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Reference conditions for rehabilitating mine stockpiles as novel upland ecosystems in Canada's subarctic

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Abstract

In Canada's subarctic Hudson Bay Lowlands, mining activity is creating stockpiles of processed kimberlites and other non-acid generating materials that must be rehabilitated to novel upland ecosystems dominated by native plant species. Reclaiming these piles to regionally compatible, productive and self-sustaining ecosystems first requires an understanding of edaphic factors, plant communities and soil-plant relationships on analogous natural environments. Currently, little is known about these factors and relationships on existing uplands in this region.

Vegetation and soil characteristics were sampled along a natural successional gradient of well-drained riverbank sites near the De Beers Victor Mine, Ontario, Canada. One plot per sere per site was sampled, up to three seres at each site. Isolated natural uplands were similarly examined along a 150 km east-west geological chronosequence beginning at James Bay. Two plots were samples per feature as accessibility permitted. Sampling reflected that of the forest ecosystem classification program in northern Ontario, in which (i) vegetation in a 10 × 10 m plot was described at each site, and (ii) soils were determined by describing a soil pit. Parameters of interest included vegetation structure and cover, species richness and species composition, forest mensuration (height, diameter at breast height, age) and soil physical and chemical characteristics. Descriptive statistics were calculated for all quantitative variables. Relationships among site types were analysed using cluster analysis, principal components analysis and non-metric multi-dimensional scaling.

The four objectives of this study are to (i) describe the mean and range of conditions of the observed plant and soil parameters, (ii) group sites by common plant and soil characteristics, iii) group plant assemblages in seres, and (iv) construct a set of reference conditions. This technical paper includes a representative sample of the results of the ongoing MSc thesis described above.

1 Introduction

Mine spoils are often stockpiled on the surrounding land, creating barren features of low or negative ecological value that must be reclaimed to novel, environmentally compatible and self-sustaining ecosystems. In the relatively untouched subarctic of the Hudson Bay Lowlands, Canada, the challenge of reclaiming these anthropogenic features requires knowledge of the variety of native plant species, community assemblages, and associated soil characteristics that are present on natural features analogous to mine stockpiles. Currently, there is insufficient knowledge about prospective natural analogues in this area to make informed recommendations of suitable plant and soil reference conditions for the reclamation of these barren stockpiles.

Initiating vegetation at primary succession increases entropy potential in a developing system. Accepting and working with the dynamic flux incurred by stochastic events is more congruous with natural successional processes and provides a more realistically achievable ecosystem target map, albeit less precise, than a traditional homeostatic view of a mature climax community and ecosystem (Cooke, 2004). Optimally, these possibilities are synthesised as moving targets (Cooke, 2004; Jackson et al., 2005), based on natural analogous features.

Reference conditions often focus on plant communities, as plants are one of the most obvious, measurable and desirable components of a terrestrial ecosystem. In tandem with this, targets are often mature communities (Walker and del Moral, 2003), which may be difficult to achieve or direct without active involvement.

Soils support plant growth and, like plant communities, are also obvious and measurable. However, precise emulation of key natural physical and chemical properties, those influencing vegetation type and success, may be more readily reproducible in a synthesised soil compared to a top-down approach that attempts to replicate a natural plant community directly (Urbanska, 1997). The natural heterogeneity of soils requires that a range of soil and related plant community characteristics be considered, to advise on the properties required in the growth medium to 'best' support the variety of possible future ecosystems. Here we approach ecosystem replication from the bottom up (soils), and top-down (vegetation), which will provide stronger direction for achieving plant community targets.

This is a descriptive study that documents plant and soil conditions of uplands in the Hudson Bay Lowland as they are found in nature. The goal of this study is to use this data as reference conditions that will guide the reclamation of anthropogenic features on the landscape.

