University of Guelph Arboretum Gravel Pit Rehabilitation

A 40-Year Research and Demonstration Project

Report on Baseline Research Findings

University of Guelph Arboretum
March 2022

Introduction

The University of Guelph Arboretum was established in 1970 on nearly 400 acres of land that included agriculture, wetlands, old growth forest and in one area, a former gravel pit. The gravel pit site was actively rehabilitated over three years from 1976-1978. After this time, it was largely left to naturalize. Forty years later, with support from The Ontario Aggregate Resources Corporation (TOARC), a research team, composed of a graduate research assistant and several undergraduate students with support of faculty and Arboretum staff members, began studying the site to assess the effectiveness of the rehabilitation and naturalization process, including the changes in woody plant species (planted, naturalized, and introduced) over this period. This research has substantive implications for understanding naturalization at this aggregate site in the Arboretum, and naturalization efforts in general.

This research project sought to address the following questions:

1) What are the major changes that have occurred in terms of woody plant survival, abundance and colonization over the last 40 years as the site has naturalized?

2) How can we continue to improve the site in terms of integrating it into the wider habitat matrix for the benefit of native biodiversity?

3) What findings can we take away that could apply to similar locations?

This research provides insight into the relative success of specific woody plant species in the rehabilitated gravel pit area, measuring the changes in their abundance and distribution in the site after forty years. In addition, our findings emphasize the effects of the naturalization process and provide a framework for continued research, education efforts and future monitoring of the site. Summarized below are the results of the research conducted in 2021 at the reclaimed gravel pit area including an overview of the research project, summary of results from the woody plant inventory and soil analysis, and an overview of changes in policies affecting the site. In addition, recommendations and next steps for continued research and education from this rehabilitation project are included.

The Research Project

Planning for the gravel pit rehabilitation, which had been part of the Arboretum's original master plan, began in 1976. Land surveys were conducted, inventories for plant and animal diversity taken, and final site maps created (Figure 1). Grading of slopes with the addition of soil amendments in the spring of 1977 prepared the site for planting between 1977 and 1979. Over this three-year period, 90 woody plant species were planted between the 4 regions of the gravel pit. A variety of woody plant species, materials and methods were used. The methods included direct transplant from stock at local nurseries, direct seeding, and planting of rooted and unrooted cuttings propagated in The Arboretum's greenhouses. Some of the plant species selected were those recommended at the time for rehabilitation, some for commercial purposes such as forestry and agriculture, and others were chosen for ornamental value or benefit to wildlife. The primary goal of the rehabilitation was to create a living demonstration of trees and shrubs that can withstand the conditions of pits and quarries to inform reclamation options for similar sites. Over this time period The Arboretum's research coordinator, Sarah Lowe and manager of the project took detailed notes on the ongoing maintenance and survival of species.

As per design, when the project was finished in 1979 the site was left to naturalize. The collection would not be formally addressed again by arboretum staff for 40 years, except for occasional mowing and maintenance along the collection trail running through the site, and in 1996 when the site was awarded the bronze plaque by the Ontario Stone Sand and Gravel Association.

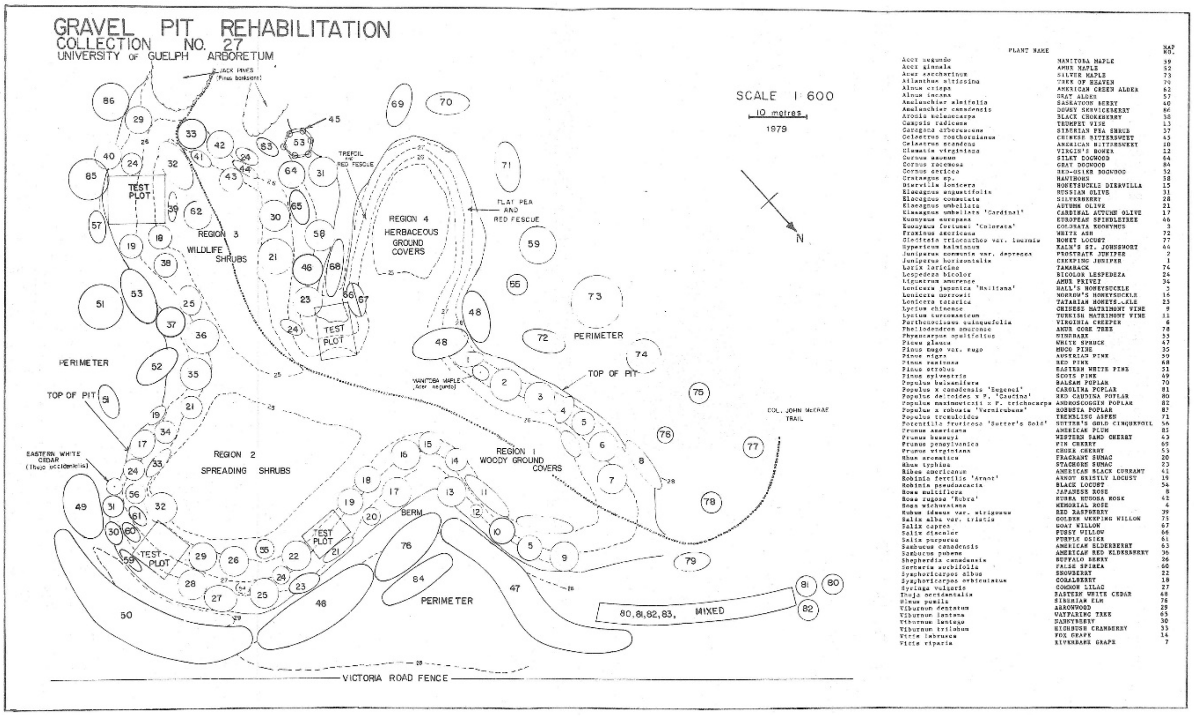

Figure 1: Original site and planting map for the Gravel Pit Rehabilitation Collection (1978).

