THE RELATIVE MERITS OF NATIVE TRANSPLANT PLUGS AND TOPSOIL ISLANDS IN THE ENHANCEMENT OF UNDERSTORY BIODIVERSITY ON RECLAIMED MINELANDS[1]

Keith Winterhalder[2]

Abstract. In northeastern Ontario, Canada, mine tailings and lands rendered barren by smelter emissions are commonly revegetated using a grass-legume mixture, then planted with native trees, mostly conifers such as Red, White and Jack Pine. Vigorous colonization by native pioneer tree species such as White Birch and Trembling Aspen occurs, as well as that of native herbs associated with forest openings, such as Asters and Goldenrods. However, it is rare for the herbs and shrubs found in the understory of a mature pine forest to colonize these artificially wooded sites. Native understory species have been transplanted from natural habitat at an experimental level over a number of years on grassed smelter-affected barrens and grassed tailings, to determine whether such transplants survive and spread. Small islands of forest topsoil have also been established on grassed tailings. The source of native plugs has been predominantly mature Jack, Red and White Pine forest, but species adapted to naturally exposed sites such as sand dunes have also been transplanted with success. Not surprisingly, the species that spread most readily are those possessing rhizomes or stolons, such as Canada Mayflower (*Maianthemum canadense*) and Starry False Solomon's Seal (*Smilacina stellata*) in the case of plugs, and Spreading Dogbane (*Apocynum androsaemifolium*) in the case of topsoil islands. Since results so far suggest that both approaches are valid, the relative advantages of each are critically appraised.

Additional Key Words: tailings, revegetation, restoration

---

[1] Paper was presented at the 2004 National Meeting of the American Society of Mining and Reclamation and the 25th West Virginia Surface Mine Drainage Task Force , April 18-24, 2004. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2]Keith Winterhalder is Associate Professor of Biology (retired), Laurentian University, Sudbury, Ontario P3E 2C6, Canada.

Proceedings America Society of Mining and Reclamation, 2004 pp 2042-2060
DOI: 10.21000/JASMR0402042
https://doi.org/10.21000/JASMR04012042

Introduction

In northeastern Ontario, Canada, the establishment of vegetation on natural landscapes rendered acidic and phytotoxic by smelter emissions, as well as on acid-generating mill tailings, usually consists of three phases. The surface is detoxified in some way, usually involving neutralization with limestone, followed by establishment of a grass-legume mixture, and finally the planting of native coniferous trees (Winterhalder, 1996; Peters 1995). This gives the appearance of a natural pine forest, but the vegetation lacks the understory species normally found in such plant communities. The goal of the study described here is to explore the relative feasibility of the transplantation of understory species from undisturbed forest as plugs, and the deposition of piles of forest topsoil on the minesoil surface as a source of propagules. While it is acknowledged that characteristic understory species will eventually become established through the transport of seeds by wind and animals, it appears advisable to accelerate the process so that the partially-restored ecosystem can more rapidly begin to function in a manner similar to that of a native forest.

Plugs

The transplantation of native species and associated soil from natural habitats has been carried out successfully in a number of different environments. Bowler (1994) 'salvaged' coastal sage scrub species in California with 'generous quantities of soil from the salvage site" around the roots, and planted them at a restoration site after stabilization in a greenhouse for two weeks. In the mountains of southern Colorado, USA, 25-30cm x 30-50 cm x 15 cm turf blocks, rich in *Carex elynoides* and *Geum rossii*, have been transplanted in areas disturbed by hiking trails (Ebersole *et al.*, 2002). In the UK, a similar technique has been used for heathland restoration, using larger turves (1.2m x 2.3 m x 15 cm), and requiring specialized hydraulic equipment (Pywell *et al.*, 1995).

Forest Understory Plugs

Method. The approach taken was to dig up small blocks of soil, approximately 30 cm^3 cubes, each containing one or more target understory species, from a natural forest. Similarly sized blocks of the vegetated tailings soil were removed, and replaced by the transplant blocks or "plugs". Since the climax vegetation of the Sudbury area is primarily pine forest, a Jack Pine (*Pinus banksiana*) forest near Cartier, north of Sudbury, and a Jack Pine-Red Pine (*Pinus resinosa*)-White Pine (*Pinus strobus*) forest near Nairn, west of Sudbury, were chosen as donor sites. The recipient sites were four different sections of the Copper Cliff tailings complex, varying in age, but all having been grassed and planted with pines by the technique described in Peters (1995). In total, 40 native species were planted, most of them being understory herbs and shrubs. In this preliminary experiment, no attempt was made to transplant equal numbers of each target species, so no intensive statistical analysis of the results was possible. Nevertheless, it is felt that the results give a useful indication of the feasibility of the approach, and of the species most amenable to this technique. Plugs were monitored for survival and quantitatively assessed for tendency to spread several times each year. In 2001, 2002 and 2003, the maximum extent of spread of each species from the original plug was also measured.

Results. Of the forty species planted, twenty-two survived, several with a relatively high survival rate (Fig. 1), and many of them growing vigorously (Figs. 2 & 3).

