75
Agrostis scabra	4	5	13	5	14	nd	3
Carex aenea	12	6	7	5	5	4	0.3
Poa compressa	nd	nd	89	76	90	87	81
OTHER MONOCOTYLEDONS							
Spiranthes spp.	0	0	0	0	0	5	10
HERBACEOUS DICOTYLEDONS							
Anaphalis margaritacea (L.) C.B. Clarke	0.7	2	12	16	35	59	60
Solidago spp.	0	0	0	0	0.6	9	27
Trifolium hybridum	8	15	24	46	52	55	57
WOODY SPECIES							
Betula papyrifera	0	0	0	0.6	2	4	5
Myrica asplenifolia	0	0	0	0	2	4	5
Populus tremuloides	0	8	8	13	17	17	21
Salix spp.	21	21	28	35	43	36	43

nd - not determined

While table 2 gives an indication of the rate of spread of colonizers, table 3 gives a better idea of the actual increase in importance of selected species in the community as measured by percent cover.

Table 3. -- Percent cover of selected species growing on a sandy site seeded with Canada bluegrass, August 1974.

Species	Year '75	'77	'79	'80	'81	'82	'83
MOSSES							
Pohlia nutans	nd	nd	3	5	9	9	12
GRASSES AND SEDGES							
Agrostis scabra	0.4	0.5	1	0.5	2	0.7	0.3
Poa compressa	nd	nd	3	6	3	3	4
HERBACEOUS DICOTYLEDONS							
Anaphalis margaritacea	nd	nd	0.2	0.6	0.8	2	3
Solidago spp.	nd	nd	0	0	0.1	1	3
Trifolium hybridum	nd	nd	0.8	5	4	5	6
WOODY SPECIES							
Betula papyrifera	nd	nd	0	0.1	0.2	0.4	0.5
Myrica asplenifolia	nd	nd	0	0	0.4	1	4
Populus tremuloides	nd	nd	0.1	0.5	0.6	1	3

nd - not determined

The single species used, Canada bluegrass, was chosen because of its drought-tolerance and its suitability for sandy soils. Whereas in a site with more diverse microhabitats the use of a single species would be unwise, the establishment of a single species on a homogeneous site can clearly constitute an adequate trigger factor to further colonization. Canada bluegrass is a particularly suitable species for this purpose since its rhizomatous habit not only binds the soil, but it also gives a relatively open sward, allowing colonization by volunteers to occur.

COLONIZATION OF STONY SLOPES SOWN TO A GRASS-LEGUME MIXTURE

The approach used on the sandy valley-bottom was only possible because of the flatness and accessibility of the terrain. A study of the highways and railways entering Sudbury, sponsored by the Regional Municipality in 1974 (Winterhalder et al. 1975), showed that 10% of the highway margin mileage was barren, 20% very damaged, and 40% perceptibly damaged. Most of the barren land consisted of steep, eroded slopes with a cover of stones left behind as the fine material was washed away, with frequent rock outcrops.

In spite of the surface erosion that had occurred, these soils were still acid, metal-contaminated, and phytotoxic. Earlier attempts to revegetate these steep, stony slopes (Peters 1978) had required the use of heavy landscaping machinery, and were too expensive to use on a large scale. It was believed that in order to establish plants, it would be necessary to till the soil so as to bring some of the less toxic material from the subsoil to the surface. However, the author's trials initiated in 1974 showed that the surface application of ground limestone, fertilizer, and seeds was effective in establishing plant cover, the stones on the surface acting as an effective mulch and preventing the washing away of seeds and ameliorants. The experimental phase eventually gave way to a large-scale job-creation programme, in which over 2,500 ha of land were grassed, and 1,200 students and 1,600 unemployed adults were employed in a 5-year period (Lautenbach 1985).

The seed mixture used varied somewhat from year to year, but its composition during the 1983 and 1984 programmes (table 4) is typical.

Table 4. -- Percent composition by weight of the 1983 and 1984 Regional Land Reclamation seed mixtures.