In January 2021, Arboretum staff began to assess archival materials from the 1976 Gravel Pit Rehabilitation Project. Ian Murphy, Arboretum project research assistant and recent University of Guelph Biodiversity BSc Graduate, led the digitization and organization of original planting lists, maps, and detailed notes to generate a clear record of the historic rehabilitation effort. In reviewing the original research notes it was found that, like other rehabilitation projects of this era, many of the plants used, (e.g., autumn olive (*Eleagnus umbellata*) and glossy buckthorn (*Frangula alnus*)), would not be recommended today due to their tendency to become invasive. It was also found that not all species in this rehabilitation experiment were planted in a way that could provide systematic comparisons. For example, some species were planted abundantly whereas others, such as gray dogwood (*Cornus racemosa*) were planted in only a single location. In addition, information about planting conditions including specific amendments like nitrogen tablets that were occasionally added were either not adequately recorded or lost in the archives after the project was completed.

Although project records were incomplete, the research team was able to assemble baseline planting lists to complement original planting maps. These documents enabled the creation of a novel geographic information system (GIS) that proved valuable for both the identification of original planting locations on the site, and for the collection of new woody plant data recorded during the inventory completed between May and August 2021. In addition to detailed geotagging of original, and new woody plants on the site, a soil assessment and quadrat-based vegetation survey of woody and herbaceous species was completed by summer researcher interns Casey Howard and Ceilidh Tomljenovic for a more complete assessment.

Summary of Results

A. Inventory of Woody Plants

One of the primary objectives of this investigation was to assess the presence and abundance of the original plantings in the gravel pit. The goal of the inventory was to understand what individuals and/or species have survived, which ones died out, and which species from this experiment might be beneficial to reclamation efforts at similar sites. After the completion of the inventory, it was found that many of the original plantings have survived since the last survey in 1979. The analysis indicated:

- 250 individual trees, shrubs, and vines from the original planting were identified, comprising 53 of the original 90 species planted.
- The majority of surviving species (41 of the 53) show signs of self-regeneration and expansion beyond the original planting area. The remaining 12 species are either decreasing or maintaining their overall level of abundance.
- Five woody plants appear to have increased the number of individual stems either by spread or natural colonization from outside the site. These species are gray dogwood (*Cornus racemosa),* staghorn sumac (*Rhus typhina*), autumn olive (*Eleagnus umbellata*), tatarian honeysuckle (*Lonicera tatarica*), and black locust (*Robinia pseudoacacia*).
- Some of the large trees still found on site are *Acer negundo* (Manitoba maple), *Acer saccharinum* (Silver maple), *Ulmus pumila* (Siberian elm), *Thuja occidentalis* (Eastern white cedar), *R. pseudoacacia (Black locust)*, and several *Populus* species (*e.g., P. deltoides, P. balsamifera*). These individuals make up most of the upper canopy in the gravel pit today.

The figure below summarizes the data related to the original woody species planted that are still found on the site. This figure demonstrates how many plants of each species are from the original planting and how many are new growth, highlighting the variable rates of survival and success of these plantings.

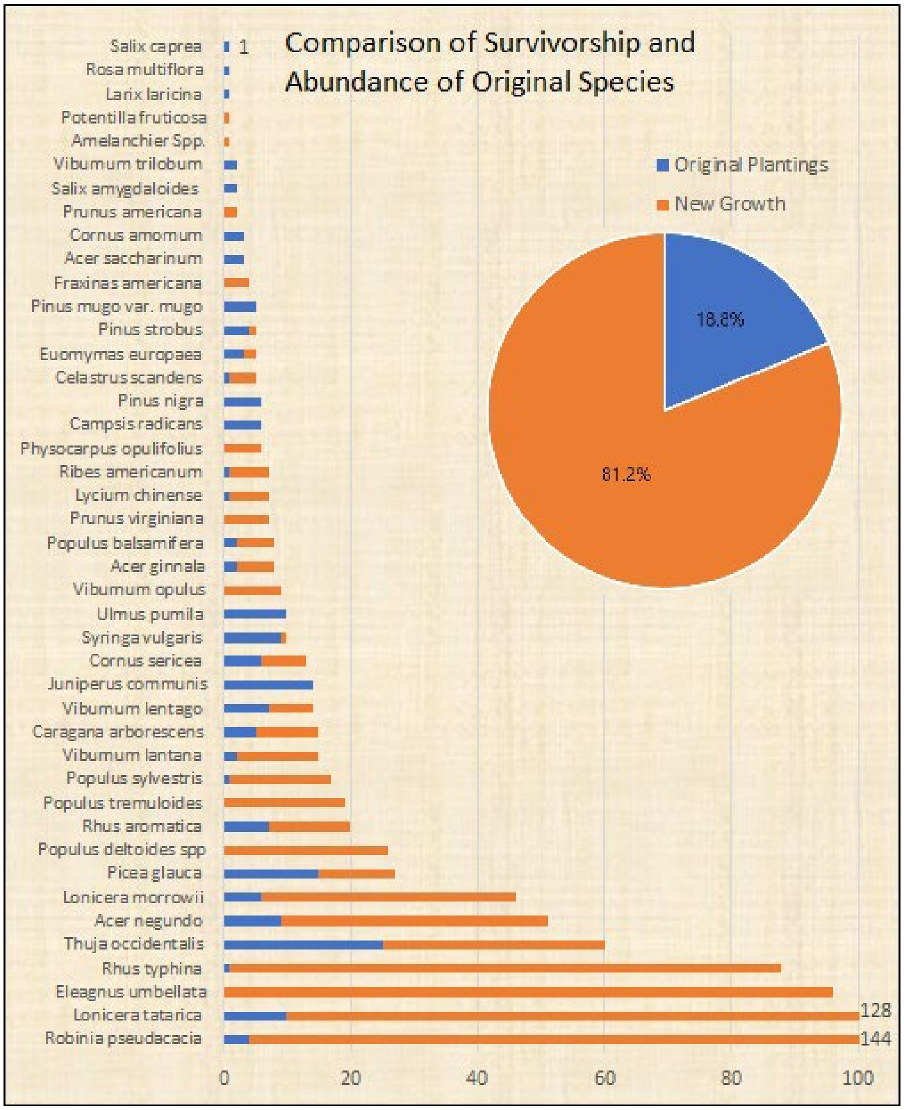

Figure 2: Abundance of remaining plants compared to the number of new individuals planted for the original species included in the Gravel Pit Rehabilitation Collection.