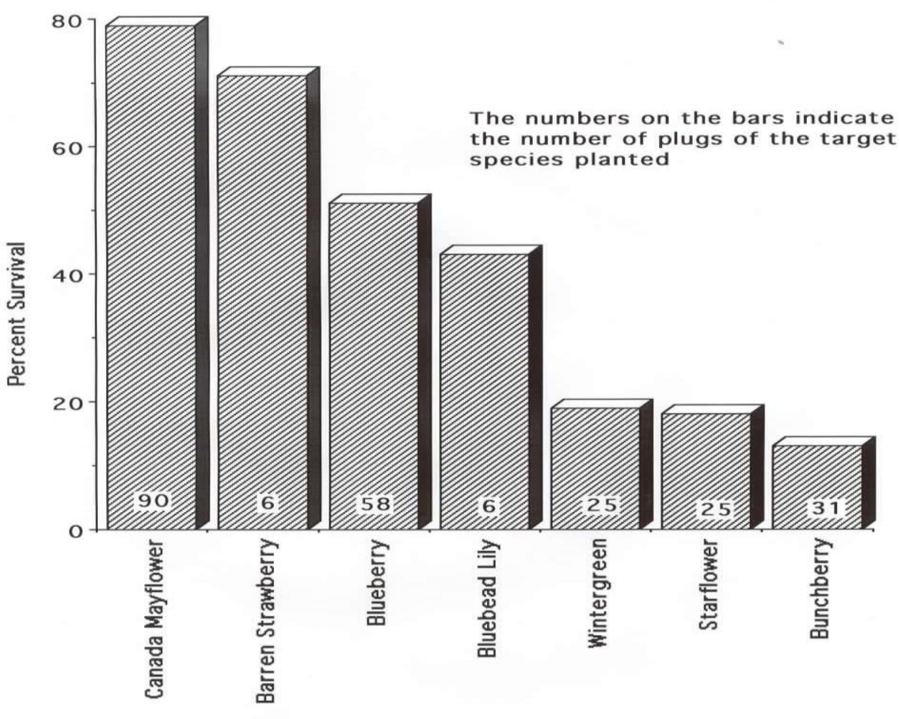

Figure 1. Percent survival over six years of the seven most successful species planted as plugs.

Figure 2. Barren Strawberry (*Waldsteinia fragarioides*) & Bluebead Lily (*Clintonia borealis*) spreading from a single plug.

Figure 3. Canada Mayflower *(Maianthemum canadense)* spreading from a plug.

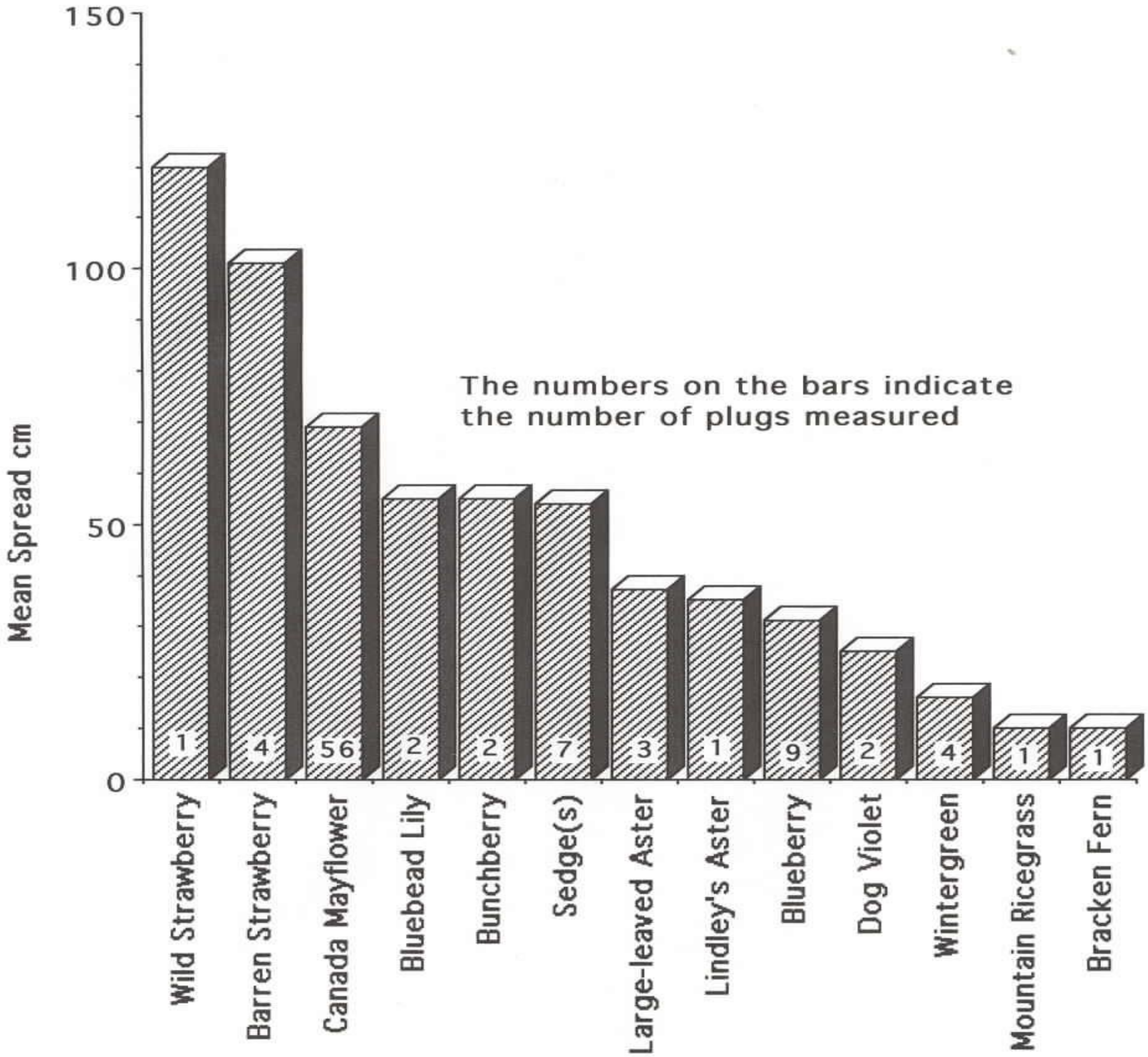

Figure 4. Horizontal spread over six years of selected species planted as plugs.

