APPLICATION OF SWOT - C ANALYSIS AND STATE-AND-TRANSITION MODELING TO THE DESIGN OF RECLAMATION PLANS FOR ABANDONED OR OPERATING MINES IN BRITISH COLUMBIA

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ABSTRACT

SWOT - C (Strengths, Weaknesses, Opportunities, Threats, and Constraints) analysis is a structured planning method that evaluates the important elements of an ecologically-based project and provides a framework for organizing data collection and synthesizing available information. In terms of ecological restoration, strengths are factors such as remnant patches of undisturbed vegetation that can be considered assets. Weaknesses are deficiencies or stressors such as erosion, sedimentation, and contamination that can cause problems. Opportunities are important factors for the practitioner to restore ecosystem structure and function. Threats are undesirable issues, challenges, or trends that may cause further ecosystem degradation. Constraints are environmental, cultural, and socioeconomic limitations.

State-and-transition models (STMs) are compartment diagrams and associated narratives that can be used to describe changes in ecosystem properties (i.e., composition, structure, and function) and the mechanisms by which a developing ecosystem transitions from one developmental state to another. The narratives and diagrams can be generated using (1) historical information, (2) local and professional knowledge, (3) general ecological knowledge, and (4) relevant monitoring or experimental data.

These tools when combined can yield effective, holistic, and ecologically based mine reclamation plans.

KEYWORDS

Reclamation planning, SWOT - C analysis, state-and-transition model narratives, succession, adaptive management

INTRODUCTION

Planning is an essential component of successful reclamation. Activities related to reclamation and closure planning typically include (1) preparation of detailed drawings of the disturbed landscape, (2) compilation of baseline information, (3) discussions with regulators and stakeholders on end land use objectives, (4) design of supporting research programs, and (5) preparation of budgets and schedules (Tripathi et al. 2016).

The following is a methods paper that describes two tools that can be used in reclamation planning. Strengths, Weaknesses, Opportunities, Threats, and Constraints (SWOT - C) focusses on a structured information-gathering checklist approach to planning while state-and-transition modeling (STM) addresses ecosystem development/reassembly (i.e., abiotic – biotic interactions and mechanisms of recovery). Both tools can be used in the design, implementation, monitoring, and adaptive management of mine reclamation.

BACKGROUND

Ecological reclamation relies on the autogenic (self-sustaining) capabilities of ecosystems (Bradshaw 2000, Cooke and Johnson 2002). Reclamation activities can be categorized as either (1) construction and installation strategies (site preparation and revegetation) or (2) management strategies. Management-based activities are implemented to reinitiate autogenic ecological processes that are absent due to on-site stressors, such as altered topography, soil loss/removal, and substrate contamination. Construction and installation activities create the habitat template for subsequent ecosystem recovery and require both planned and as-built documentation. Following completion of site preparation and revegetation, a period of maintenance and monitoring ensures persistence of the developing ecosystems. Management strategies generally involve changes in present and past management practices and the use of a variety of management techniques (e.g., herbivory and exotic species control and application of fire). Construction and installation techniques (e.g., landform modification, soil/substrate manipulation, addition of structural elements, and revegetation) tend to be more resource intensive than are management activities.

The foundation of a reclamation project is established during the planning phase. The goals and objectives set during this stage form the basis for subsequent decisions, starting with reclamation design strategies, design approach, plant materials, and the construction and installation schedule. The process of coordinating with stakeholders and obtaining consensus among stakeholders (e.g., regulatory agencies, First Nations, and general public) is essential to the project development process. Once a plan has been established, a more thorough site analysis, such as SWOT - C, should be undertaken (Figure 1). The SWOT - C analysis can be used to refine goals and objectives by examining factors that can influence the outcome of the reclamation effort and ensure appropriate mitigation is applied (e.g., for acid rock drainage). The STM narrative can then be used in the development of the reclamation plan.

Reclamation plans require the delineation of reclamation planning units and the development of reclamation prescriptions. SWOT - C and STM can be used to develop reclamation prescriptions and to evaluate ‘ecosystem recovery conjectures’ or ‘reclamation working hypotheses.’ A working hypothesis is also beneficial in developing monitoring programs and anticipating adaptive management strategies.

Fundamentally, mine reclamation and closure have the following objectives:

- structures have been removed and any remaining are physically stable;
- contaminant release, where present, is reduced and does not result in unacceptable exposure to surrounding receptors;
- hazards to public, workers, and wildlife are minimized;
- landscape performance goals and regulatory requirements are addressed;
- ecological conditions (i.e., terrestrial, aquatic, and atmospheric) have been reclaimed, and a self-sustaining ecosystem is developing and satisfies end-land-use objectives;
- visual (aesthetics) considerations;

- socio-economic expectations (adverse conditions minimized, socio-economic benefits maximized); and
- long-term monitoring and maintenance (adaptive management) following reclamation activities and comparison of the performance prediction relative to objectives.