Figure 2 displays a portion of the surviving species previously mentioned, excluding those whose abundance could not be accurately measured due to propensity for suckering and/or lack of older stems. Of the 43 species included there was an average of 4 original plants per species, however the most common number of surviving original plants overall is 0 and 1 respectively. Most of the current abundance of the original species is representative of new growth (81.2%), either from spread of original plants, or colonization from outside of the site by local populations. Many of the original species have only managed to survive and have had little to no recruitment. As will be seen in the following figures, most of the vegetative cover in the gravel pit today is a result of the rapid growth of just a handful of the original planted species, and successful colonization of new species in the site.

To evaluate the major changes in distribution that have occurred over the last 40 years at the site, a new site map was generated to compare the original and current gravel pit woody plant diversity.

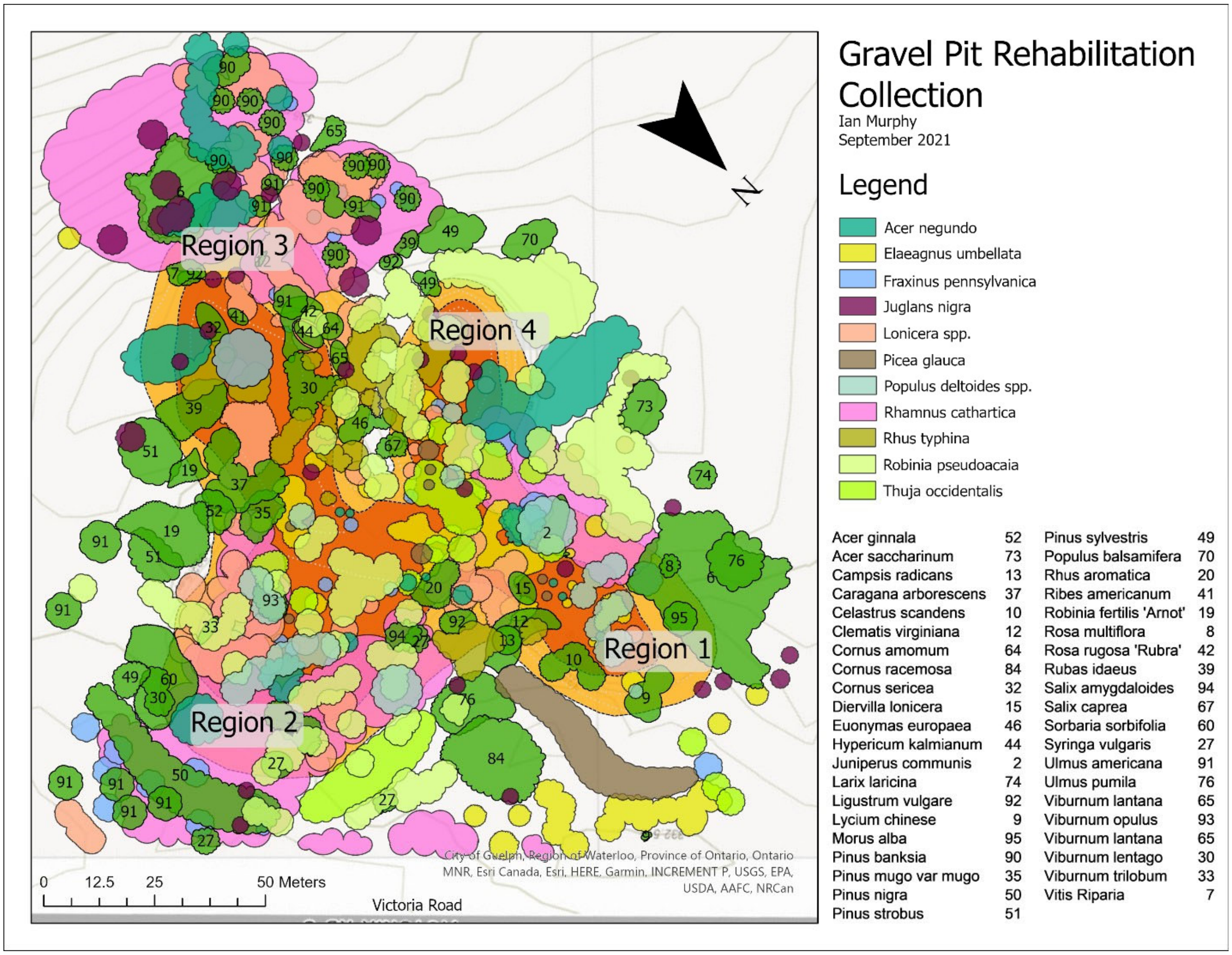

Figure 3: Map of the distribution of woody species in the Arboretum's rehabilitated gravel pit collection (2021). The most abundant species are uniquely colored, with the remaining species in green and labeled according to the original planting maps.

