ABANDONED PIT AND QUARRY SITES: LIVING EXPERIMENTS

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ABSTRACT

The Ministry of Natural Resources' pit and quarry rehabilitation research has concentrated on determining the potential that extraction sites have to support different types of wildlife communities and identifying the critical factors for success in the establishment of specific habitats or ecosystems.

Important sources of information for this research are the numerous abandoned extraction sites scattered across southern Ontario. These can really be considered as living experiments that were begun at the time of abandonment.

Botanical surveys are being carried out at a variety of such abandoned pit and quarry sites in southern Ontario. Randomly located transects and quadrats on these sites provide a description of vegetation patterns. Associated physical variables such as hydrology, topography and soil characteristics are also measured . These are being correlated with the plant patterns to suggest underlying mechanisms.

Initial results from this study are showing that a wide variety of habitat types are possible. Developing marsh, fen, swamp, alvar, and prairie ecosystems have all been found on old extraction sites. Some examples of these are described and the important environmental factors controlling their development discussed.

Finally, data from current field trials set up to test techniques for speeding these natural regeneration processes are presented with emphasis on establishing tallgrass prairie and red oak stands.

Introduction

While there is a fair amount of information and knowledge regarding rehabilitation of extraction sites to agricultural or recreational types of after-uses (Yundt and Augaitis 1992; Mackintosh and Hoffman 1985), there is very little available describing methods to be used in pits and quarries for the establishment of different types of natural communities such as grassland, prairie, wetland or upland forest. With ever increasing interest by the public, industry and government in pursuing this type of rehabilitation, there is a need to determine what factors and processes are involved in naturalisation and what procedures can be developed to facilitate or speed natural regeneration. At an Aggregate Resources Research Workshop, the top research strategy recommended by the rehabilitation group was to "Document and assess previous rehabilitation efforts for extent of naturalization and integrity of ecological function" (Fraser and Ward 1995).

Few extraction sites exist in Ontario that have been deliberately restored to some form of defined native historic ecosystem and most of these are very new with little time to develop structure and function. Fortunately (for this research), there are numerous abandoned pits and quarries across southern Ontario, many having over 30 years of naturalization since abandonment. These are the "living experiments" that can be tapped into, to discover the potential of aggregate sites to become good wildlife habitat. More importantly, these sites provide

clues as to what environmental conditions should be worked into the rehabilitation plans of current and future licensed extraction sites to enable the establishment of a given type of ecosystem or habitat.

The objectives of this study are threefold: 1) to determine the types of ecosystems possible on extraction sites; 2) to identify the critical factors for success in the establishment of these ecosystems; and 3) to develop tools and techniques to facilitate or speed these naturalization processes.

For the third objective this paper will report on some results from a tree shelter experiment for red oak (*Quercus rubra*) establishment and a tallgrass prairie seedling experiment. The red oak experiment looked at the influence of two tree shelter types and two different weed control treatments on red oak survival and growth in comparison to open grown seedlings. The tallgrass prairie experiment compared the growth of 8 native prairie species either planted as plugs or sown as seed and the impact of two different cover crops on both plugs and seed.

Methods

Vegetation Sampling of Abandoned Extraction Sites

The length of each site (x) in meters was measured along one of the long pit or quarry faces. Transects across a site were located by randomly selecting numbers between zero and the site length x. Numbers were chosen until 2.5% of the distance x had been sampled. Transects were run across the width of a site at right angles to the first line. The length of each transect (y) was measured and quadrats to be sampled were located by randomly selecting numbers between zero and the transect length y. Numbers were chosen until 10% of the distance y had been sampled.

A $1M^2$ quadrate frame, divided into twenty-five 20cm x20cm squares, was assembled around the vegetation at each quadrate location. Frequency scores out of 25 were recorded for all plant species, including bryophytes and lichens, which had above ground parts extending into the quadrate. This was done for all plant parts between ground level and 1 meter above ground and then repeated for plant parts of all species overhanging the quadrate between 1 and 2 meters, between 2 and 3 meters, and over 3 meters above ground to get an estimate of the vertical structure of the community.

