RESTORATION PLANNING AND APPLICATION OF ECOLOGICAL SUCCESSION PRINCIPLES: UNITED KENO HILL MINE CASE STUDY

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ABSTRACT

Restoration of post mining disturbed sites within the boreal sub-alpine ecological communities of the Yukon has varied levels of success (Sheroan et al. 2010; Stewart and Siciliano 2013). Employing ecological succession principles to further the science of restoration of northern ecosystems on post-mining sites will contribute to the restoration body of knowledge. It will allow us to gain a better understanding of how to restore northern boreal forest sites where climate and poor soil development pose unique challenges for restoration (Clark and Hutchinson 2005). The re-establishment of ecosystems to conditions that once supported community and traditional land uses are another challenge in this region (ERDC 2012). Understanding how ecosystems respond to restoration designs will inform regulators and practitioners and therefore contribute to establishment of best practices policies.

The goal of this paper is to demonstrate the use of ecological succession principles to increase restoration success and ecosystem functional sustainability in the north, coupled with applying the planning tool "SMART" (Doran 1981). To demonstrate the application of ecological succession principles, this paper will use the former United Keno Hill Mine (UKHM) site in the Yukon as an example. The goal for the former UKHM site is to establish communities containing pioneer species that, over time, will be self-propagating on boreal low to subalpine bio-climate units (EBA 2003). In this paper we will apply the "SMART" planning tool to describe how to define goals and how to successfully establish appropriate objectives and targets to support this goal.

Key Words: Boreal, Community, Monitoring, Phytotoxic, Sub-Alpine, Restoration Ecology, Mine Tailings, Waste Rock, Pioneer Species, Biological Soil Crust, SMART Planning Tool.

INTRODUCTION

The successful long-term restoration of disturbed sites in northern regions is a complex and difficult task (Clark and Hutchinson 2005). Post-mining landscapes are generally void of several or all of functioning ecosystem components such as soil flora and fauna (Cooke and Johnson 2002). Remnant soils are compacted and or phytotoxic, lacking a seed bank which inhibits or prevents the recovery of once thriving ecosystems (Polster 2009). Often these undertakings require numerous interventions such as slope engineering, soil toxicity treatments and other treatments over an extended timeframe. In addition to physical and geochemical challenges, establishing a self-perpetuating vegetative cover in northern climates is challenging. Poor soil nutrients, arid environments, cold temperatures and a general lack of information on successful restoration processes present challenges. The use of native vegetation that has adapted to these harsh physical, chemical and climatic conditions is therefore a practical option (Clark and Hutchinson 2004). The focus of the terrestrial restoration project at the former United Keno Hill (UKHM) property is to produce clear and meaningful goals, objectives and targets to reach a sustainable, functioning, successional ecological community on sites with varying degrees of disturbance. The "SMART" planning tool (Doran 1981) is a useful guide in the development of attainable and management project goals in concert with application of ecological succession principles as detailed below.

HISTORY AND PROJECT DESCRIPTION

The historic Keno Silver Mining District, located in central Yukon, produced over 214 million ounces of silver from 1914 to 1989 (Alexco 2013). Mining methods used to extract resources included open pits and underground workings. Ownership of the former UKHM property defaulted to the Canadian Government in 2004. Alexco Resource Group became the preferred purchaser of the assets in 2005 and entered into a unique cost sharing partnership with Canada to continue the care and maintenance of the property under the project specific company Elsa Reclamation and Development Company (ERDC). Continuing investigations to inform and support the closure selection process are in the final phase and selection of preferred closure options by the closure team is expected to take place early 2014.

The former UKHM property has an area roughly 250 km^2 out of which approximately 110 ha will require some degree of ecosystem restoration including the 90 ha valley tailings facility. Mining disturbances include three tailings deposits, 68 waste rock dumps, 19 open pits, multiple shafts, buildings and infrastructure. Waste rock dumps associated with adits contain some low grade ore and will require soil covers whereas waste rock dumps associated with pits are comprised mainly of country rock and are not considered phytotoxic (Alexco 2013). The UKHM terrestrial program focuses on creating suitable conditions for the establishment and perpetuation of early seral native plant species found in adjacent reference communities, including disturbed areas where soil and ecological memory has been removed, and on sites that have been ameliorated by the installation of soil covers (Alexco 2013).