2 Study

2.1 Regional setting

Mining activity is increasing in Canada's subarctic Hudson Bay Lowland in particular, and in the north in general. Officially opened in 2008, the De Beers Canada Victor Mine is Ontario's first diamond mine. Located in the Attawapiskat Basin, the open pit mine is approximately 90 km west of Attawapiskat (Figure 1). This operation alone will create approximately 530 ha of new non-acid generating uplands, formed primarily from processed kimberlite stockpiles and limestone pads. In 2007, high-grade nickel-copper-platinum-palladium deposits were discovered by Noront Resources Ltd. in the Hudson Bay Lowland near Webequie, 200 km west of Victor Mine. This has been followed by unprecedented staking in the McFauld's Lake area, commonly referred to as Ontario's "Ring of Fire" (Noront Resources Ltd., 2008). It is therefore increasingly important that relevant, dependable guides be available for creating structurally and functionally sound re-vegetated ecosystems on reclaimed stockpiles.

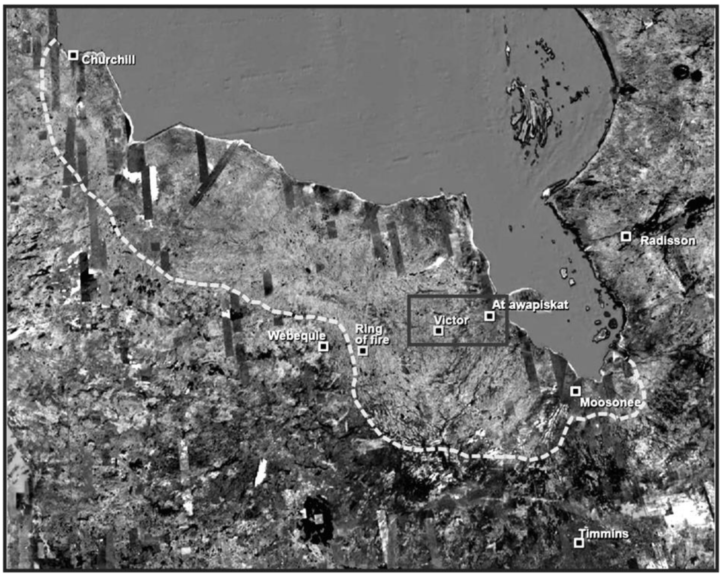

Figure 1 Location of the De Beers Victor Mine and the 'Ring of Fire' prospection region. Hudson Bay is the large water body, James Bay is the protruding water body. The Hudson Bay Lowland is outlined by a dashed line; study area is outlined by a solid rectangle (base map from Google Earth)

The study was carried out in the James Bay Lowland, northern Ontario, Canada, located in the subarctic region of the larger Hudson Bay Lowland which covers a land area of 325,000 km^2 (Figure 1). The sample area, approximately 1,125,000 hectares, extended 150 km east-west from Attawapiskat ON, on the west coast of James Bay, and 75 km north-south (82°00’W to 85°00’W and 52°30N to 53°15’N; Figure 2).