Abiotic Measurements Taken at Abandoned Extraction Sites

A frequency score out of 25 was also given to certain abiotic features in each quadrate including: four diameter classes of stones, exposed solid rock, bare ground, fallen woody debris, and standing or flowing surface water. Other physical measurements were taken at each quadrate including: slope angle, slope aspect, height above the water table, mean and variability in depth of soil organic layers, mean and variability in total substrate depth to bedrock (quarries only), presence of marl, mean and variability in depth of surface water. Specific notes were also made on recent disturbances and on the relative location of the plot. A composite soil sample of the top 10 cm (or less if depth to bedrock was < 10cm) was taken from 5 sampling locations within each quadrate. Soils were measured for pH, texture, organic content, total N, extractable P, and exchangeable Mg, Ca and K. Site level measurements included years since site abandonment (determined by historic air photos, reports, and knowledge of landowners) and a scoring of the type and extent of surrounding land uses.

Data Analysis

Vascular plant species encountered in the quadrates at each site were used to calculate a mean coefficient of conservatism (C) and a floristic quality index (FQI) using the Floristic Quality Assessment System for

Southern Ontario (Oldham et al. 1995). This system assigns a numerical value between 0 and 10 to each species based on it's habitat fidelity or specificity. Species from a wide variety of plant communities, including disturbed sites score low whereas species found only in a narrow range of conditions with low tolerance to disturbance score a 9 or 10.

Plant frequency data and corresponding abiotic data are being examined using Canonical Correspondence Analysis (CCA). This is one of a group of multivariate techniques used to detect the main pattern in the relations between species and the observed environment. CCA can deal simultaneously with many species and many environmental variables. The species are assumed to have a unimodal response to linear combinations of environmental variables (Ter Braak and Prentice 1988).

Red Oak Establishment Experiment

Three tree shelter treatments (Tubex® shelter, Tree Pro® shelter, or no shelter) and three weed control treatments (brush blankets, glyphosate spray, or no weed treatment) were combined in a factorial design and applied to newly planted bareroot seedlings of red oak (*Quercus rubra*) in the spring of 1994 at the Uxbridge pit of Lafarge Canada. Seedlings were planted in a randomized block design with 10 trees in each replicate and six replicates for each of the 9 treatments giving a total of 540 trees.

Tallgrass Prairie Experiment

Eight tallgrass prairie species from genotypes collected in southwestern Ontario were sown as seed or planted as plugs in 3m x 3m plots at the Henderson pit (Plympton Tp.) in June 1996. The eight species were *Andropogon gerardii* (Big Bluestem), *Sorghastrum nutans* (Indian grass), *Panicum virgatum* (Switch grass), *Desmodium canadense* (Showy Tick-trefoil), *Lespedeza capitata* (Round-headed Bush-clover), *Ratibida pinnata* (Tall Coneflower), *Rudbeckia hirta* (Black-eyed Susan), and *Asclepias tuberosa* (Butterfly Weed). Five plugs of each species were planted in each of the plug plots for a total of 40 plugs per plot. The three grass species were sown at a rate of 1600 seeds per plot and the forbs were sown at a rate of 960 seeds per plot for a total of 9,600 prairie seeds per sown plot. Both plug and seed plots were sown with a cover crop of either *Lolium perenne* (perennial rye), *Avena sativa* (cultivated oats) or received no cover crop. Cover crops were sown at a rate of 30 kg/ha. There were 5 replicate plots for each planting method/cover crop treatment combination for a total of 30 plots. A randomized block design was used to assign treatments to plots.

Results

The vegetation surveys of abandoned pits and quarries are turning up a wide variety of community types. Developing marsh, fen, swamp, prairie and alvar ecosystems have all been found on old extraction sites. Some examples of these are described below.