Surviving species varied widely in their tendency to spread (Fig. 4), and even within the same species there was considerable variation (Fig. 5).

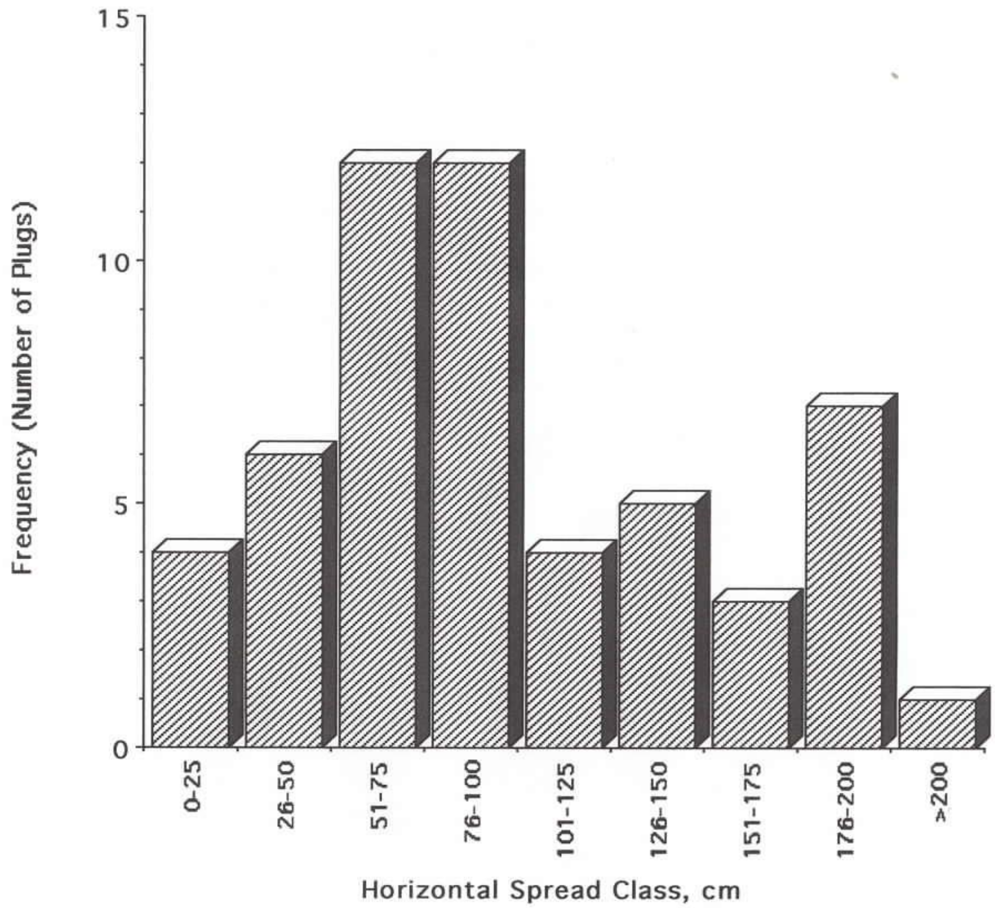

Figure 5. Frequency distribution of horizontal spread classes for fifty-six Canada Mayflower (*Maianthemum canadense*) plugs

Non-Forest Plugs

In view of the open nature of much revegetated tailings and metal-contaminated landscapes, experiments have also been initiated using the following species characteristic of non-forest communities such as sand dunes and old fields, as indicated:

Arctostaphylos uva-ursi	Bearberry	Stabilized L. Huron dune
Convolvulus spithamaeus	Low Bindweed	Sandy (acid) old field
Hypericum kalmianum	Kalm's St. John's Wort	L. Huron dune marsh
Lathyrus japonicus	Dune Pea	Active L. Huron dune
Senecio pauperculus	Balsam Ragwort	L. Huron dune marsh
Shepherdia canadensis	Soapberry	Sandy (neutral) old field
Smilacina stellata	Starry False Solomon's-seal	Stabilized L. Huron dune

Bearberry (*Arctostaphylos uva-ursi*) and Starry False Solomon's-seal (*Smilacina stellata*) have been established on smelter-damaged slopes that were limed and grassed in 1978, and they are spreading vigorously by vegetative means, as well as flowering and fruiting annually. At the same site, Soapberry (*Shepherdia canadensis*) shows no evidence of reproduction, but produces flowers and fruits regularly. On a formerly barren valley-bottom, limed and grassed in 1972, Dune Pea (*Lathyrus japonicus*), Kalm's St. John's Wort (*Hypericum kalmianum*) and Balsam Ragwort (*Senecio pauperculus*) are healthy but have achieved only limited expansion. In the case of grassed mine tailings, Bearberry, Soapberry and Low Bindweed (*Convolvulus spithamaeus*) have been successfully established and are spreading, the Bearberry through its stoloniferous habit, and Starry False Solomon's-seal and Low Bindweed through rhizomatous growth.