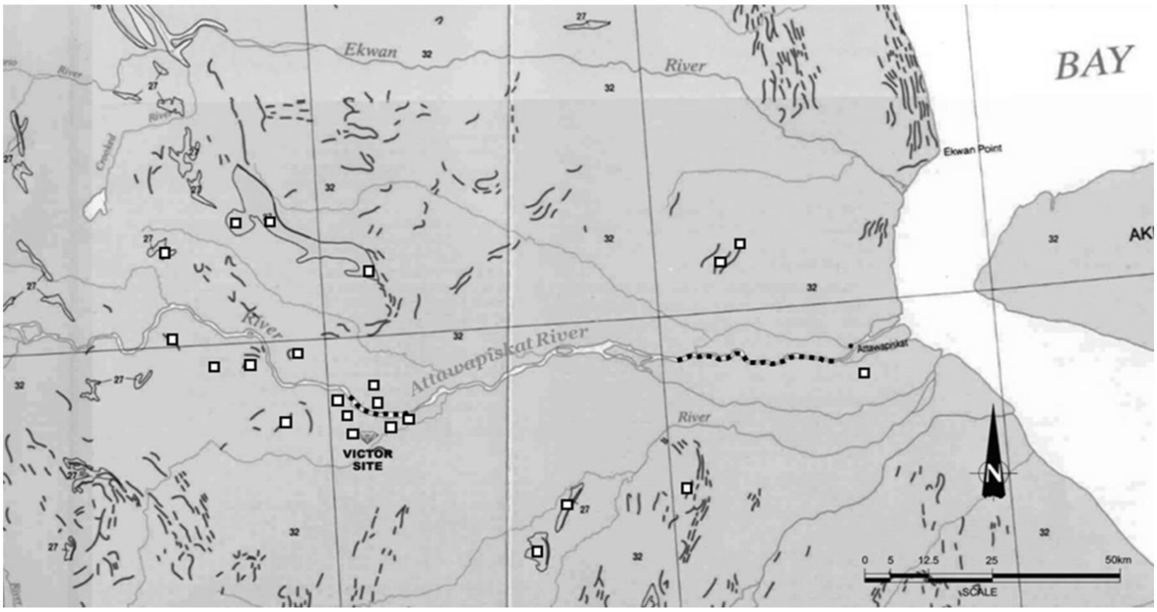

Figure 2 Location of sites on which this study was conducted. Note the dominance of peatlands (lightest grey) and the scarcity of upland landforms across this entire region. Discrete dark grey lines indicate beaches, bars or spits. Isolated enclosed areas indicate sandy or gravelly glaciomarine and marine deposits. The white area on the right denotes James Bay, in which the western half of Akimiski Island, NU, is visible

2.2 Sample sites

Two candidate natural ecosystem types were examined for the purpose of extracting and measuring key reference condition criteria: a) mineral-based isolated uplands, and b) well-drained banks of the Attawapiskat River (Figure 2).

Isolated uplands included eskers, beach ridges and bioherms (Lower Silurian relic coral reefs persisting as limestone and dolostone outcrops (De Beers Canada, 2004; Suchy and Stern, 1993). It was inferred that being mineral-based, raised and well-drained, these features potentially share physical characteristics with mine stockpiles. The isolated upland feature component of the study were primarily to investigate the variability of the mineral substrates and associated vegetation, and secondarily to investigate the potential for a chronosequence of upland vegetation west of James Bay, anticipated due to the increasing geologic age of the land from east to west as a result of continuing land emergence due to glacial isostatic rebound.

Convex sites along the river were explored for their potential to have sandy or silty textured materials, similar to the processed kimberlite containment facilities and be similarly well-drained. Riverbanks are subjected to annual erosion by ice flows, which, coupled with isostatic rebound, results in an observable chronosequence of exposed bedrock, bare soil, organic matter accumulation and successional vegetation establishment orthogonal to the river. Where possible, river sites were selected in favour of an observable successional chronosequence. To avoid pseudo-replication, one plot per sere per site was sampled, up to three seres at each site. A total of 37 river plots were sampled.

3 Sample methods

Variables of interest were the same for interior sites and sites along the riverbank. Plots were located on local area maximum elevation and presence of common, homogenous vegetation community types on site-typical geomorphic surfaces (Darmody et al., 2004). A homogeneous plant community type was judged to be similar presence and per cent cover of forest layers. Plot location avoided straddling obvious ecotones, breaks and edge communities. An attempt was made to sample the entire population of interior and river uplands, as their presence in the HBL is nil – known and accessible uplands were sampled as time permitted. Larger features were prioritised in the interior. At the river, locations were selected based on the presence of adjoining seres on tiered banks. Water levels regulate the accessibility of the river, and so travel earlier in the season, after hazardous snowmelt conditions but before drier summer months, allowed further access. Plots were 100 m^2 with dimensions 10 × 10 m, with two exceptions along the riverbank. Vegetation was described by measuring species presence and abundance. Other plant community and environmental attributes were documented and will be reported in associated thesis work.

3.1 Soil profile description

Soil pits were placed at the centre of each plot, at the highest point of elevation, and were dug after vegetation had been surveyed. Soil horizons were profiled using a 1 × 1 m pit dug one metre deep or until permafrost, bedrock or water table was encountered (Darmody et al., 2004). Variables of interest in the organic and mineral soils were described in the field according to procedures and classifications of the Field Manual for Describing Soils in Ontario (Denholm and Schut, 2003). The effective layer, the soil horizon which influences primary soil profile characteristics and is used to determine moisture regime, was determined using protocol from the Canadian System of Soil Classification (CSSC). Effective texture was considered to be the texture associated with the effective layer. The horizon with the highest root density was noted, and a measurement of average maximum rooting depth was taken (Depth to Root Presence).