Kerncliff Quarry (City of Burlington)

Located right at the edge of the Niagara Escarpment where it was excavated into the original cliff face, this quarry supports a surprisingly large number of both native and non-native species for such a small site (3 ha approx.). The talus and boulder piles along the three quarry faces now support 34 tree and shrub species. Ground water seepage from the base of the north quarry wall accumulates in several large marly ponds near the north and east walls as the floor is higher towards the centre of the quarry. A marsh community dominated by both *Typha angustifolia* (Narrow-leaved Cattail) and *T. latifolia* (Broad-leaved Cattail) as well as several *Scirpus* (Bulrush) species has developed here. To the west is an associated wet meadow dominated by

Equisetum variegatum (variegated horsetail) and various *Carex* (sedge) species. Both Sora and Virginia Rails have bred here successfully indicating the relatively high quality of this small marsh.

Fletcher Creek Quarry (Puslinch Tp.)

In the1930's the Puslinch Quarry Co. excavated another 17 feet out of the north end of the older Maloney quarry. Constant seepage from this deep water area now flows across the floor of the older quarry which slopes to the south. An old narrow outlet channel at the south end was blasted through the rock. A rich fen is developing on the accumulating marl deposits in this seepage zone. Fen indicator species here include *Rhynchospora capillacea* (beak-rush), *Muhlenbergia glomerata* (Marsh Wild-timothy), *Spiranthes romanzoffiana* (Hooded Ladies-tresses) and *Liparis loeselii* (fen twayblade). A snake hibernaculum among the boulders and broken limestone pavement is used by eastern garter snake, northern ribbon snake, northern water snake and the eastern milk snake.

Wildwood Pit Complex (Zorra Tp.)

These pits were opened to provide aggregate for the construction of the Wildwood reservoir dam in the 1960's and later for development of the Wildwood conservation area. The last of these pits to be extracted now supports a fen community. As with the Fletcher Creek quarry, groundwater seepage plays an important role here although Ca and Mg concentrations are not as high due to the nature of the substrate. Groundwater discharge from the base of the sand and gravel ridges on the east side of the pit flows across the floor of the pit which is gently sloping from east to west. Toward the west side the seepage merges to form a small stream and then infiltrates into the sand and gravel layer at the toe of the west pit face. The fen community includes *Muhlenbergia glomerata*, *Equisetum variegatum*, six *Carex* species, *Liparis loeselii*, *Cypripedium reginae* (Showy Lady's Slipper) and the cotton grass *Eriophorum viridi-carinatum*. The pit is the only known location for this cotton grass in Oxford County (M.Oldham pers. comm.). The exposed sand and gravel ridges are used by turtles from the reservoir for egg laying and young snapping turtles take refuge in the deeper seepage zones.

Another, somewhat older pit in this complex is developing into a shrub swamp. While it has yet to be surveyed using the methods described above, the floor is dominated by *Cornus* (dogwood) and *Salix* (willow) species. As in natural swamps, the annual fluctuations in the hydrology at this site are extreme with 1.5 m of surface water being present in the spring while only a few small pools remain at the surface by the end of June. Wood frogs use this site for breeding in early spring.

Colwell Pit (Vespra Tp.)

Portions of this ballast pit used by CN Rail were being worked in the early 1970's but older parts were extracted in the mid 1940's. Much of the droughty sandy floor is dominated by the tallgrass prairie species *Schizachyrium scoparium* (Little Bluestem). Other prairie species that have colonized this site include *Andropogon gerardii*, *Elymus canadensis* (Canada Wild-rye), *Monarda fistulosa* (Wild Bergamot) and *Asclepias tuberosa*. The finding of a small patch of *Bouteloua curtipendula* (Side-oats Grama) at this site represents a new record for Simcoe Co. (W.Bakowsky pers. comm.). Given the rarity of this native grassland in Ontario today, it is interesting to speculate on the source of these naturally colonizing plants. One possibility is that the seeds came in on rail cars or that the plants spread slowly along the railway right-of-ways. Older rail lines often harbour prairie relics (Morgan et. al 1995). Another source could be the remnant native prairie which is still present on the old glacial lake shoreline at Fort Willow, 5.5 km away (W. Bakowsky pers. comm.). Regardless of source this large, open site with a rapidly draining, low nutrient substrate appears suited to these species. Ontario Hydro workers have indicated that garbage was often dumped at this site in the past and later set on fire by local youths. Certainly there is a strong connection between the maintenance of tallgrass prairie and periodic burning (Morgan et al 1995).