It is of particular interest that several of the non-forest species were collected from alkaline dunes, and are know to be calciphiles. It is therefore surprising that they thrive on acidic, metal-contaminated substrates. Even after liming, the Sudbury barren soils rarely have a pH above 5.5. A possible explanation is a combination of lack of competition and the fact that the plants are provided with an appropriate calcium-magnesium balance through the use of dolomitic limestone in the revegetation process (McHale & Winterhalder, 1997). Although the use of species that are not part of the Sudbury area's 'normal' vegetation might be questioned by restorationists, it must be recognized that the limed metal-rich soils of Sudbury are still quite different from the original boreal forest soils. Indeed, attempting to grow native species from the local gene pool might, to some extent, be considered as trying to put 'a square peg in a round hole'. Jones (2003) distinguishes between genetic identity and adaptation, and justifies the use of a better adapted plant material over material from a limited target gene pool, so long as a decision is made individually for each plant species 'in the scientific context that ecosystem management demands'.

<u>The use of plugs – Discussion</u>

It is clear that the use of plugs is an effective means of introducing certain species to a partially-revegetated site, especially species that spread vegetatively by rhizomes or stolons. It remains to be seen whether these species will begin to form new colonies through seed dispersal, although the fact that some of the succulent-fruited species such as Canada Mayflower and

Bluebead Lily have flowered and fruited suggests that dispersal by birds or other vectors may take place at some time in the future..

The present author has previously used the term "nucleation" to describe the introduction of plugs of target species from which spread can occur. This use of the term is rather different from that of Yarranton & Morrison (1974), who used it to describe the tendency of new species to become established within the environmental influence of a pioneer species in a natural succession, and Miller (1978), who suggested that this principle might be applied in revegetation. In the project described here, it is hypothesized that the establishment of a "nucleus" by means of a plug is likely to give rise to two beneficial phenomena – the spread of the species itself, and the establishment of new species within its sphere of influence.

Topsoil Islands

The idea of using topsoil as a source of seeds in strip revegetation (Beauchamps *et al.*, 1975; Farmer *et al.*, 1982; Wade & Thompson, 1990), and enhancing vegetation diversity on mined land (De Puit, 1984), is not a new one. The role of other potential propagules such as root fragments and stem bases has also been recognized, e.g. Fedkenheuer & Heacock (1979) and Pywell *et al.* (1995).

Methods

Each topsoil island was created by collecting a tandem truckload of 'topsoil' (10-20 cm depth) from wooded sites, using a front-end loader or backhoe. Donor sites were mostly selected on the basis of being threatened by industry or being on an electrical power transition corridor, so that damage to pristine vegetation did not occur. The topsoil was deposited on the grassed tailings in piles, then leveled out to varying degrees, depending on the diligence of the operator, using a front-end loader. Inevitably donor sites tended to be marginal and/or successional, in view of constraints of access and the desire not to damage mature forest. Nineteen such islands were created on the ‘CD’ tailings (Fig. 6), and four on the ‘M’ tailings.

Islands were monitored several times each summer, either qualitatively by species presence or (once each season) by percent cover. The spread of plants from the island onto the tailings was also recorded, and measured where this was significant.

Figure 6. Topsoil islands on CD tailings in 2003. Note colonization by Smooth Brome

Results

If all twenty-three topsoil islands are taken into account, the total number of species transferred to the tailings is fifty-seven. Table 1 lists these species, and categorizes them with respect to their life form and native vs. non-native status.

Table 1. List of species transferred to the tailings on topsoil islands.

Latin Name	English Name	Life Form/Status
Acer rubrum	Red Maple	NT
Achillea millefolium	Yarrow	NH
Agropyron repens	Quack Grass	AH
Agrostis scabra	Tickle Grass	NH
Amelanchier sp.	Serviceberry	NS
Apocynum androsaemifolium	Spreading Dogbane	NH
Arabis sp.	Rock Cress	NH
Aster puniceus	Red-stemmed Aster	NH
Aster ciliolatus	Lindley's Aster	NH
Aster macrophyllus	Large-leaved Aster	NH
Aster paniculatus	Panicled Aster	NH
Aster umbellatus	Flat-topped Aster	NH
Betula papyrifera	White Birch	NT
Carex sp.	Sedge	NH
Chrysanthemum leucanthemum	Ox-eye Daisy	AH
Cirsium arvense	Canada Thistle	NOX
Comptonia peregrina	Sweet Fern	NS
Danthonia spicata	Poverty Grass	NH
Deschampsia flexuosa	Wavy Hairgrass	NH
Diervilla lonicera	Bush Honeysuckle	NS
Epilobium angustifolium	Fireweed	NH
Fragaria virginiana	Wild Strawberry	NH
Galeopsis tetrahit	Hemp Nettle	AH
Gaultheria procumbens	Wintergreen	NH
Hieracium aurantiacum	Devil's Paintbrush	AH
Hieracium piloselloides	Yellow Hawkweed	AH
Kalmia angustifolia	Sheep Laurel	NS
Maianthemum canadense	Canada Mayflower	NH
Melilotus alba	White Sweet-clover	AH
Melilotus officinalis	Yellow Sweet-clover	AH
Oenothera biennis	Evening Primrose	NH
Oryzopsis asperifolia	Mountain Ricegrass	NH
Polygonum aviculare	Knotweed	AH
Polygonum cilinode	Fringed Black Knotweed	NH
Populus tremuloides	Trembling Aspen	NT
Potentilla norvegica	Rough Cinquefoil	AH
Prunus virginiana	Choke Cherry	NT
Pteridium aquilinum	Bracken Fern	NH
Rosa acicularis	Bristly Rose	NS
Rosa blanda	Smooth Rose	NS
Rubus canadensis	Blackberry	NS
Rubus strigosus	Raspberry	NS
Rumex acetosella	Sheep Sorrel	AH
Smilacina racemosa	False Solomon's Seal	NH
Solidago canadensis	Canada Goldenrod	NH
Solidago graminifolia	Grass-leaved Goldenrod	NH
Solidago juncea	Early Goldenrod	NH
Solidago rugosa	Rough Goldenrod	NH
Taraxacum officinale	Dandelion	AH
Tragopogon pratensis	Meadow Goat's-beard	AH
Trifolium pratense	Red Clover	AH