After the soil profile had been photographed, described and sampled, soil and sod were replaced. Soil profiles were classified by Great Group and Soil Order using the Canadian System of Soil Classification.

3.2 Soil chemistry

Soils from the horizon with the highest rooting density were sub-sampled and used in the chemical analyses.

Characteristics of natural analogues are compared to those of "raw materials" (spoils) that will synthesise a soil cap emulating natural conditions – spoils being overburden and processed kimberlite. Comparisons are made using ANOVA and contrasts comparisons. Commonalities among sites are extracted using cluster analysis, principal components analysis (for soils) and non-metric multi-dimensional scaling (for vegetation).

Soil pH in water was determined for all samples. Analysis of cation exchange capacity (CEC) used the carbonate portion of the soil sample. Sample was mixed with 0.1 M $BaCl_2$ in a ratio of 1:10 for mineral soils and 1:60 for organics and shaken for 12 hours. Samples were then centrifuged, decanted and filtered. Same ratios of 18MΩhm water were added to the remaining samples, which were shaken for twelve hours before the supernatant was disposed of. Same ratios of 1M NH_4Cl were then added and shaken for 12 hours to check for a balanced reaction, as $BaCl_2$ exchange method assumes a 98% recovery.

Determination of bioavailable nutrients was done using lithium nitrate (LiNO3) extraction as per methodology developed by Spiers and Courtin. C:N:S ratios were determined through loss on ignition. Analysis of C:N:S was outsourced to Thunder Bay, Ontario via the Elliot Lake Research Field Station, Sudbury, Ontario.

Overburden and kimberlite soil chemistry values are from other ongoing research in the Campbell Lab, Laurentian University (Bergeron, 2010). Chemistry data from coarse processed kimberlite (C), fine processed kimberlites (F), overburden marine silts (S) and peat overburden (P) are used to compare dissimilarity from natural conditions, as these raw materials will compose s a synthesised soil cap.

3.3 Vegetation

All individual species within the plot were recorded for species presence and abundance. Where a species could not be identified on site, a sample was taken, labelled and later identified in the lab, and verified by an expert. Voucher specimens were taken for all species. A ten minute reconnaissance scanning the community adjacent to the plot determined if local incidental species had been overlooked. A list of the species within the plot and incidental species encountered outside the plot was recorded. Per species abundance was recorded in per cent cover. All per cent cover values were determined by the same individual, the researcher.

The software program PRIMER-E was used to compute a cluster analysis, a non-metric multidimensional scaling (NMDS), and per cent similarity (SIMPER) on the square-root transformed matrix of species per cent cover data (Clarke and Gorley, 2006; Clarke, 1993). A Bray-Curtis resemblance matrix analysing between samples was created. The cluster-analysis used group average to analyse between samples to produce clusters of more than 95% similarity ('Simprof' parameters of 1,000 permutations for mean profile; 999 simulation permutations; 5% significance level). These clusters were further clumped into ecologically meaningful plant community groups based on the observed environment and the per cent site similarity by species contribution (SIMPER) using the Bray-Curtis resemblance matrix. The cut-off for low species contributions to these groups was 90%. NMDS used the Kruskal stress formula 1 and had a minimum stress of 0.001 with a minimum of 25 restarts (Clarke and Gorley, 2006; Clarke, 1993). The best 2D configuration had a stress of 0.159, which occurred eight times.

4 Sample results

Here, mine spoils and mine waste materials are collectively referred to as 'raw materials', as they will compose the majority of the soil-cap that has yet to be engineered. Soil chemistry was compared between interior and river sites, referred to as 'natural' analogue conditions; as well natural analogue conditions were compared to the chemistry of the mine spoils silt (S) and peat (P), and mine waste materials including coarse processed kimberlite (CPK) and fine processed kimberlite (FPK).

Cation exchange capacity was not significantly different between all samples of the two natural site types and the four raw materials ($t = 0.406$, $P = 0.686$). Interior sites had a mean CEC of 120.262 (S.E. = 27.6) and river sites had a mean value of 62.606 (S.E. = 7.36). Contrast comparisons did not reveal significant differences between natural analogue conditions and raw material states, nor between the natural analogue environments of river and interior sites. Outliers and extreme values were observed to be above the 99% confidence at four interior sites and two river sites, and below for one interior sites and four river sites (Figure 3).