The new site map (Figure 3) appears in stark contrast to the original produced in 1978 (Figure 1). Many of the original plantings have died out or are shrouded by the growth of new species in the site, or by the few original species that fared disproportionately better in the rehabilitation process. Species such as Manitoba maple (*Acer negundo*), black locust (*Robinia pseudoacacia*) and autumn olive (*Eleagnus umbellata*) have spread beyond their original planting locations, and now visually dominate the site. Other species such as common buckthorn (*Rhamnus cathartica*), a naturalized woody invasive species, have seeded in and now occupy much of the upper and middle story of the gravel pit canopy.

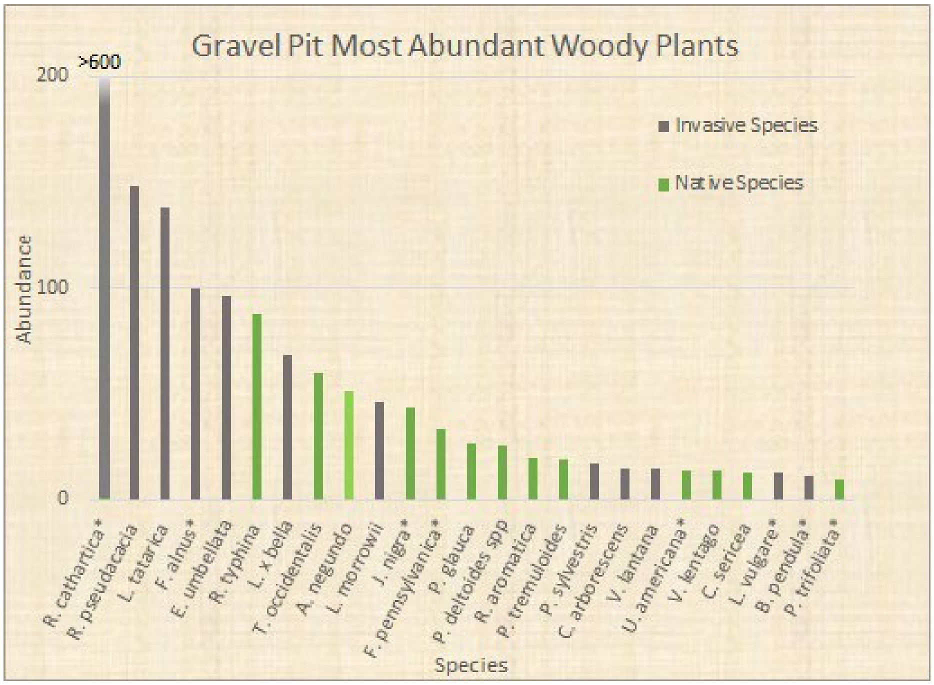

Figure 4: The 25 most abundant woody plant species in the gravel pit rehabilitation collection today. This chart includes both original species of the rehabilitation planting, and new species in the site (*). Columns are differentiated based on the plants being introduced (invasive) or species native to this region.

Figure 4 summarizes the structure of the gravel pit today in terms of the most prevalent species of plants:

- The site is now dominated by common buckthorn (*Rhamnus cathartica*), followed by several other invasive species. However, many of the original plantings appear in the 25 most abundant species, including several native species such as staghorn sumac (*Rhus typhina*), and Northern white cedar (*Thuja occidentalis*).

- There are several native trees that were not included in the original planting but are now found on site, including black walnut (*Juglans nigra,* n=46), green ash (*Fraxinus pennsylvanica*, n=20), and the common hop-tree (*Ptelea trifoliata*, n=10).

- Native trees are greatly outnumbered by introduced or invasive trees that colonized the site. Introduced plants proportionally make up ~41% of the woody species on the site, yet in abundance they represent over 1256 of the 1730, or 72.6% of individual plants identified on the site.

The difference in these proportions, specifically the high abundance of several species results in low evenness of the species on the site, an important metric of biodiversity. Additionally, species richness, or the number of unique species, has not dramatically changed from the time of the original restoration event, decreasing from approximately 90 woody species in 1979, to 81 in 2021, albeit with a large turnover of species in this community. This decline in species count should not be surprising considering that many mature forest types surveyed in our region do not support the elevated levels of species richness seen in the planting of the gravel pit (Bell et al. 2016).

B. Soil Sampling

To provide a new comparison for the original reclamation efforts, several soil samples were taken from the site in late August in regions 1 through 4 of the gravel pit, and two from the adjacent old-growth forest Victoria woods to act as a control site for comparison.