Table 1. List of species transferred to the tailings on topsoil islands (continued).

Ulmus americana	American Elm	NT
Vaccinium angustifolium	Blueberry	NS
Verbascum thapsus	Mullein	AH
Vicia cracca	Cow Vetch	AH
Viola conspersa	Dog Violet	NH
Waldsteinia fragarioides	Barren Strawberry	NH

Native species significantly outnumbered non-native species (Fig. 7)..

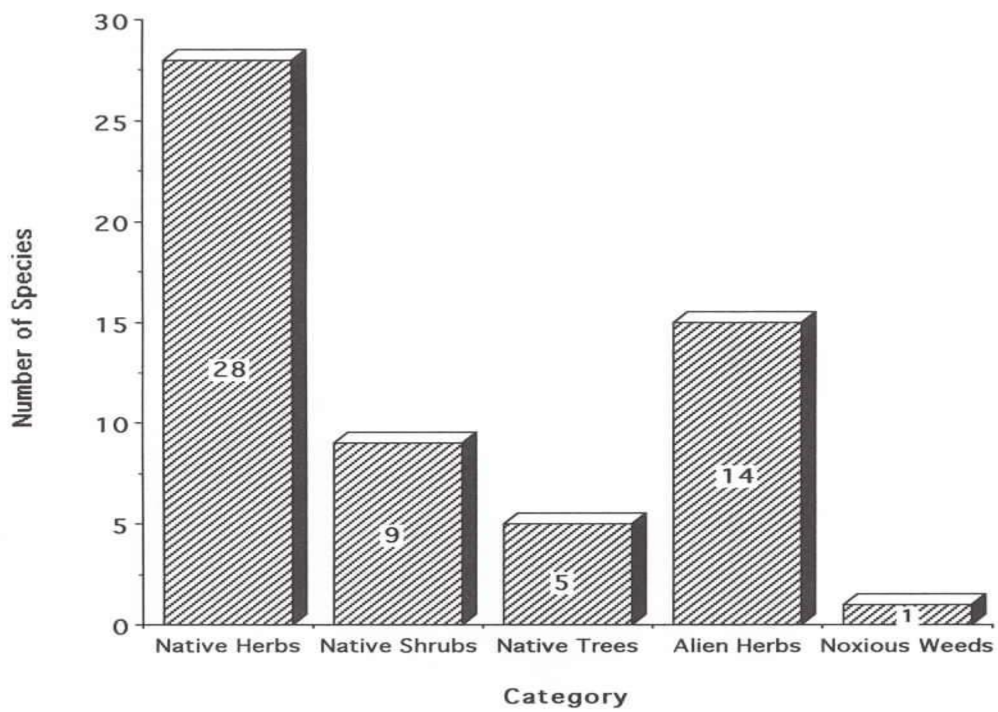

Figure 7. Numbers of native and non-native species transferred to tailings on topsoil islands.

The only non-native species categorized as a noxious weed under Ontario's Weed Control Act, Canada Thistle (*Cirsium arvense*), occurs on only one of the islands, and has fluctuated in cover over the years, reaching a high of 15% in 2002, but dropping to 3% in 2003. So far, it shows no sign of spreading onto the tailings. It should also be noted that this species is very common in the Sudbury area, and its wind-dispersed seeds are likely to be part of the seed rain on the tailings quite independently of its presence on the topsoil island. It should also be noted that the non-native species originally seeded onto the tailings have not been included in the list, but that one of them, Smooth Brome or Brome Grass (*Bromus inermis*), has actively colonized the topsoil islands since their installation (Fig 6).