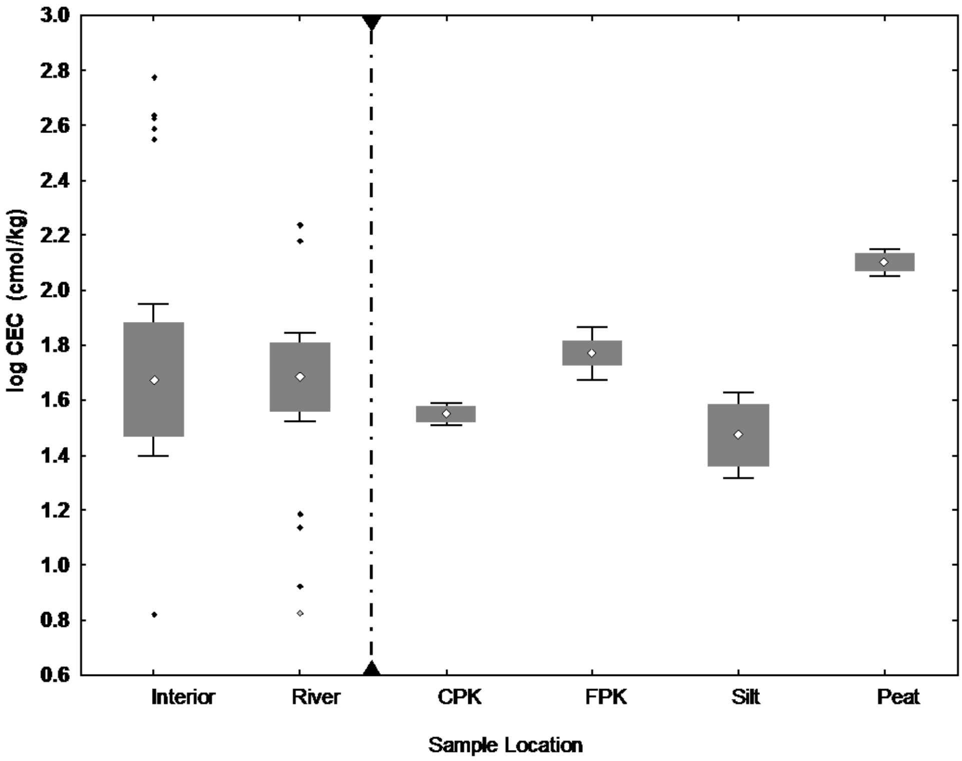

Figure 3 Soil chemistry results of electron cation exchange capacity comparing river natural analogue values to interior natural analogue values. Mean and 95% confidence limits are represented by the box plots. Whiskers represent the 99% confidence limit. Outlier and extreme values are presented beyond the whiskers

A cluster analysis based on group average of plant community composition (Figure 4, inset) creates six statistically and environmentally distinct plant community groups as informed by a SIMPER (PRIMER v6) analysis of per cent similarity. A non-metric multi-dimensional scaling (NMDS) separates sites by plant community composition and species abundance (Figure 4). Based on the species within each plant community group, and presence and age of tree species (not presented here), mutually exclusive natural analogues (interior and river) and the successional sequence of their respective plant community types can be inferred.

Two plant community groups are apparent by the relationships of the interior sites. These groups are underlain by Humoferric Podzols and Folisols (group iA) and Dystric brunisols (group iB). Trees of group iA were older than trees of group iB. Four plant community groups were made distinct by the relationships of the interior sites, one group underlain by Regosols and Static Cryosols (rC), one group with an assortment of soil types (rD) another group by Regosols and Gleysols (rE) and another by Regosols and Humic Regosols (rF). Each plant community group is associated with a plant community from the SIMPER analysis. Group rC trees were oldest, followed by groups rD and then rE. Trees sizable enough to measure (height >137 cm) had not yet established on sites of group rF. Two sites were anomalous (P13 and P54); two sites were less than 5% different (P05 and P07) and would form their own cluster but have been left unconsolidated to reflect the results of the SIMPER analysis (Figure 4, inset).