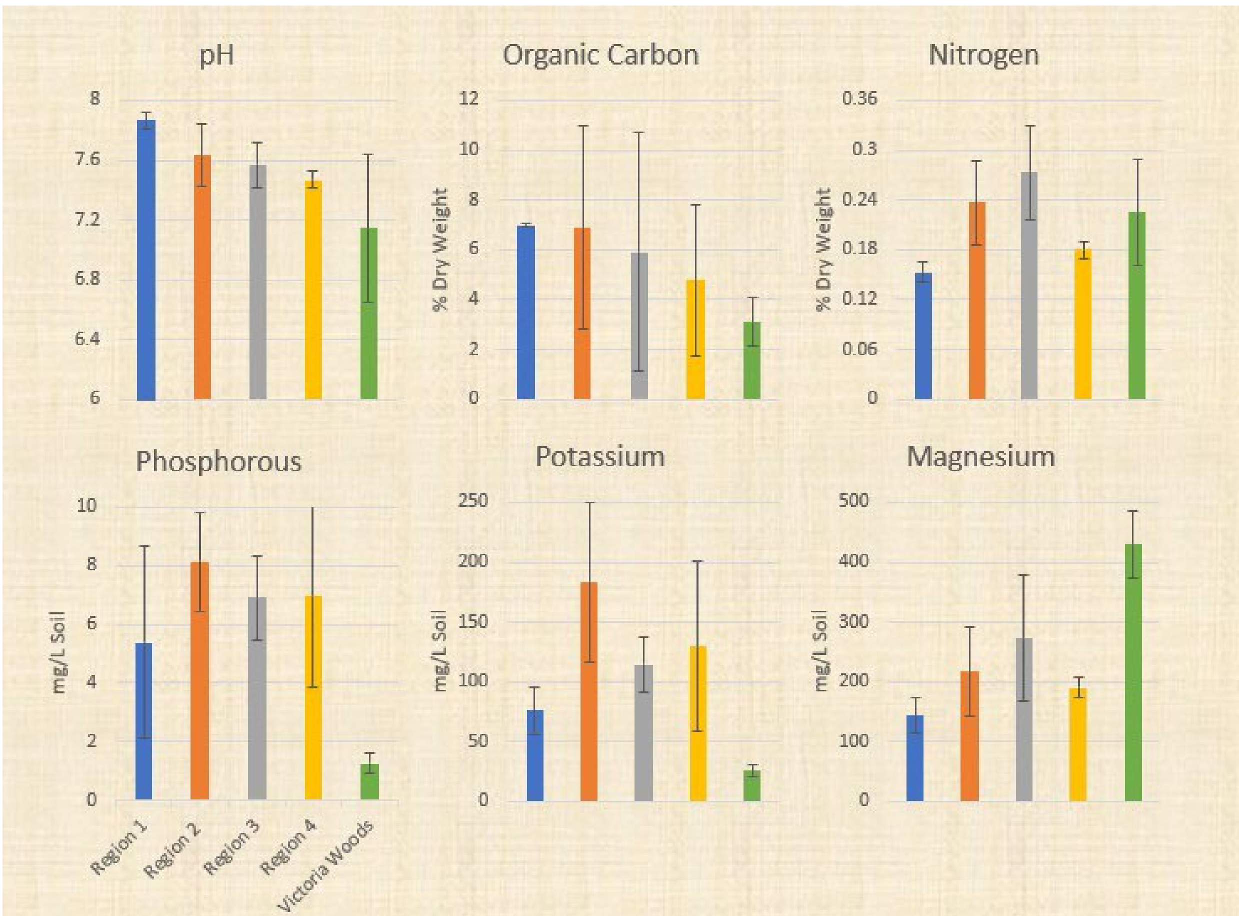

Figure 4: Results from the soil inventory conducted in August 2021 (Average +/- Standard Deviation, n=3 for regions 1-4, n=2 for Victoria Woods). A total of 14 samples were collected, 12 from the restored gravel pit and 2 from Victoria Woods. Measurements for relative pH, organic carbon content, nitrogen content, phosphorous, potassium, and magnesium were taken.

While some of these measurements of soil nutrients and pH (Figure 5) indicate little variation between the different regions of the gravel pit, and between the gravel pit and Victoria woods, significantly higher values of key plant nutrients phosphorous and potassium exist at the gravel pit compared to Victoria woods. This is likely the result of the more complete plant community in Victoria woods consuming any available amount of these nutrients, leaving little freely available in the soils. Other significant differences include the variation in both nitrogen, and magnesium among sampling sites where regions 1 and 4 of the gravel pit have decreased nitrogen, and magnesium is increased in Victoria woods samples. In addition to the woody plant inventory conducted, these basic soil measurements serve as an important metric for comparison of the site at various points in the future.

Recommendations

Species recommended for rehabilitation plantings under current best practices for ecosystem restoration are subject to a stricter selection criterion than they were in the past (Choi et al. 2008). At the time of the original Arboretum gravel pit rehabilitation, selection of native taxa was a preference of some practitioners, but in practice both native and non-native taxa were utilized (Lowe, 1976). Common to restoration practitioners of this era, there were no assessments made to determine what non-native species had the potential to become invasive. Today, the use of native species is considered critical to sustainable rehabilitation projects and is a key message of the UN Decade on Ecosystem Restoration (Aronson et al. 2020). Therefore, plant species that are known to be non-native to this region are excluded from the recommendations that follow. In this section we will synthesize data collected on the survival and change in abundance of the 27 native woody plant species that remain from this rehabilitation effort and compare it to information relevant to the ecological and societal benefits of these species in ecological restoration.

Table 1 highlights descriptive metrics of growth and survival calculated for the original species planted in the gravel pit. The MCE (Multi Criteria Evaluation) score demonstrates the direction and magnitude of growth in terms of abundance for the surviving species. MCE < 0 indicates a decrease in the number of individuals, MCE = 0 indicates no mortality or growth, and MCE > 0 indicates recruitment of that species in the pit, either by the plants originally introduced, or by propagules outsideof the site. Species with an asterisk in the place of an MCE score had insufficient data on abundance to calculate the relative growth rate and mortality, however anecdotal observations on growth and spread qualify them for consideration. In addition, information regarding current and previous uses in rehabilitation efforts, as well as descriptions on habitat preferences and tolerances to different soil conditions, drought, temperature and levels of sun are included. Many of the 27 species evaluated have been used for rehabilitation at different locations either in Canada or the United States, and the survival and growth of these species in the gravel pit is reflective of this. There are likely several factors influencing the success of these species in disturbed sites, such as their ability to tolerate drought, temperature extremes and specific soil conditions. Several species listed here are considered “pioneer” or “early successional” species that take advantage of recently disturbed locations such as *Juniperus virginiana* (Anderson, 2003). Natural history traits such as those mentioned above provide context when assessing results of both the MCE metric and survival rate, which reveal that some plants have fared better than others at this site.

Table 1: Comparison of surviving gravel pit rehabilitation plantings of native origin for recommendation. This matrix compares values of mortality rates, and a multicriteria evaluation (MCE) score that is the sum of mortality and growth rates between 1979 and 2021, followed by its legend.