Species	Percent in mixture
GRASSES	
Redtop	20
Timothy	20
(Phleum pratense L.)	
Canada bluegrass	15
Kentucky bluegrass	15
(Poa pratensis Schreber)	
Creeping red fescue	10
(Festuca rubra L.)	
LEGUMES	
Alsike clover	10
Birdsfoot trefoil	10
(Lotus corniculatus L.)	

Following the first seeding in 1978, a study carried out in the summer of 1979 showed the distribution of cover classes seen in table 5.

Table 5. -- Frequency distribution of Domin classes on grassed stony hillsides, July 1979, as determined by 1-metre-square quadrats.

Cover class	Number of quadrats
Bare	10
Less than 4% (reduced vigour)	10
Less than 4% (1 or two individuals)	8
Less than 4% (several individuals)	5
Less than 4% (numerous individuals)	30
4 - 10%	70
11 - 25%	108
26 - 33%	42
34 - 50%	68
51 - 75%	62
76 - 90%	13
91 - 100%	5

Note that 25% of the sample plots had a plant cover of between 11% and 25%, while 80% of the plots had a plant cover between 0 and 50%. The open sward created is beneficial for colonization, offering numerous openings and microhabitats for volunteer seedlings.

One of the striking aspects of the colonization of stony slopes seeded with a grass-legume mixture is the rapid colonization by woody plants, especially trembling aspen,white birch, and willows.The seed source for these woody plants lies in the frequent relict individuals that are found in the barrens. The subject of the role of these relics is discussed more fully in Winterhalder (1987a). Early herbaceous colonizers include yarrow (Achillea millefolium L.), pearly everlasting, and Carex aenea. Also striking is the increasing importance over time of one of the sown legumes - birdsfoot trefoil. This species is sown at a relatively low rate (11 kg/ha), and is rather slow in becoming established, but it spreads rapidly once establishment occurs. The rapid spread of birdsfoot trefoil suggests that it is highly suited to the terrain and is actively fixing nitrogen. A preliminary survey of soil nitrogen status, however, shows little buildup of nitrogen in the soil itself within the first few years (Winterhalder 1987b).

Table 6 shows the changes that are occurring on these revegetated barren slopes.

Table 6. -- Importance values* for selected species over a 5 to 6 year period following limestone/fertilizer/grass-legume seed treatment of stony slopes.

	Number of years after seeding					
Species	1	2	3	4	5	6
Populus tremuloides	0.0	0.9	3.1	3.9	5.7	nd
Anaphalis margaritacea	nd	0.2	0.3	1.1	1.2	3.4
Lotus corniculatus	nd	1.0	7.0	10.0	15.0	21.0
Agrostis gigantea	nd	34.0	20.0	18.7	11.0	9.0

* (Relative Frequency + Relative Cover + Relative Density) / 2
nd - not determined

The major seeded grass species, redtop, can be seen to decrease in importance over time. Whereas the gradual reduction in importance of this introduced grass might be considered desirable, and the reduction in relative importance of herbaceous species as woody cover increases is to be expected, the rapid loss of grass cover may be a source of concern. The fear is that the development of a woody community with bare patches between the trees might initiate the erosion cycle once more. In fact, there is evidence (table 7) that in the first few years following seeding, mean percent cover increases as a result of the growth of colonists, but the frequency of low-cover patches also increases. However, the presence of tree roots and of leaf litter will almost certainly mitigate against erosion, so long as the unvegetated patches are not too large.

Table 7. - Changes in plant cover, measured in July, on revegetated sites near Coniston (seeded in 1978).