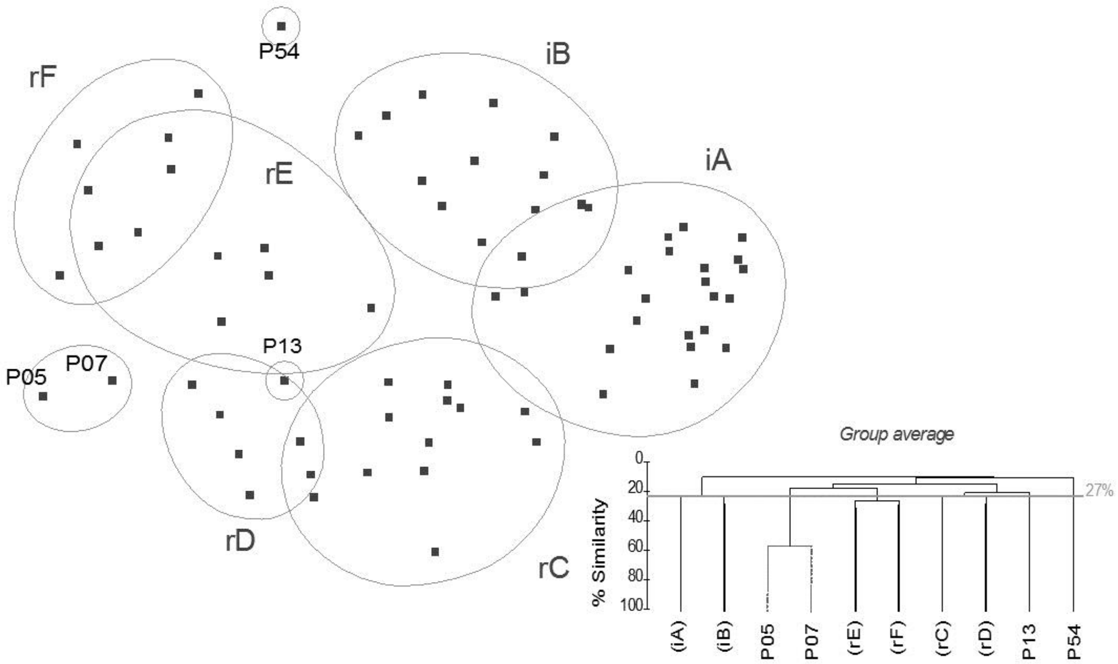

Figure 4 Non-metric multi-dimensional scaling ordination diagram based on Bray-Curtis similarity resemblance measure of species per cent cover in plant communities of the interior and river uplands sites. Two-dimensional stress is 0.159. A cluster analysis (insert) using group average based on the same resemblance matrix produced clusters that were refined to six environmentally distinct clusters (at 27% similarity, circled) informed by the results of a SIMPER analysis

5 Summary

In-progress results reviewing the soil characteristics, vegetation composition, the soil-plant community relationships and the influence of key environmental variables indicate a distillation of a condensed series of six ecologically sound reference conditions based on natural conditions.

Box plots such as for CEC (Figure 3) and other variable summaries (not shown) describe the mean and range of conditions of the observed plant and soil parameters. Sites are grouped by relationships of common plant traits using NMDS, clustering and SIMPER (Figure 4). Similarly, sites can be grouped and relationships described using principal components analysis of soil chemistry (not shown). Plant community groups can be interpreted as seres and ordered by developmental sequence according to the types and ages of species that contribute to the group (SIMPER, Figure 4). By describing the attributes of each of these plant community groups and the conditions of the interior and river sites in general, we are able to provide a series of reference conditions that can inform on soil requirements as well as direct plant community establishment and development on features requiring reclaimed. Having appropriate reclamation targets will expedite the process of successful reclamation and will assist in furthering the long-term integrity of the site.

Using these methods of data collection at various successional stages over relative geomorphic classes and applying these statistical techniques, we are able to agglomerate and synthesise potential ecosystem targets at various successional stages based on shared underlying physical and chemical soil characteristics, and plant communities. The variability in the natural environment provides parameters for creating locally compatible novel ecosystems on mine stockpiles, which will provide a template of possible upland community targets and successional trajectories in similar environments, as well as a methodology for producing a variety of appropriate templates in other regions.

Acknowledgements

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