Old Point Anne Quarry (Thurlow Tp.)

Point Anne has a long history of quarrying and cement production going back to the turn of the century. Species from the surrounding natural alvar community have moved back onto the floor and the long low mounds of broken stone that are found in this very old quarry. Alvar species colonizing this site include *Juniperus virginiana* (red cedar), *Quercus macrocarpa* (Bur Oak), *Rhus aromatica* (Fragrant Sumac), *Penstemon hirsutus* (Hairy Beard-tongue), *Ranunculus fascicularis* (early buttercup), and *Bouteloua curtipendula*. As well, there are extensive thick crytogammic crusts on the floor of this quarry which are typically found on the exposed rock of natural alvars in Ontario (Reid 1996). These crusts may have an important role in nitrogen fixation, water retention and ultimately seedling germination and establishment (Casper et al. 1998). The hydrologic regime at this quarry is similar in many ways to the shrub swamp pit at Wildwood. Spring water levels are almost a metre deep in many areas of the floor with only the rocky mounds and talus remaining above water. By July the floor is dry and the very shallow soils are baked in the heat. This annual cycle of flooding followed by extreme drought may be critical in the maintenance of some alvar communities (Reid 1996; Catling and Brownell 1995).

A summary of the sites discussed above, the total numbers of native and non-native vascular plant species found in the quadrats, and the Floristic Quality Indices are shown in Table 1.

Site and Location	**Age Since Abandonment (approx.)**	**Major Ecosystem Type Developing**	**# Native Species**	**# Non-native Species**	**Floristic Quality Index ***
Wildwood Pit Zorra Tp.	25 years	Fen	80	39	25.48
Colwell Pit Vespra Tp.	25 years + portions back to 50 years	Prairie	55	18	28.56
Kerncliff Quarry Burlington	40 years	Talus Forest, Marsh and Wet Meadow	96	61	25.54
Fletcher Creek Quarry Puslinch Tp.	60 years + older portions	Fen and Alvar	73	21	31.15
Point Anne Quarry ThurlowTp.	65 years	Alvar	93	22	37.77
Deliberately Rehabilitated Sites (Age is years since rehabilitation done)					
Tp. of Uxbridge pit Uxbridge Tp.	2 years	Forb Meadow	17	25	5.38
Glen Major Pit Uxbridge Tp.	10 years	Forb Meadow	36	39	11.52

Table 1 **Site History, Location and Results of Floristic Quality Assessment based on Presence Absence Data from Vegetation Sampling Transects.**
*** Floristic Quality Index calculated to include non-native species**

Also included in Table 1 for comparison purposes are two younger, deliberately rehabilitated pits surveyed in the same manner as part of a study on naturalizing pits on the Oak Ridges Moraine (Dance & Browning 1998). The number of non-native vascular plant species exceeded the number of native species in the younger, deliberately rehabilitated pit sites (Table 1). Abandoned sites in the 25 to 50 year age range had approximately twice the number of native species compared to non-native species. The greatest overall species total (157 species) occurred in the quadrats at the 40 year old Kerncliff quarry. The two oldest quarries had fewer overall species but native species outnumbered non-natives by almost 4 to 1. The Floristic Quality Index (FQI) is very low in the youngest, deliberately rehabilitated site but doubles approximately every 10 years until about 25 years of age. After that age the FQI continues to increase but at a slower rate.