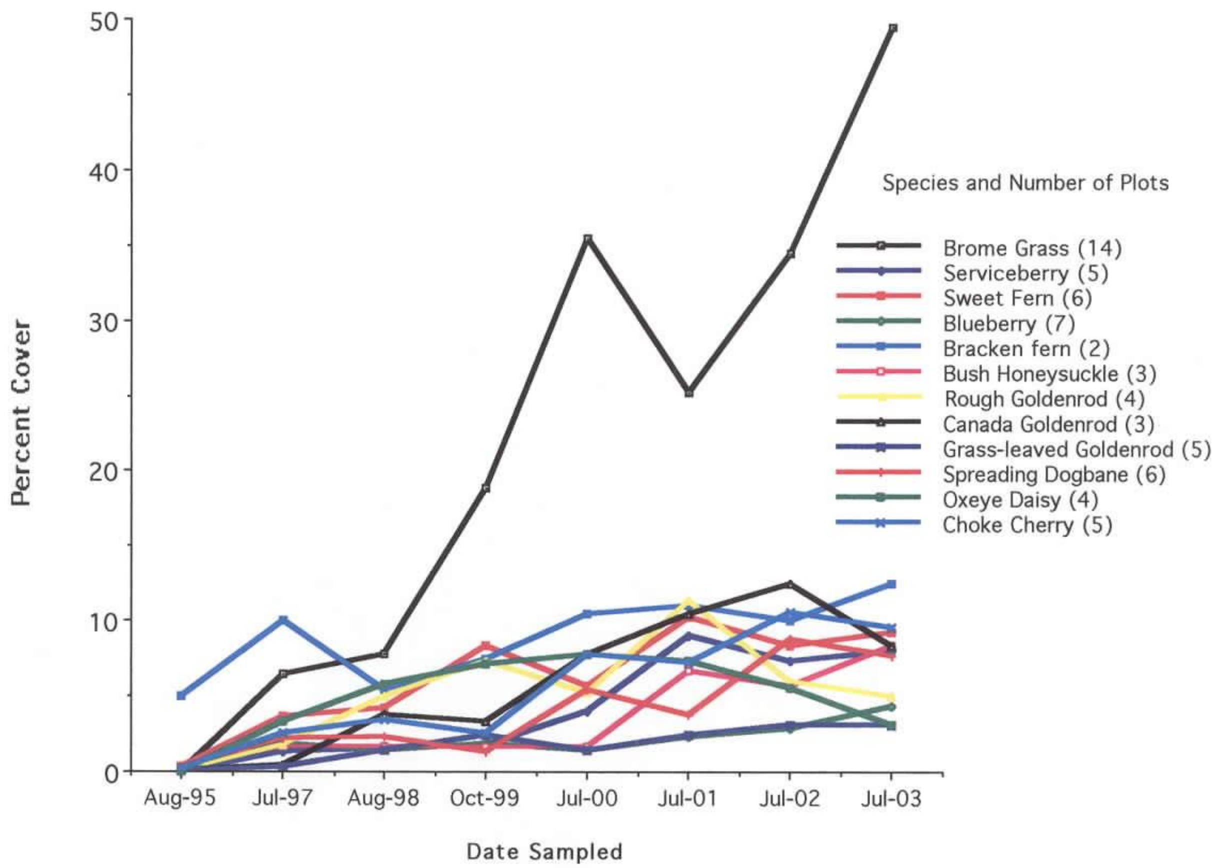

Figure 8. Mean change in percent cover on by Brome Grass and selected native species on topsoil islands over eight years

Although the rate of spread of Brome Grass is much higher than that of the native species (Fig. 8), the latter are maintaining a steady increase. In view of the fact that the main role of the topsoil island is to provide a source of propagules, survival is more important than relative vigor. In terms of actual colonization of the tailings surrounding the topsoil islands, the number of species involved is more limited. So far, at least a dozen species have been observed spreading from the islands, many of them non-native weedy species like Mullein (*Verbascum thapsus*) and

Hawkweed (*Hieracium* sp.). Nevertheless, certain native species are also expanding, some by seed and some by vegetative means (Figs. 9 – 12)