Species	Habit	Tolerance	Soils	Benefit for Wildife	Reccomended use for Rehabilitation	Hardiness	Survl. (%)	MCE
Viburnum trilobum	D, Shrub	D, T, LN, FS/S	M	P, F, B - many birds and mammals	Not widley assessed	Zones 2-7	9	-1.8
Cornus amomum	D, Shrub	S, FS/S	O, M, A	P, F, B - many birds and mammals	Artificial wetlands	Zones 5-8	30	-1.5
Larix laricina	C, Mdm. Tree	T, FS	W, A	B, F - birds, mammals	Revegitating disturbed peatlands	Zones 0-9	33	-1.3
Celastrus scandens	D, Vine	LN, FS/S	W, S/R	P, F - birds and mammals	Not widley assessed	Zones 3-8	14	-1.1
Cornus sericea	D, Shrub	D, FS/S	O, M, Most	N, B, F - deer, birds & sml. mammals	Stream bank rehabilitation, mine sites	Zones 3-8	30	-1.1
Juniperus communis var d.	C, Sml. Shrub	D, T, FS/S	S	N, F - birds, sml. mammals	Long-term restoration at high latitudes	Zones 2-7	100	-0.8
Pinus strobus	C, Lrg. Tree	D, T, FS/S	M, R, A	N, F - birds (bald eagles), mammals	Stabalizing strip-mine spoils	Zones 3-8	80	-0.2
Acer saccharinum	D, Lrg. Tree	D, FS/S	W	N, B, F - birds, sml. mammals	Strip mines, other disturbed areas	Zones 3-9	100	0.0
Campsis radicans	D, Vine	D, FS/S	Most	P, H, F - hummingbirds, insects	Not widley assessed	Zones 4-9	100	0.0
Ribes americanum	D, Sml. Shrub	FS/S	M, B	F, B - songbirds, sml. & Lrg. mammals	Not widley assessed	Zones 3-6	25	0.0
Salix amygdaloides	D, Mdm. Tree	FS	M	B, N - Large mammals, many birds	Stream and bank stabalization, habitat	Zones 1-7	100	0.0
Thuja occidentalis	C, Mdm. Tree	D, FS	M/B	N, F, B - deer, hares, birds	Reforestation in wetland sites	Zones 1-8	71	0.4
Picea glauca	C, Lrg. Tree	T, FS	S, Most	N, F - many birds, larger mammals	Mine overburden, disturbed sites	Zones 2-6	88	0.5
Viburnum lentago	D, Sml. Tree	D, T, FS/S	Most	P, F, B - many birds and mammals	Not widley assessed	Zones 2-9	87	0.6
Rhus aromatica	D, Sml. Shrub	D, LN, FS/S	N, S/R	F, P, B, H - birds sml. & Lrg. mammals	Reclamation of mine soils	Zones 3-9	70	0.7
Populus balsamifera	D, Mdm. Tree	FS/S	M, S	N - birds, sml. mammals	River banks, colonizes burrow pits	Zones 0-8	100	3.0
Acer negundo	D, Mdm.-Lrg. Tree	D, T, FS/S	M, B, S, Most	B, F, N - birds, Sml. & Lrg. mammals	Riparian habitat, floodplains	Zones 2-9	100	4.7
Rhus typhina	D, Sml. Tree	D, LN, FS	N, S/R,	F, B - birds Sml. & Lrg. mammals	Not widley assessed: colonizes dist. sites	Zones 3-8	9	6.1
Cornus racemosa	D, Shrub	D, FS/S	Most	P, F, B - many birds and mammals	Mine spills, disturbed areas	Zones 3-8	100	*
Diervilla lonicera	D, Sml. Shrub	D, FS/S	R, A	P, B, N, H - moths, moose, caribou.	Not Assessed, colonizes tailings	Zones 3-7	*	*
Juniperus virginiana	C, Sml. Tree	D, T, FS	Most	N, F - birds, sml. mammals	Surface mines and other areas	Zones 2-9	*	*
Parthenocissus quinquefolia	D, Vine	FS/S	S, Most	F - songbirds, sml. mammals, deer.	Watershed protection, slopes	Zones 3-9	*	*
Populus deltoides spp	D, Lrg. Tree	D, FS/S	M, A/B	N, B - birds, sml. mammals	Reclamation, disturbed riparian sites	Zones 2-9	*	*
Populus tremuloides	D, Lrg. Tree	FS/S	M, S, A	N, B - birds, sml. mammals, deer	Restoration of disturbed sites	Zones 1-7	*	*
Prunus virginiana	D, Sml. Tree	FS/S	O, M, B	F, P, B - birds, moose, elk, deer & bear	Wildlife benefit in dist. sites, slopes	Zones 2-7	*	*
Rubas idaeus var strigosus	D, Sml. Shrub	FS/S	O, M, A	F - many birds and sml. mammals	Slow growth slope stabilization	Zones 4-8	*	*
Vitis riparia	D, Vine	FS	M	F - many birds and mammals	Not widley assessed: colonizes dist. sites	Zones 2-6	*	*

Category	Species	Habit	Tolerance	Soils	Benefit for Wildife	Reccomended use for Rehabilitation	Hardiness	Survl. (%)	MCE
Description	Scientific name	Growth form	Conditions the species can tolerate	Soil preferences	Observed uses by wildlife	Past and hypothesized uses	Hardiness Zones	Survival Rate (%)	MCE Score
Abbreviations & Examples		D - Deciduous C - Coniferous Sml. - Small Lrg. Large Tree Shrub Vines	D - Drought T - Tempurature LN - Low Nutrients FS - Full Sun S - Shade	O - Organic soils M - Moist soils S, R - Sandy, Rocky A - Acidic soils B - Basic/Alkaline soils N - Neutral pH	P - Pollination F - Food: Fruit, seeds, nuts B - Browse and forage N - Nestings and habitat	Dist. - Disturbed	Ontario (5b)	Survival of original plantings between 1979 - 2021	Mortality Rate (1979 - 2021) + Relative Growth Rate (1979 - 2021)