Multivariate analysis of the plant data and corresponding abiotic data collected from the quadrats is still on-going. However, in most cases to date the site hydrology is proving to be the main factor influencing the development of vegetation communities on abandoned extraction sites. This is illustrated in a CCA ordination diagram for data from the Fletcher Creek quarry shown in Figure 1. In the analysis two axes are chosen which account for the greatest amount of variation in total species composition between quadrats. The aim is to locate quadrats (or sites) that are similar in species composition close together on the axes and have quadrats that are dissimilar farther apart. Species are represented by diamonds corresponding to their approximate optima between the axes. Environmental variables are represented by arrows indicating their direction and rate of change. In this case quadrats with surface water ≥ 10cm deep were removed from the analysis as they were very different in plant composition from all other quadrats. Even with that adjustment, the x-axis which

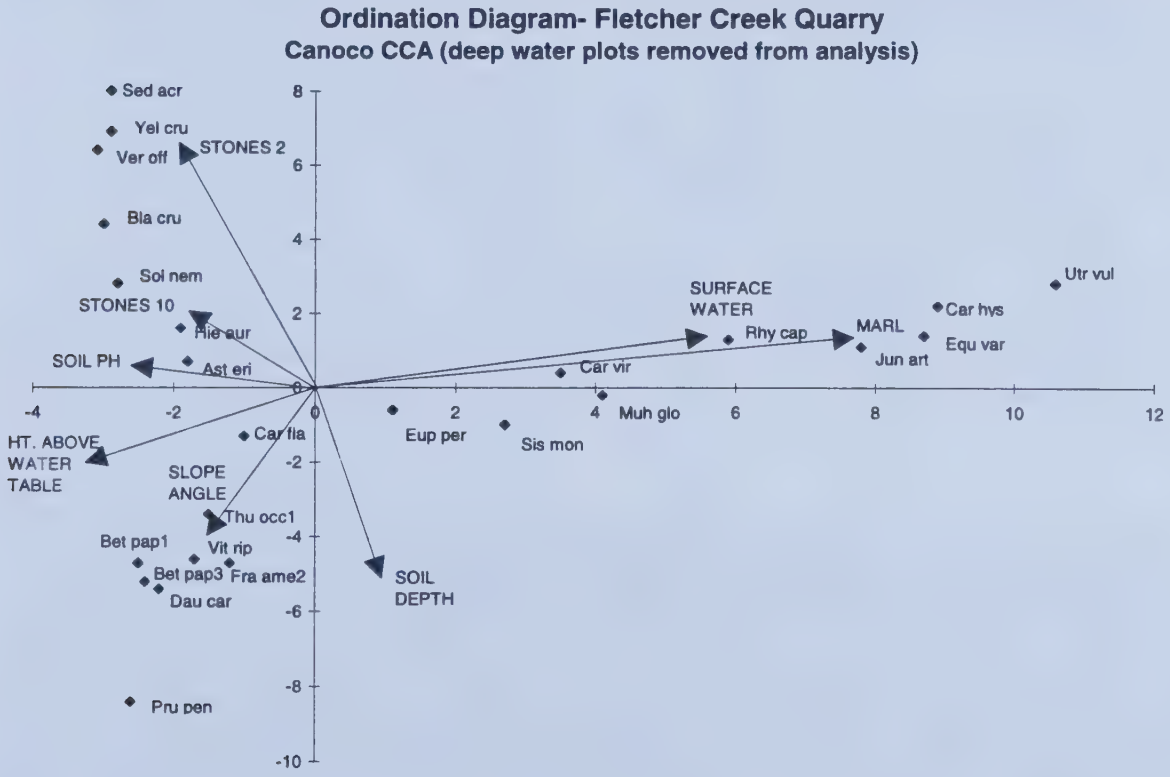


Figure 1 **Ordination Diagram for the Fletcher Creek Quarry. Axes 1 and 2 from a Canoco CCA Analysis with some Species Optima and major Physical Variables shown. (Quadrats with ≥10cm surface water depth were removed prior to analysis).**

explains the greatest amount of variation in the data is strongly related to the presence of surface water, marl (the calcium carbonate deposits which precipitate out of surface waters) and the height above the water table. All these arrows are relatively long and closely parallel the x-axis (Figure 1). Soil pH is also associated with this first axis. The y axis which explains the next biggest chunk of variation in plant composition between quadrats is related to soil depth and stoniness. Slope angle was also related to this second axis as vegetation on the sides of mounds and the main talus generally had deeper substrate to root in than plants on the gently sloping quarry floor.