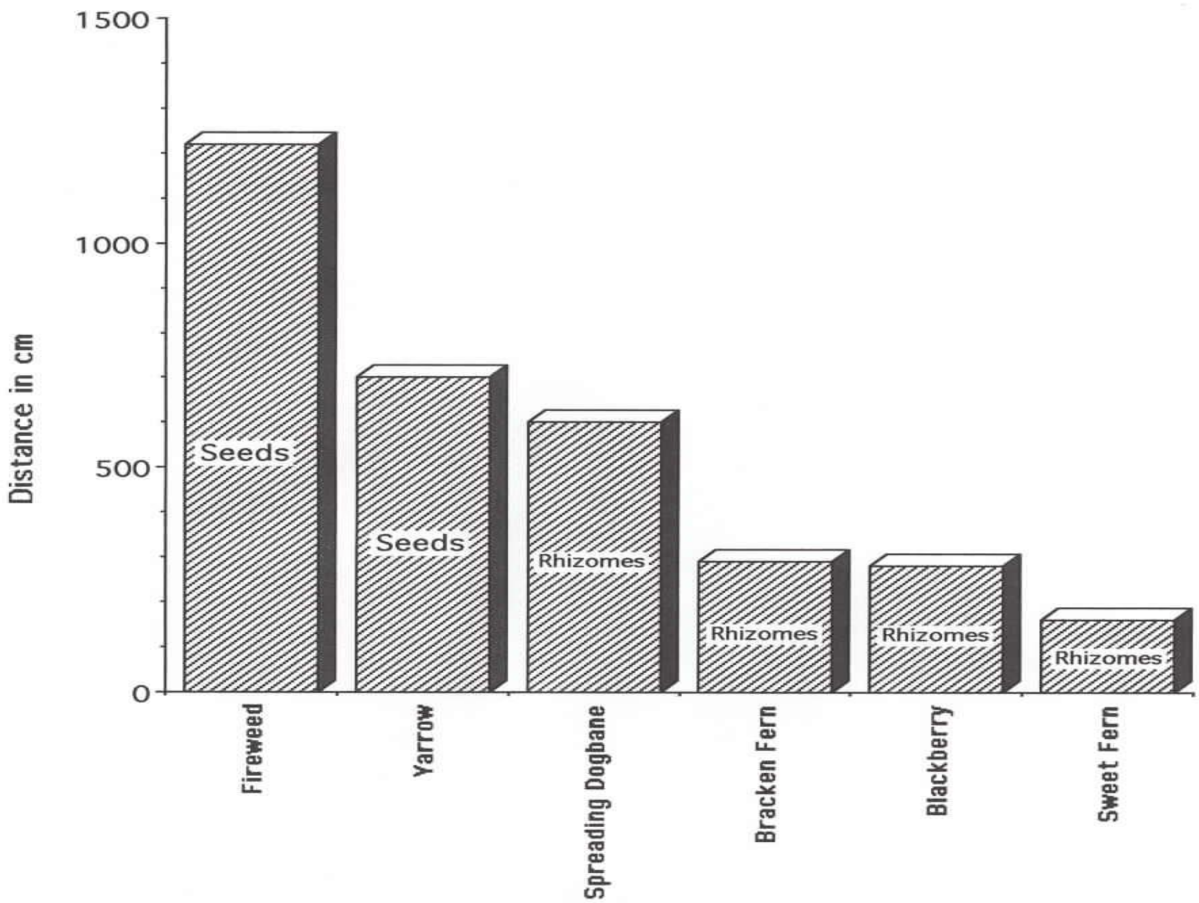

Figure 9. Maximum distance of spread of the native species that are advancing the most vigorously onto tailings, over eight years.

Figure 10. Fireweed (*Epilobium angustifolium*) spreading from topsoil island onto Brome Grass dominated tailings

Figure 11. Spreading Dogbane (*Apocynum androsaemifolium*) spreading onto grassed tailings

One of the native shrubs that is spreading onto the tailings, Sweet Fern (*Comptonia peregrina*) (Fig. 12) is considered by some foresters to be a 'weed' (Hall *et al.*, 1976), but the fact that it is native, a nitrogen-fixer and a normal component of disturbed Jack Pine forest in the Sudbury area makes it a desirable species in this context.

Figure 12. Sweet Fern (*Comptonia peregrina*) spreading onto grassed tailings.

The use of Topsoil Islands - Discussion

A possible concern after a period of eight years is the observation that the percent cover and presumably the competitive strength of Brome Grass is continuing to increase. Indeed, Wade (1989) found that combining non-native reclamation species with forest topsoil over mine spoil reduced the numbers and biomass of native species. Nevertheless, the presence of reclamation species such as Smooth Brome on the Copper Cliff tailings is inevitable, and it should be remembered that these species have played n important role in the soil-forming processes that have taken place over up to 40 years, preparing the tailings for colonization by native plants. Some colonization of the topsoil islands by Birdsfoot Trefoil from the tailings has also occurred.

However, Brenner et al. (1984) observed that, although the presence of Birdsfoot Trefoil tended to inhibit colonization by native plants on Pennsylvania coal mine spoils, the high nitrogen content of the Trefoil had the beneficial effect of increasing the decomposition rate of plant litter.

In arid zones, Howard & Samuel (1979) have stressed the importance of the transfer of rhizomes and other vegetative plant parts in topsoil, and this seems to by true in the case of the Sudbury tailings. For example, Sweet Fern is difficult to grow from seed (Del Tredici & Torrey, 1976), but can be propagated from root fragments (Goforth & Torrey, 1977). Its successful introduction onto the Copper Cliff tailings by means of topsoil islands is likely to be largely the result of this phenomenon.

General Discussion

A few tentative generalizations can be made based on the project so far. It appears that the two techniques are complementary, with some species being more successfully transferred as plugs, and others by topsoil islands. For example, the Canada Mayflower and Barren Strawberry plants on topsoil islands have not spread onto the tailings, whereas those introduced by plugs have spread vigorously. On the other hand, Spreading Dogbane and Sweet Fern, which did not survive in plugs, have spread successfully from topsoil islands.

A cautionary aspect of the use of the plug or topsoil island approach that should be taken into account is a genetic one. If understory plants are introduced from a limited range of habitats, especially if they spread vegetatively, there is a risk of a limited and vulnerable gene pool being created. It would therefore seem desirable to attempt to introduce members of the same and different species from a number of sites and environments, in an attempt to enrich the gene pool. Lesica & Allendorf (1999) have suggested that a diversity of genotypes from different sources is the best restoration strategy where the degree of disturbance has been high. Ideally, if the revegetated site can be extended so that it makes contact with natural vegetation, or if corridors are created, gene exchange will be able to take place, although this may be unlikely in a mine site or urban setting.

In conclusion, the use of plugs and topsoil islands as an approach to the biodiversification and consequent enhancement of ecosystem function on reclaimed minelands is a feasible and economically more tenable process than applying a continuous topsoil cover. Although the "islands of biodiversity" will at first be very local in their impact, there will inevitably be some acceleration of the process of biodiversification, relative to relying on the vagaries of long-distance transport of propagules.

Acknowledgements

This long-term study is supported by Inco Ltd., and the logistical support of Lisa Lanteigne and Inco's environmental staff is gratefully acknowledged.