Year	Most frequent cover class	Mean % cover ± s.d.	Number of samples
1979	11 - 25%	nd	376
1980	11 - 25%	15.1 ± 11.7	199
1981	4 - 10%	15.5 ± 13.8	198
1982	0 - 9%	17.8 ± 15.2	199

nd - not determined

Another concern is the fact that colonization by woody species is so far confined to birch, poplars and willows. In the case of maple, for which ample seed sources exist from stunted individuals on the barrens, seeds germinate on grassed land, but rarely survive the heat of the summer. It appears that soil detoxification is not at a level at which red maple seedlings can become fully established. Even the coppiced relict maples seem beyond salvation in most areas. Without soil amelioration they show a steady year-by-year regression, in which large stems die and are replaced by smaller stems. Following soil amelioration there is some evidence of partial recovery, but this does not appear to be universal. Although there is not, so far, any evidence of oak recruitment from relics on grassed land, there is some evidence of this in untreated scrub-oak woodland south of Skead, where relict oak is dominant. Another group of woody species that has so far shown little sign of colonization is the conifers. In this case, the seed source is more limited, and suitable seed bed conditions are rare. For this reason, such species as red pine, jack pine, and white pine are planted in groups (see abstract by Beckett in these Proceedings) to act as a seed source for future natural ecosystem development. In addition, some exotic tree species such as European larch (Larix decidua Mill.) and black locust (Robinia pseudo-acacia L.) are also planted, raising controversial questions concerning the advisability of using exotics when the creation of a quasi-natural plant community is the stated aim (Winterhalder 1987a).

The reason for planting black locust is a rather special one: Like the clover and trefoil used in the seed mixture, it is a nitrogen fixer, and it has been highly successful wherever it has been planted. The only native nitrogen-fixer to spread effectively following treatment is sweet fern, which occurs occasionally on barren land and spreads quickly once the land is treated. Unfortunately the native alders (Alnus rugosa (Du Roi) Spreng. and Alnus crispa (Ait.) Pursh.), although producing winged seeds similar to those of white birch, do not readily volunteer on revegetated land. Experimental planting of alder container stock has recently been initiated. Small-scale transplants of another native nitrogen-fixing shrub, soap buffalo berry (Shepherdia canadensis (L.) Nutt.) from Manitoulin Island have been highly successful, as have those of bearberry (Arctostaphylos uva-ursi (L.) Spreng.). Although the latter species is not normally considered to be a symbiotic nitrogen fixer, it has been reported as nodulated in Alaska (Sprent 1979). The green vigorous growth of this ground-cover-forming species causes the author to suspect some form of symbiotic nitrogen fixation, possibly rhizosphere-based. The question is under investigation.

LIMING AS A TRIGGER FACTOR

When a thin sprinkling of ground limestone is applied to the surface of a barren soil, colonization occurs rapidly. Preliminary evidence points to the existence of a small persistent seed bank, but it appears that most of the seedlings arise from seeds that are blown in following liming. Table 8, from Winterhalder (1985), summarizes the results of colonization over a 5 to 6 year period of twelve 1-m^2 plots, the surface of which had been lightly sprinkled with pulverized limestone.

Table 8. -- Importance values (Cover/Frequency Index*) for species colonizing twelve limed 1-m^2 plots over a 5 to 6 year period.

Species	Mean % Cover	% Frequency	Importance Value
WOODY			
Betula papyrifera	41.3	66.6	47.5
Salix spp.	3.6	50.0	11.5
Populus tremuloides	3.3	41.7	9.8
P. grandidentata Michx.	0.8	8.3	2.1
HERBACEOUS			
Agrostis scabra	5.6	83.3	18.8
Rumex acetosella L.	1.3	8.3	2.5
Aralia hispida Vent.	0.8	8.3	2.1
Conyza canadensis (L.) Cronq.	0.1	8.3	1.5
Festuca rubra **	0.1	8.3	1.5
Phleum pratense **	0.1	8.3	1.5
Poa compressa **	0.1	8.3	1.5

* (Relative Frequency + Relative Cover) / 2
** From seeds blown in from nearby revegetated area

Some mortality occurs following initial germination on limed areas. As the percent cover of woody plants like white birch increases, the numbers decrease through competition. Frost action, which is enhanced on these barren sites (Sahi 1983), also plays a part in the mortality of small seedlings. Table 9 shows the effect of frost-heaving on the seedlings in a single 1-m^2 plot near Coniston, as observed June 4, 1981.