Red Oak Establishment Experiment

The influence of tree shelter and weed control treatments on red oak seedling survival is shown in Figure 2. Seedling survival after 4 years ranged from 93% for those in Tubex shelters used in combination with brush blankets, to 27% for open grown red oak with no weed control. A two-way ANOVA on the arcsine transformed percent survival data indicated that both shelter treatment ($F=37.91$; $p \leq 0.0001$) and weed control treatment ($F=11.98$; $p \leq 0.0001$) had a significant effect on red oak survival. Both tree shelter types significantly improved seedling survival compared with open grown seedlings and a Tukey's studentized range test showed no difference between Tubex and Tree Pro. Similarly, using either brush blankets or glyphosate as a weed control significantly improved survival and there were no significant differences between these two weed control methods although the brush blankets had a mean survival rate that was 10% higher than the glyphosate treatment.

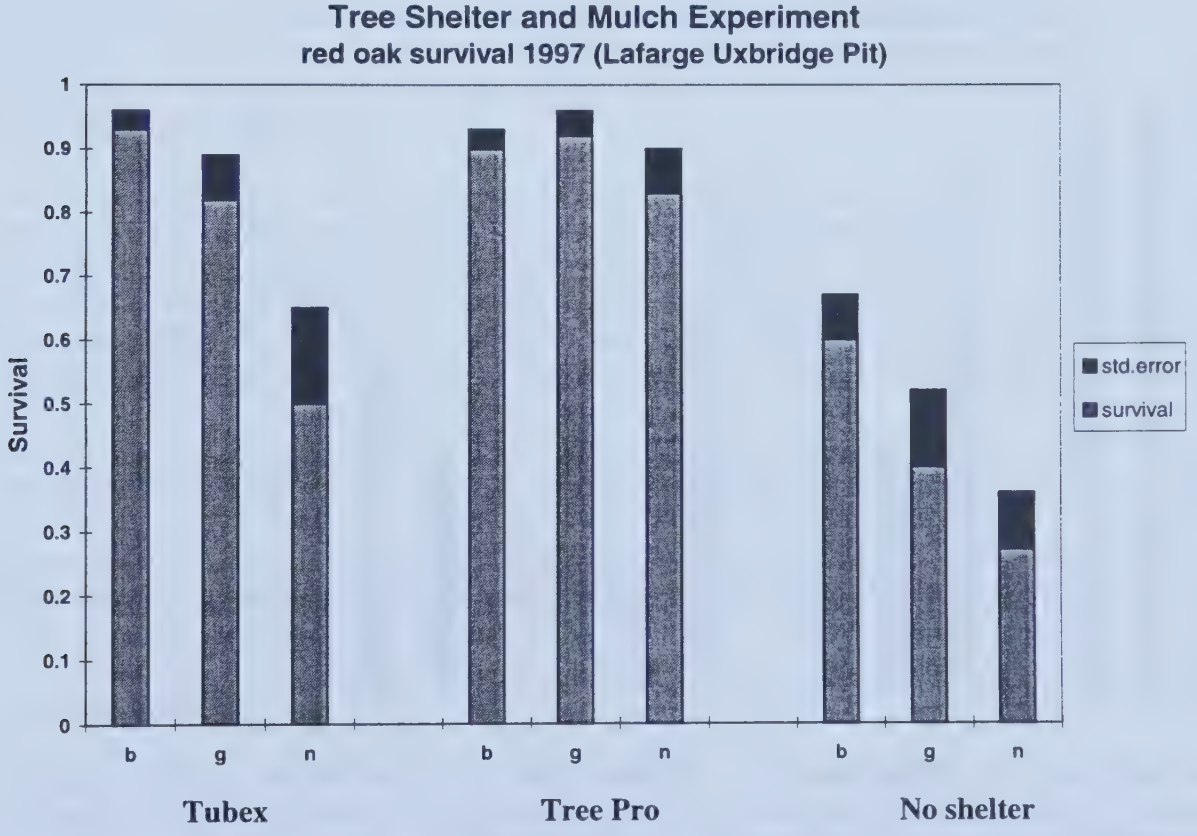


Figure 2 **The Influence of three Tree Shelter Treatments (Tubex, Tree Pro or No Shelter) and Three Mulch Treatments (Brush Blanket, Glyphosate, or None) on Survival of Red Oak Seedlings after 4 Growing Seasons in a Gravel Pit.**

b=brush blanket g=glyphosate n=no mulch treatment

Similar results were obtained for total seedling height and height increment but not for diameter increment. Many of the red oak have now grown out of the tops of the shelters and it will be interesting to see if the rapid height growth continues or slows.

Tallgrass Prairie Experiment

The perennial rye cover crop had a significant impact ($F=14.05; p \leq 0.0007$) on total weed cover in the prairie plots. Mean percent total weed cover during the second growing season was 20.4% in the no cover plots, 15.6% in the oat cover plots but only 3.6% in the perennial rye cover plots. In spite of this, cover crop treatment had no effect on plug survival. This points out the advantage of using plugs in prairie restoration projects. Large plants get a bigger head start on the weed species and are less likely to be out-competed. In the case of the seeded plots there was a significant interaction term between species sown and cover crop for seedling frequency ($F=2.76; p \leq 0.0018$). This indicates that the impact of cover crop varied depending on the species sown. The impact of cover crop type on four of the sown prairie species is shown in Figure 3. These species had different responses to cover crop. There was no impact of cover crop on seedling frequency for *Andropogon gerardii* but an increase in seedling frequency for *Asclepias tuberosa* and especially *Desmodium canadense* when sown with a perennial rye cover. The opposite response was seen in seedlings of *Rudbeckia hirta* which had the highest frequency in the no cover plots.