Literature Cited

Beauchamp, H., R. Lang & M. May. 1975. Topsoil as a seed source for reseeding strip mine spoils. University of Wyoming Agriculture Experiment Station Research Journal 90: 1-8.

Bowler P.A. 1994. Transplanting coastal sage scrub seedlings from natural stands (California). Restoration & Management Notes 12(1): 87-88.

Brenner, F.J., M. Werner & J. Pike. 1984. Ecosystem development and natural succession in surface coal mine reclamation. Minerals & the Environment 6: 10-22. http://dx.doi.org/10.1007/BF02072661.

Del Tredici, P. & J.G. Torrey. 1976. On the germination of seeds of Comptonia peregrina, the sweet fern. Botanical Gazette 137: 262-268. http://dx.doi.org/10.1086/336868.

De Puit, E.J. 1984. Potential topsoiling strategies for enhancement of vegetation diversity on mined lands. Minerals & the Environment 6: 115-120. http://dx.doi.org/10.1007/BF02043991.

Ebersole, James J., Robin F. Bay & David K. Conlin. 2002. Restoring high-alpine social trails on the Colorado Fourteeners. pp. 389-391 *In:* Perrow, Martin R. & Anthony J. Day (eds.), Handbook of Ecological Restoration, Volume 2, Cambridge University Press: Cambridge.

Farmer, Robert E. Jr., Maureen Cunningham & Mary Ann Barnhill. 1982. First-year development of plant communities originating from forest topsoils placed on southern Appalachian minesoils. J. appl. Ecol. 19: 283-294. http://dx.doi.org/10.2307/2403011.

Fedkenheuer, A.W. & H.M. Heacock. 1979. Potential of soil amendments as sources of native plants for revegetation of Athabasca oil sands tailings. Proceedings of the Fourth Annual

Meeting of the Canadian Land Reclamation Association, Regina, Saskatchewan, 13-15 August 1979, pp. 223-237.

Goforth, P.L. & J.G. Torrey. 1977. The development of isolated roots of Comptonia peregrina (Myricaceae) in culture. American Journal of Botany 64(4): 476-482. http://dx.doi.org/10.2307/2441778.

Hall, I.V., Lewis E. Aalders & C. Fred Everett. 1976. The biology of Canadian weeds 16. Comptonia peregrina (L.) Coult. Canadian Journal of Plant Science 56: 147-156. http://dx.doi.org/10.4141/cjps76-022.

Howard, G.S. & M.J. Samuel. 1979. The value of fresh-stripped topsoil as a source of useful plants for surface mine revegetation. J. Range Management 32: 76-77. http://dx.doi.org/10.2307/3897392.

Jones, T.A. 2003. The restoration gene pool concept: beyond the native versus non-native debate. Restoration Ecology 11(3):281-290. http://dx.doi.org/10.1046/j.1526-100X.2003.00064.x.

Lesica, Peter & Fred W. Allendorf. 1999. Ecological genetics and the restoration of plant communities: mix or match? Restoration Ecology 7(1): 42-50. http://dx.doi.org/10.1046/j.1526-100X.1999.07105.x.

McHale, D. & K. Winterhalder. 1997. The importance of the calcium-magnesium ratio of the limestone used to detoxify and revegetate acidic, nickel- and copper- contaminated soils in the Sudbury, Canada mining and smelting area. pp. 267-273 *In*:: Jaffré, T., R.D. Reeves & T. Becquer. *The ecology of ultramafic and metalliferous areas.* Proceedings 2nd International Conference on Serpentine Ecology, Nouméa, July 31- August 5, 1995. Centre ORSTOM de Nouméa, Nouvelle Calédonie.

Miller, G. 1978. A method of establishing native vegetation on disturbed sites, consistent with the theory of nucleation. pp. 322-327 *In:* Proceedings of the Third Annual Meeting of the Canadian Land Reclamation Association, Sudbury, Ontario, 29 May - 1 June.

Peters, Tom H. 1995. Revegetation of the Copper Cliff tailings area. pp. 123-133 In: Gunn, J. (ed.) Environmental Restoration and Recovery of an Industrial region. Springer-Verlag: New York. http://dx.doi.org/10.1007/978-1-4612-2520-1_9 PMid:7795322

Pywell, R.F., N.R. Webb & P.D. Putwain. 1995. A comparison of techniques for restoring heathland on abandoned farmland. Journal of Applied Ecology 32: 400-411. http://dx.doi.org/10.2307/2405106.

Wade, Gary L. & Ralph L. Thompson. 1990. Establishment of native plant species from forest topsoil seedbanks on a borrow area in Kentucky. pp. 451-460 *In:* Skousen, J., J. Sencindiver & D. Samuel (eds.), Proceedings of the 1990 Mining and Reclamation Conference & Exhibition, 2 Vols. West Virginia University, Morgantown, WV.
https://doi.org/10.21000/JASMR90020451

Wade, Gary L. 1989. Grass competition and establishment of native species from forest soil seed banks. Landscape & Urban Planning 17: 135-149. http://dx.doi.org/10.1016/0169-2046(89)90022-4.

Winterhalder, K. 1996. Environmental degradation and rehabilitation of the landscape around Sudbury, a major mining and smelting area. Environmental Reviews 4(3): 185-224. http://dx.doi.org/10.1139/a96-011

Yarranton, G.A. & R.G. Morrison. 1974. Spatial dynamics of a primary succession: nucleation. Journal of Ecology 62(2): 417-428. http://dx.doi.org/10.2307/2258988.