Table 9. -- Frost-heaving and mortality in seedlings on limed plots near Coniston.

Species	Total number of living seedlings	Number of living seedlings showing signs of heaving	Number of dead seedlings (all species)
Salix spp.	81	36	
Populus tremuloides	6	0	
Betula papyrifera	2	0	
Agrostis scabra	64	2	
All species	153	36	44

The overwinter mortality of woody seedlings was 33%, while 41% of the surviving seedlings showed signs of frost-heaving. Tickle grass is heaved very little, presumably because of its fibrous root system, and it almost certainly plays a role in stabilizing the soil and reducing the amount of heaving in woody seedlings.

IS SEEDING NECESSARY OR DESIRABLE?

This question has arisen as a result of the trigger factor effect mentioned above. If the application of limestone alone is sufficient to initiate plant growth, then a number of arguments could be produced favouring the elimination of fertilizing and seeding as now practiced. There would be an evident economic advantage to this approach, while from the ecological standpoint it could be argued that the introduction of exotics should be avoided wherever possible. The idea of creating a woodland with an understory of agronomic grasses may at first seem to be ecologically inappropriate. In actuality, however, there is a tendency for woody species to become more important and herbaceous species less important during the years that follow grassing (Winterhalder 1985). The potential benefits of the legumes in the seed-mixture to the growth of woody plants should also be remembered. In one of the more successful pine plantations on revegetated land, near Wahnapitae, there is a dense understory of birdsfoot trefoil, and both conifer and legume seem to be thriving.

Another point for consideration is the difference in colonizer spacing between seeded and non-seeded areas, and the effect on later competition. If the grass-legume mixture is established as an open community, as practiced in Sudbury's Regional Land Reclamation Programme, then the woody plants that colonize will be found in a somewhat random arrangement, with spaces between the seedlings. If, however, the site is limed only, then the colonizing birches, willows, and poplars form a dense stand that will lead to vigorous competition until certain individuals can achieve dominance. This phenomenon is shown in table 10, where the woody plants on two 1000-m^2 plots (one limed, fertilized and seeded, the other merely limed) are recorded.

Table 10. - Percent Cover and Importance Value (Cover/Frequency Index*) achieved in 2 years by woody colonizers on a limed, fertilized, and seeded plot and on a unseeded, unfertilized, limed plot.

Species	Seeded Plot		Unseeded Plot	
	% cover	IV	%cover	IV
Populus tremuloides	0.6	1.5	9.1	29.1
Salix spp.	0.1	0.9	5.5	20.1
Betula papyrifera	0.0	0.0	0.4	4.5
Populus grandidentata	0.0	0.0	0.0	3.2

*(Relative Frequency + Relative Cover/2

SUMMARY AND CONCLUSIONS

It has been shown that the surface application of ground limestone to acid, metal-contaminated, barren soils in the Sudbury area detoxifies the soil and allows plant growth. If limestone is applied alone, a cover of mostly woody plants develops. If grass seed is also applied, other species, including legumes, will eventually colonize. In practice, limestone, fertilizer, and a grass-legume seed mixture are applied manually to the surface of stony barren slopes. Within a few years the treated land bears a rich mixture of herbaceous and woody species, with seeded legumes and woody species increasing in importance over time.

Image improvement through revegetation of highly visible barren land is a declared policy of the Regional Municipality. To quote the Region's Official Plan (Lautenbach 1985):

"It shall be the policy of the Council to .... Give priority initially to reclamation projects in those areas where the results would be immediate, dramatically obvious and economically feasible. This includes areas which are most visible to the public, such as major transportation corridors and locations surrounding public facilities."

For this reason, revegetation efforts so far have been confined to highway view-corridors. Because of the visibility of the land and the need for an instant "cosmetic" effect, the potential for allowing natural revegetation to occur following minimal amelioration (i.e., limestone only) has not been fully exploited. Even on grassed land, however, volunteer colonization has given rise to a diverse plant cover with a strong native component.

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