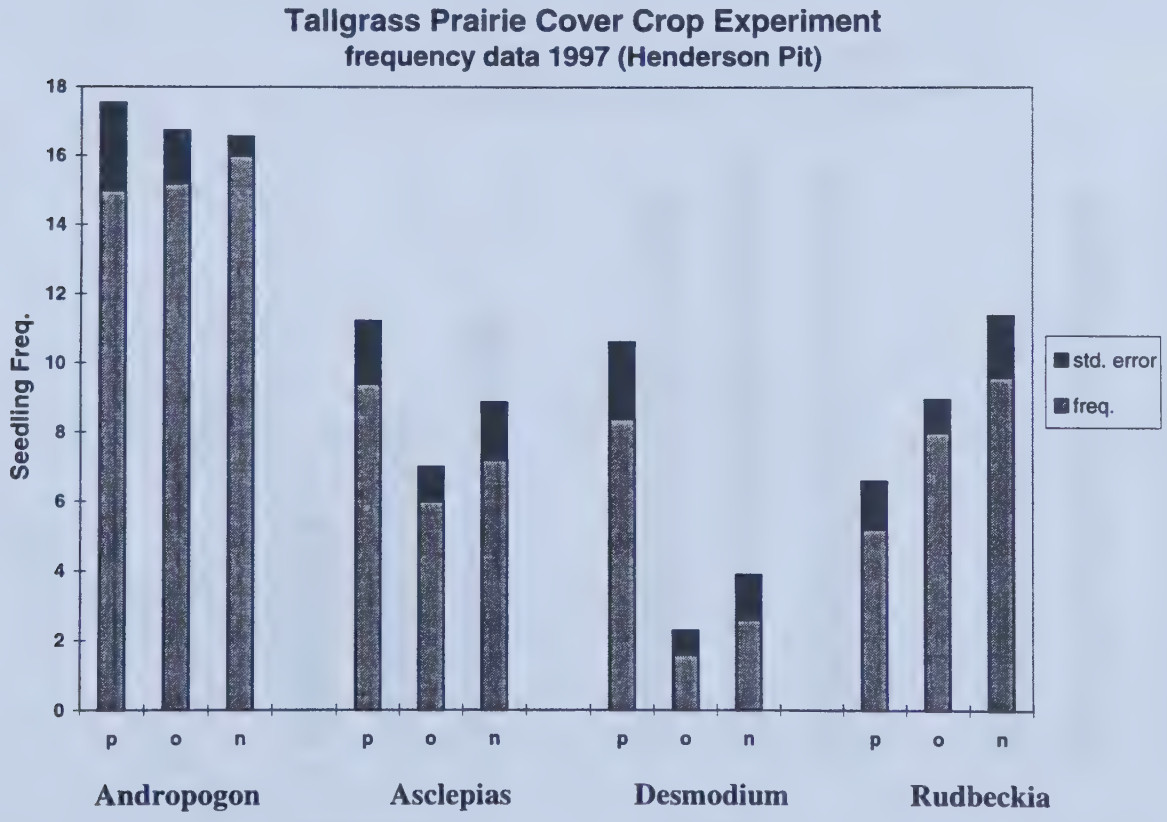


Figure 3 **The Influence of three Cover Crop Treatments (Perennial Rye, Oats or None) on the Seedling Frequency of four Sown Prairie Species during the 2nd Growing Season in a Gravel Pit.**
p=perennial rye o=oats n=no cover crop

Discussion

These results demonstrate that the potential is there for extraction sites to become good wildlife habitat and to support unusual and even rare native Ontario biotic communities. There is an important role for natural regeneration in the rehabilitation site plans of current and future licensed sites. It is critical to create the right physical conditions. The sites described above were abandoned ones that had no deliberate plantings done. However, they were left in such a way that the environment was suitable for certain groups of native species to colonize successfully.

One of the key elements influencing the successional patterns is the site hydrology and the related variables of topography and hydrogeology. These results points to some relatively simple structural work that can be done to direct naturalization. Groundwater seepage areas should be identified. Slope the pit or quarry floor towards these for marsh development. Sloping the floor gently away from these seepage areas should create the right hydrology for fen development. Elevation changes of only 1 or 2 meters in total across a site should be sufficient for this.

There is some indication from the results that quite long time periods, in the order of 25 years, are required for native plant communities to begin to dominate on former extraction sites, although this requires further work to confirm. It is important to start progressive rehabilitation early and to develop techniques for speeding