The closure plan goal for the UKHM property is to establish a northern boreal sub-alpine community containing pioneer species that will be self-propagating. To reach this goal we have proposed the application of ecological succession principles. Primary succession will be facilitated by assessing, planting and monitoring native pioneer species onsite including the use, where appropriate, of biological soil crusts.

NATURAL SUCCESSION

Natural succession, a process of ecological change in which a series of natural communities are established and then replaced over time, from shade intolerant species eventually supplanted by shade tolerant species (Kimmins 1997; Tansley 1920), can be used as an indicator for appropriate species selection and design in restoration. The theory of natural succession asserts plants have an optimal range for growth and development (Polster 1991) and that over time, increases in biomass, primary production, respiration, and nutrient retention lead to diversity and changes in species composition and ultimately, increased structural complexity, or climax succession. Mechanisms that drive ecological succession include facilitation, tolerance, and inhibition and can be generalized into two stages.

1) Primary succession is the community formation process that begins on substrates that had never before supported any vegetation (Mueller-Dombois and Ellenberg 1974). Depending on the conditions, pioneer species can take many years to establish and therefore, selection of appropriate plants is critical for long term success of any reclamation program (Polster 2009). Generally, pioneer species trend from bryophytes, lichens and biological soil crusts to graminoids, herbs, dwarf shrubs, large shrubs, sapling trees to late seral tree species. Several pioneer plants fix nitrogen and create conditions and space for successional advancement. Decomposition and nutrient cycling enables soils to support the more complex plants that are eventually replaced by later seral coniferous tree species.

2) Secondary Succession originates only from a partial disturbance of an ecosystem (Mueller-Dombois and Ellenberg 1974). The general trends during secondary succession are similar to primary succession. Graminoids or forbs, such as fireweed (*Epilobium angustifolium*) may dominate the herb layer. Annual species, over time are replaced by perennial species, and then, depending on the ecological zone, by shrubs, an early seral forest, followed by mature boreal forest consisting of late seral coniferous tree species.

Understanding the process of ecological change is essential in planning for successful restoration as it mimics models from nature. The underlying idea in application of successional theories in restoration is to let nature do the work. Walker and del Moral (2003) suggest primary succession is integral to restoration planning as it allows for direct observation over time, employs comparative studies to later seral stages, enables linkages to long term processes, and provides tools for restoring anthropogenic and naturally disturbed ecosystems. Furthermore, ecological restoration is a manipulation of successional processes to meet realistic targets in restoring damaged landscapes (Walker et al. 2007).

Prior to initiating a restoration program, the following three necessary steps should be considered:

1) Determine the ecological zone, moisture regime and nutrient regime;
2) Confirm the site successional stage. If the site is in a state of primary succession the use of pioneer species appropriate for the region including nitrogen fixers is recommended. Adjacent or nearby permanent reference sites located on a similar slope and aspect will provide historical system information and species autecology (Walker et al. 2007) ensuring selected species are suitable for the site conditions. Sites that are advanced to the stage of secondary succession will benefit from using opportunistic species appropriate for the area. Reference sites should ideally contain the species of the desired ecological community; and
3) Finally, determine if there are any limiting factors that would prevent the establishment of vegetation (soil contaminants, compaction, erosion processes, biotic pressure, social components, or any other abiotic/biotic factors).

Following completion of the above three steps, goals, objectives, targets (and performance indicators) can be developed. These are discussed in detail below.

"SMART" PLANNING TOOL: APPLIED TO RESTORATION

The "SMART" tool has been adapted from a simple planning process and is related here in terms of Restoration Program development (as adapted by the University of Victoria course Restoration Ecology ASP503).

Table 1: "SMART" Terms Defined

Letter	Minor Term	Minor Terms	Planning Term
S	Specific	Significant, Stretching, Simple	Objective
M	Measureable	Meaningful, Motivational, Manageable	Target
A	Appropriate	Appropriate, Achievable, Agreed, Assignable, Actionable, Ambitious, Aligned, Aspirational	Objective
R	Realistic	Realistic, Resourced, Resonant	Objective/Target
T	Time-Bound	Time-oriented, Time framed, Timed, Time-based, Timeboxed, Timely, Time-Specific, Timetabled, Time limited, Trackable, Tangible	Target
E	Evaluate	Ethical, Excitable, Enjoyable, Engaging Ecological	-
R	Re-evaluate	Rewarded, Reassess, Revisit, Recordable, Rewarding, Reaching	-