The data collected from this rehabilitation effort indicate that species with an MCE score of greater than or equal to 0 could be valuable planting options for similar restoration efforts in the future as they have shown adequate survival and growth in the Gravel Pit Collection to merit consideration. Therefore, the use of species such *Thuja occidentalis,* and *Picea glauca* can be recommended by the findings of this analysis, while also being supported by evidence of previous uses in mine overburden and other disturbed sites (Carey, 1993; Abrahamson and Ilana, 2015). In contrast, certain species such as *Rhus typhina* that have a high calculated growth rate in this trial do not appear to being used as extensively for rehabilitation in its native range (Zhang et al, 2009, CABI, 2022). Due to this species' prolific vegetative growth, observed ability to tolerate the harsh conditions of pit and quarries both in the Arboretum's gravel pit and where it has naturally colonized other disturbed areas, we recommend that this species be more extensively trialed in future restorations via direct transplantations or cuttings of the root and/or shoot such as was done in the pit (Lowe, 1976; Zhang et al, 2009). Other species that have a score greater than 0 and could be useful in future rehabilitation efforts are *Viburnum lentago, Rhus aromatica, and Populus balsamifera.* In addition, Manitoba maple, while native to places in the province of Ontario and naturalized due to settler planting in southern Ontario, is not considered through historical evidence to be native to the region of the gravel pit, is representative of a species that displays tolerance to the conditions of the site, and has spread to other areas of the pit, demonstrating that it could be of value in restoration plantings elsewhere (Frank & Anderson, 2009).

Next, species with an MCE score of 0 are included as a recommendation. Even though these plants may not be demonstrating recruitment at the site, many species such as *Acer saccharinum* (silver maple), have had 100% survival from the time they were planted. This indicates that although they may not be increasing in abundance, the high survival rate means they can withstand the conditions of the landscape and still provide benefits such as erosion control where they are planted. Future recruitment may also occur as the soil conditions and understory vegetation change over time.

The species that have been given an asterisk (*) in the Survival and MCE columns of Table 1 show significant signs of growth and increased abundance, so much so that it hindered accurate counts. Again, several of the species in this category such as *P. deltoides,* and *P. tremuloides* have a long history of use in restoration of degraded landscapes, whereas others including *C. 11acemose* and *J. virginiana* tend to be underutilized in rehabilitation. Since *C. 11acemose* and *J. virginiana* have been successful in this trial, and observed in other disturbed sites, further investigation into their use in restoration is warranted. This is not only due to their increased abundance and rates of survival, but also because of the potential benefits to wildlife and provisioning of ecosystem services by acting as a source for pollination and food for many different animal species. In addition to these two woody plant species listed above, many of the other plants included in this category appear to provide significant benefits for wildlife. Flowering and fruit bearing plants such as those in the genus *Cornus,* Prunus*,* and the two woody vine species *Vitis riparia* and *Parthenocissus quinquefolia* have significant potential for supporting biodiversity and ecological functioning.

Recent thought in the field of restoration ecology suggests that no single species should be the focus of a restoration event (Choi et al. 2008). Conditions of pits and quarries are too variable to have a single species, or set of species, guaranteed to thrive in every location. Reliance on a single (or just a few) species would limit the potential to support and improve ecological functioning, a key goal of gravel pit and quarry rehabilitation today (Choi et al. 2008). Loreau et al. (2001) suggest that biodiversity can act as insurance to maintain integrity in ecosystems during detrimental conditions. Hedging your bets by including multiple appropriate species in any given restoration effort can increase the odds that at least one of the selected species will survive, but it is also the beginning of a complete community. Loreau et al. (2001) show that having redundancy in the provisioning of ecosystem services by having increased diversity makes plant communities more resilient in the face of harsh environmental conditions such as those that rehabilitation efforts are supposed to address.

To align with the lofty ideals mentioned above, it is important to look beyond traditionally observed factors such as parent material and pH. This research has found that local wildlife and vegetation in or adjacent to the site has significant impacts on the success of certain plant species and overall trajectory of the naturalization process. For example, in the 1970's restoration, countless individual plants and several species were lost due to herbivory by the groundhogs (*Marmota monax*) that have inhabited the site even before the rehabilitation, finding some of the species planted to be more than palatable (Lowe, 1976). Besides avoiding losses, adopting a wider ecological approach can allow practitioners to capitalize on potential species–dependent interactions, such as insect pollinated woody plants, or the use of cavity-forming tree species like *A. saccharinum* to help support birds and small mammals in the future. Consideration of these needs is critical because for many plant species animals are responsible for the dispersion of local plant propagules and this inclusion of these interactions may have a direct benefit for local biodiversity, and the rehabilitated site. The recent spread of black walnut (*Juglans nigra*) in the site for example can be attributed to the observed caching of walnuts by squirrels in and around coniferous trees of the Gravel Pit. These relationships also provide pretext to potential trajectories for the site, as this is in part determined by surrounding vegetation, and dispersion of local propagules. By selecting appropriate species, accounting for and taking advantage of relationships that may already exist or could be facilitated at any given site can help with its integration into the wider socioenvironmental matrix; yet another consideration of practitioners today (Choi et al. 2008).

One question that could arise from this multi-species approach is how many woody species should ideally be planted? There is no definitive answer to this, as the field is still in its infancy. However, given the guiding principles of protecting ecosystems and supporting biodiversity stated by the UN Decade on Ecosystem Restoration as many species as seems appropriate in respect to the surrounding habitat matrix seems appropriate (Choi et al. 2008). A line of thought in the field of biodiversity and ecosystem functioning is that biodiversity begets biodiversity, thus it could be predicted that maximizing the diversity of suitable plants on any given site should maximize the opportunities for the diversity of animals, fungi, and other plants facilitating the site along its chosen trajectory (Loreau et al, 2001).