the naturalization process. It appears to take 20 to 30 years for significant colonization by tree and shrub species in gravel pits on the Oak Ridges Moraine without active management (Dance and Browning 1998). Use of tree shelters, especially in combination with weed control, may be an answer for the rapid establishment of a native hardwood cover. The work by Ursic et al. (1997) on quarry faces points to the building of a suitable talus and the planting of white cedar (*Thuja occidentalis*) in this talus as a means for speeding development of a native cliff community on quarry walls.

The importance of maintaining corridors to surrounding natural areas for facilitating native plant colonization is demonstrated in the cases of the Colwell pit and the Point Anne quarry. Creating the right physical structure on site may not be enough without these linkages. Tallgrass prairie is such a rare ecosystem in Ontario now that in most locations there will be no prairie seed in the seed rain falling on a site. Plugs of prairie plants grown from local genotypes can be used effectively on pits sites. The importance of weed control and cover crops for direct seeding of these species has been shown. More work is needed on the relative merits of plugs vs. seed.

The Floristic Quality Assessment system for Southern Ontario provides a useful tool for comparing different sites and different rehabilitation strategies, and for tracking the progress of individual sites through time.

Next steps in this research will include developing and linking site level predictive models for naturalization to landscape level models of changing land use patterns to guide future planning and resource management.

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