The planning terms outlined as part of the "SMART" tool are Goals, Objectives and Targets. Goals are long-term, broad statement about what a program/project hopes to achieve. Objectives are the short-term, concrete, stepping stones towards achieving a goal. Objectives should be Specific, Appropriate, and Realistic; the S, A, and R in "SMART". Targets are Measurable, Realistic and can be achieved within a specified Time frame; the M, R, and T in "SMART". The term performance indicator will also be used, which is a measurable unit to help define the target. These terms and the "SMART" planning tool will be used to develop the restoration plan for the former UKHM site.

DEVELOPMENT OF A RESTORATION PLAN: UKHM CASE STUDY

The former UKHM site is located in the North Yukon Plateau Ecoregion. The landscape was formed by past glacial activity and soil is limited. Primary tree species along the mid and lower slopes are white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), Alaskan birch (*Betula neoalaskana*), and the occasional balsam poplar (*Populus balsamifera*). The lowlands are vegetated by a matrix of scrub birch (*Betula glandulosa*), willow (*Salix sp*.) and Ericaceous shrubs with sparse to open black spruce cover. White spruce in a matrix of dwarf willow, birch, Ericaceous shrubs, and, occasionally, lodgepole pine forms extensive open forests, particularly in the northwestern portion of the ecoregion. Black spruce, scrub willow, birch, and mosses are found on poorly drained sites. Alpine fir and lodgepole pine occur in higher subalpine sections, whereas alpine vegetation consists of mountain avens, dwarf willow, birch, ericaceous shrubs, graminoid species and mosses (Smith et al. 2004).

Several areas requiring reclamation are devoid of topsoil and remain in a state of primary succession; however, limited ingress of pioneer species is evident in some locations and an inventory of species as candidates is presented in Table 2.

Table 2: Pioneering and early seral species identified at former UKHM property

Botanical Name	Common Name	Growth Form	Habitat	Soil Moisture	Soil Characteristics
Agrostis scabra	Ticklegrass	Graminoid	Low to mod elevations. Dry to wet disturbed areas, dry rocky slopes.	Sub-xeric to sub-hygric	Tolerant of acidic soils, drought and low nutrients and permafrost.
Calamagrostis canadensis	Bluejoint	Graminoid	Widespread in boreal to subarctic. Riparian, cool, moist forest communities.	Sub-mesic to sub-hygric	Moist to wet sites; tolerant of acidic and saline soils.
Carex aqualtilis	Water sedge	Herb	Wet sites.	Mesic to sub-hygric	Moist to wet.
Epilobium angustifolium	Fireweed	Herb	Low to subalpine elevations. Mesic open forests, burns.	Mesic	
Equisetum arvense	Common horsetail	Herb	Riparian, lake edges, marshes, fens, bogs, low to mid elevations.	Mesic/Sub-hydric	Moist to wet.
Lupinus arcticus	Arctic lupine	Herb	Range from lowland riverbanks to alpine, tundra.	Mesic	Tolerant of low nutrients, permafrost, nitrogen fixing.
Oxytropis campestris	Field Locoweed	Herb	Gravel bars, rocky outcrops, roadsides, dry and open woodland into alpine tundra.	Sub-mesic to xeric	Nitrogen fixer.
Alnus crispa	Alder	Shrub	Widespread.	Very Xeric/Mesic /Subhydric	Moist, gravelly to rocky, generally acidic pH 5.0 to 6.5. Nitrogen fixer.
Betula glandulosa	Scrub Birch	Shrub	Sub alpine, found in many *P. mariana* and white spruce *P. glauca* communities.		Moist, sandy, gravelly loam to organic soils. Tolerant of salinity and pH 3.1 to 6.5.
Dryas spp.	Avens	Shrub		Mesic	Moist, river bars, lowland to alpine. Nitrogen fixer.
Empetrum nigrum	Crowberry	Shrub	Subarctic, tundra, heathlands, swamps and bogs from sea level to alpine.	Very Xeric/Mesic /Subhydric	Acidic, moist, sandy to rocky soils, glacial till. Soil pH ranges from 2.5 to 7.7.
Salix alaxensis	Felt-leaf willow	Shrub	Widespread through riparian, boreal, tundra, subalpine to alpine.	Mesic	Moist silty or mineral soil. Wet meadows and thickets.
Salix glauca	Grey-leaved willow	Shrub	Swamps, fens, bogs, streambanks, dry to wet open forest, to alpine.	Sub-Mesic-sub-hygric	Gravely soils to bogs and fens.
Shepherdia canadensis	Soapberry, Buffaloberry	Shrub	Co-dominates numerous seral willow and mixed-shrub.	Very Xeric/Mesic /Hydric	Dry, calcareous. Nitrogen fixer.
Populus balsamifera	Balsam poplar	Tree	Widespread, prefers riparian areas of boreal forests.	Very Xeric/Mesic /Subhydric	Prefers moist areas, but will grow on dry sites.
Populus tremuloides	Trembling aspen	Tree	Widespread.	Very Xeric/Mesic /Subhydric	Variable, but prefers well drained loamy soil with high OM content.