Reviewing this rehabilitation project after 40 years reminds us that while immediate constraints and resource availability usually determine actions on a site, shifting consideration to future-focused restoration opens the possibility for interventions at a later point in time, and the incorporation of current knowledge can improve the overall integrity of the project. Rehabilitation is not static, so a rehabilitation effort should not be considered a static, one-time event (Choi et al. 2008). Rather, revisiting sites over time to encourage continued ecosystem functioning and to mitigate the effects of invasive alien plant species is often more effective given that disturbed areas are generally more vulnerable to invasion. This also allows the development of important habitat features such as variation in stand age and condition, which is a widely used practice in the forestry sector that can increase biodiversity in certain ecosystems. Finally, an ‘ongoing’ rehabilitation approach allows for the incorporation of values systems that may change over time depending on the aims of the site, and the needs of wildlife and the local community.

Intact ecosystems provide innumerable and irreplaceable services to wildlife and humans. Shifting disturbed sites along the gradient towards healthier states in both an ecologically sustainable and acceptable fashion is a critical, long-term process (Choi et al. 2008). The results and recommendations provided above cannot necessarily be representative of the outcome in other sites due to the limited scale of the experiment. Specifically, those species that are in decline at this site might prove successful in other locations given the conditions, and similarly those that proved successful here may not be in other sites. However, the effort has provided a list of potentially useful woody plant species that could be used in meeting some of the needs of ecologically sound restoration actions.

Context Analysis

At the time of rehabilitation (1976-79), the Arboretum was a newly established research and outreach facility. The land surrounding the gravel pit was largely open fields, recently taken out of agricultural rotation to accommodate the early Arboretum collections. The adjacent Victoria Road was a small route largely outside of the city's main transportation corridor, used primarily to service the active agricultural lands and remaining gravel pits outside of the city. The City of Guelph itself was far smaller with a population of roughly 67,000 people in 1976 (City of Guelph, 2012).

Over the last 40 years the City of Guelph has rapidly increased in both population and footprint. Demographic trends across Ontario have placed the Greater Golden Horseshoe (GGH) including the City of Guelph, as one of the fastest growing metropolitan areas in North America (Urban Toronto, 2020). This growth, through the historic conversion of agricultural lands, forests, and other ecosystems into dense urban environments is placing additional pressures on the city's remaining greenspace. In response to this growth, the development of new land use policies from the provincial, municipal, and institutional levels have begun to prioritize intact greenspace in recognition of its social and ecological value. In this section, we aim to briefly summarize the context and some of the policies influencing the Arboretum and the rehabilitated gravel pit at these distinct jurisdictional levels.

The area is subject to overarching policies at the provincial level, including the Ontario Greater Golden Horseshoe Growth Plan and the "Cities to Grow" mandate, which sets targets for urbanization as well as land protection, including the Ontario Greenbelt Plan and development of complete communities (Government of Ontario, 2020). Municipal governance in the City of Guelph include the Guelph Natural Heritage Advisory Committee overseeing the Natural Heritage Action Plan, which has designated the area including the gravel pit as a wildlife corridor, and the nearby Victoria Woods as a natural heritage site. In addition, population targets for the city project a population increase to 203,000 residents by 2051. Victoria Road, now a major transportation corridor which runs adjacent to the East side of the site, is slated to be expanded in the long-term planning for the city. In addition, the provincial lands east of Victoria Road are currently for sale for residential development, which will both increase the numbers of people living in proximity and thus walking through the area, as well as increase urbanizing pressure on wildlife.

At the Arboretum, the Gravel Pit naturalization is part of the Arboretum Master Plan which guides long term development of the trails and collections of the grounds. The Gravel Pit is now bordered on the north side by the Indigenous Tea Gardens (a site managed in partnership with an Indigenous community organization which grows sage and other medicines for ceremonies), the recently revitalized Gosling Wildlife Gardens, Victoria Woods, and, to the south, the maturing Conifer collection.

There are several open questions about future policy designations and their related impacts on the area including: how will the City's natural heritage sites be managed in the future? What land use planning changes are expected for Guelph and Ontario? What might the impacts of climate change, expansion of Victoria Road, and further introduction of invasive species nearby, mean for the Arboretum Gravel Pit naturalization site?

Together, all of these changes and open questions are significant because they impact how people engage and interpret the site, as well as its connectivity to the wider ecological matrix. This in turn determines attributes such as accessibility by wildlife, and the local store of plant propagules – affecting its overall trajectory as a rehabilitation site and influencing the Arboretum's goals and objectives for this site over the next 40 years.

Conclusion

In conclusion, this research has produced a valuable comparison to the baseline planting data of the original effort, and it has provided an understanding of the current state of naturalization for the Arboretum's gravel pit rehabilitation project. It has identified a number of species with potential for restoration efforts in similar locations which can be followed by logistical questions such as what constraints might need to be overcome to make these species widely available for use by restoration practitioners, and how can we scale the production of native woody plants for restoration efforts? Its findings also provide a framework for future research as well as collection development and interpretation, and educational opportunities. This new updated inventory of the woody plants on the site will help us create a management plan for the gravel pit over the next 40 years. This might include the use of the gravel pit site for additional research studies, like investigating the effectiveness of different control agents for continuing rehabilitation problems such as invasive plant species. One area of future work will be to assess the conditions of other sites around the Arboretum including the Nature Reserve south woods hill and a 'borrow pit' adjacent to the Arboretum that are representative of rehabilitation sites in the region. Assessing these locations that did not receive the same original treatment as the 1976 Rehabilitation project will provide further context to the naturalization process that has occurred in the gravel pit and measure the validity of the practices used in this historic rehabilitation project.

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