To create conditions amenable to seed germination and plant growth, the disturbances or filters listed in Table 3 below must be ameliorated to improve the physical and chemical nature of the sites and prevent a state of arrested succession (Cooke and Johnson 2002).

Table 3. Limiting factors (disturbance elements) of the former UKHM Site

Disturbance Elements	Condition	Possible Solutions
Phytotoxic soil	Elevated level of zinc, cadmium etc. inhibiting plant growth	Soil covers; application of lime
Soil nutrients	Mineral soil; some biological soil crust	Seed, plugs of early seral pioneering plants including nitrogen fixers; addition of biochar/ soil amendments where warranted
Aeration	Compacted sites, smooth microtopography	Scarify where possible to create rough and loose conditions
Coarse substrate	Limited fines required for moisture retention and plant establishment	Identify where fines are located; addition of fines in some areas and pocket plant to create environmental resource patches
Moisture	Xeric, sub xeric to mesic sites	Species selection – outcome from ecosystem mapping program; soil amendments where possible

Establishment of goals are meant to ensure the long-term success of the terrestrial restoration program by developing a clear executional plan. The goal of the UKHM project, under agreement with Canada is to develop and implement an Existing State of Mine (ESM) Reclamation Plan; the goal of the terrestrial soil and vegetation program is to "establish a northern boreal sub-alpine community containing pioneering species that, over time, will be self-propagating". As stated previously, objectives are short-term concrete steps toward achieving a goal. There may be several objectives that support a single goal but should be clear and unambiguous. Using "SMART" terms, the following questions and steps are considered when formulating objectives and targets:

<u>Specific Objectives</u>

What is expected? It is expected that over time, vegetation will successfully establish on a variety of site specific locations. Tailings and waste rock piles containing elevated levels of zinc and other phytotoxic elements that are not able to support a thriving plant community will be covered and vegetated. In locations where amelioration or cover of substrates is not required, establishment of pioneering plant and biological soil crusts to attain an early seral plant community will undergo separate treatment in concert with closure team members. It is expected these sites may require scarifying to create 'rough and loose' soil conditions amenable to seed germination and growth (Polster 2011).

Why is it important? The need to plan and understand successional processes and implement this knowledge in northern restoration projects cannot be overemphasized. EDI Environmental Dynamics Inc. (2009) conducted a review of several revegetation projects and techniques in the Yukon and recommended additional research and monitoring of species other than grass, and root cutting techniques. They also suggested research and trial work on developing reliable and cost effective methods in the production of cuttings, transplants and stakes for reclamation projects in the north.

Who is involved? Where is it going to happen? Which attributes are important? The long term expectation is to continue to create capacity within the citizenship of the Nacho Nyack Dun (NND) whose traditional territory encompasses the Keno Hill Silver District and within the communities of Mayo and Keno City. The development of the ESM Plan and the completion of the regulatory and permitting process is scheduled to occur over the next 5 years with implementation of the final reclamation plan to begin in 2017. NND students and the community have been involved in several aspects of the terrestrial revegetation program including field work, ecosystem mapping and more recently, seed collection.

Appropriate Objectives

Existing infrastructure owned by local residents will be utilized to support a seed increaser program and native plant propagation trials. Enthusiasm about learning and contributing to the overall objective of restoring the sites is evident in the community and preliminary planning is underway to develop experiential and practical programming opportunities.

Realistic Objectives

Using pioneer plants for planning and selection is tailored to represent and support onsite conditions such as metal tolerance, drought resistant, nutrient poor, condition. Objectives such as using native species to attain the overall goal will set the project on the right trajectory. Realistic and successful restoration objectives are those include knowledge from the structural and functional characteristics of the natural ecosystem and from which measurable targets can be established (Cooke and Johnson 2002).

Targets are measureable, realistic and can be achieved within a specified time frame. Ruiz-Jaen and Aide (2005) recommend at least two variables within each of the three ecosystem attributes and two reference sites at a minimum are required to establish targets. The three ecosystem attributes that are measurable include diversity, vegetation structure and ecological processes. Establishing targets with these attributes will provide critical information about ecosystem resilience, nutrient cycling and succession (Ruiz-Jaen and Aide 2005).

Measureable

This target usually answers questions such as how much, how many, how to know when it has been accomplished and what are the units of measurement (Gonzales 2013). Defining measurable targets is critical for performance monitoring and implementation of adaptive management measures should monitoring results indicate a need to do so. Proposed measurable targets for the former UKHM property may include the evaluation of restoration success by comparing the trajectory of recovery of established variables through time with reference sites (Ruiz-Jaen and Aide 2005); and to establish a native pioneering community by Year 5, with a proposed target density that will be obtained from existing literature and adjacent recovering plant communities. (Cargill and Chaplin 1987; Government of Saskatchewan 2008; Greene et al. 1999; MWLAP 2002; Walker et al. 1986; Wilson et al. 1996).

Realistic

Similar to realistic objectives, targets must also be realistic. Assessing those targets can be done during the evaluation phase (below) which may trigger an adaptive management response depending on the outcome.

Time Bound

This target will usually answer questions such as when, what can be done 6 months from now, what can be done 6 weeks from now, what can be done today? (Gonzales 2013). The temporal scope of implementation and monitoring of the closure program at the former UKHM site is at minimum two decades. The time-bound targets of the ESM reclamation plan will be reflected in the terrestrial program.

Evaluate

Evaluation is a tool to measure the success of the project, in addition to providing a way to communicate and report the efficacy of the project (Gonzales 2013). Evaluation of established ecosystem attributes such as diversity, vegetation structure and ecological processes presented above will provide key information about the restorative progress of the site to the closure team and stakeholders.

Re-evaluate

This final term emphases the cumulative opportunity to learn, improve and develop when using "SMART" project management, particularly for long-term and related projects. An adaptive management cycle to advance knowledge will always incorporate re-evaluation (Gonzales 2013). An adaptive management plan is a tool that will inform the closure team what can and cannot be accomplished and must therefore have the flexibility to address results by adjusting goals or objectives if necessary (SER 2005).

CLOSURE AND SUMMARY

Through the use of ecological succession as a model, letting nature be our guide, and careful, thoughtful consideration while establishing goals, objectives and targets we can design and implement successful ecologically based restoration projects. The ecology of each restoration site is complex and dynamic; efforts will be made to guide restoration sites to an acceptable functioning state that will establish ecosystems that will provide continuing services over long periods of time and into the uncertain future of climate change. Additional attributes of success will be developed as the need arises during the planning and implementation phases of the project. Monitoring and related adaptive management are essential for continued learning. The "SMART" planning tool is recommended for development of adaptive management strategies, goals, objectives and targets within the monitoring program.

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Overcoming Northern Challenges

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Northern Latitudes Mining Reclamation Workshop

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NORTHERN LATITUDES MINING RECLAMATION WORKSHOP

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The first Workshop was held in Whitehorse, Yukon Territory, Canada in 2001 and it has been held every two years since, alternating between Canada and Alaska. The primary sponsors of the Workshop include the Yukon Geological Survey, Indian and Northern Affairs Canada, Natural Resources Canada, US Department of the Interior Bureau of Land Management, and the State of Alaska Department of Natural Resources.

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The CLRA/ACRSD is a non-profit organization incorporated in Canada with corresponding members throughout North America and other countries. The main objectives of CLRA/ACRSD are:

- To further knowledge and encourage investigation of problems and solutions in land reclamation.
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- To incorporate the advances from research and practical experience into land reclamation planning and practice.
- To collect information relating to land reclamation and publish periodicals, books and leaflets which the Association may think desirable.
- To encourage education in the field of land reclamation.
- To provide awards for noteworthy achievements in the field of land reclamation.

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