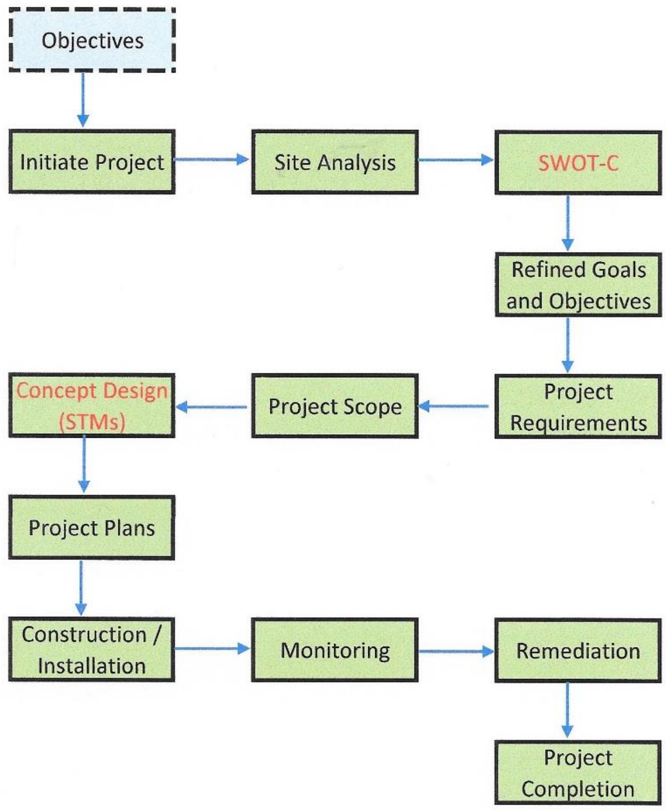

Figure 1. Reclamation planning flowchart

Developing a reclamation plan that includes the design elements listed above should use the following steps described by Tongway and Ludwig (2011):

Step 1 – Set goals,
Step 2 – Define the problem(s),
Steps 3 and 4 – Design solutions and applying technologies, and
Step 5 – Monitor and assess trends.

Unacceptable ecosystem recovery trajectories/problems identified as an adaptive learning feedback loop require reworking of solutions:

Step 1 – Reset existing or revise goals,
Step 2 – Redefine the problem(s),
Steps 3 and 4 – Redesign solutions and apply technologies, and

Step 5 – Continue to monitor and reassess trends.

INFORMATION REQUIREMENTS

Typically, information is collected prior to the completion of a SWOT - C analysis and the preparation of a STM narrative. In the absence of site-specific empirical data, site-assessment information for SWOT - C analyses and STM narratives can be generated from species and community literature.

Two types of publicly available information sources exist to prepare SWOT - C analyses and STM models in addition to experimental and site-specific site assessments:

1. Non-spatial resources – British Columbia MINFILE mineral inventory reports, reclamation guidance documents (Tripathi et al. 2016), British Columbia site field guides (e.g., MacKillop and Ehman 2016), plant species reports and websites (e.g., Hardy BBT 1989, Burton and Burton 2003, FEIS 2019), seed suppliers (e.g., Premier Pacific Seeds 2019), and climate (ClimateWNA) data (Wang et al. 2012). It is important to acknowledge that while provincial site classification guides can provide basic information, particularly with respect to end land use targets, their use needs to be supplemented by ecological succession and autecological literature that focus more on processes and mechanisms.
2. Spatial resources – BC Data catalogue (e.g., BC Watershed Atlas, BC Roads Atlas, Terrain Resource Inventory Mapping [TRIM], Soils Information Finder Tool [SIFT] Map Application, Surficial Geology Map Index, Terrestrial Ecosystem Mapping [TEM], Predictive Ecosystem Mapping [PEM], Broad Ecosystem Inventory [BEI], Vegetation Resource Inventory [VRI], Forest Tenure Managed Licenses Polygons, Historic Trails Areas, Archaeological Sites and Historic Places, and Wildlife Management Units) (BC 2019). Additional data include the Canadian Forest Service Earth Observation Sustainable Development (EOSD) and Google Earth spatial data.

SWOT - C ANALYSIS

SWOT - C analysis is an acronym for strengths, weaknesses, opportunities, threats, and constraints (Kumar and Rathore 2015) and is a structured planning method that evaluates the important elements of an ecological project (Rieger et al. 2014). Typically, a SWOT - C analysis involves a site assessment; however, it can also be performed as a desktop exercise or a combination of both activities. Qualifiers are placed on the confidence or reliability of the information used.

Data related to site conditions are available for most projects; however, misinterpretation of this data often leads to implementation of ineffective reclamation strategies. Using the SWOT - C analysis process ensures the collection of relevant data and proper interpretation. The assessment, which can be used to develop a reclamation plan, typically takes the form of a table with three columns, where data are organized by (1) factors, (2) SWOT-C categories, and (3) comments.

1. Factors:
    - General factors – e.g., political/regulatory considerations, historical context, resource constraints, history/archaeology, land use, wildlife, ownership, and ecosystem stressors;
    - Physical factors – e.g., landscape ecology, hydrology, hydrogeology, surface water volumes and quality, topography, slope and aspect, and soil physical and chemical properties, and contaminants;
    - Biological factors – e.g., succession, habitat structure and function, degree of degradation in composition, structure and function of ecosystems, and wildlife; and
    - Management factors – e.g., site preparation, substrate inputs, water management, buffering area (‘leave-strip’) requirements, access/access control, utilities required, and revegetation needs.

2. SWOT - C categories:
    - Strengths – strengths are factors such as remnant patches of native grassland or forests that positively influence reclamation; these are desirable assets that should be preserved and enhanced.
    - Weaknesses – weaknesses are deficiencies or stressors such as erosion, sedimentation, or adjacent areas that pose management problems (e.g., grazing leases). Weaknesses should also be categorized according to direct or indirect impacts and whether they require immediate or deferred attention.
    - Opportunities – opportunities are project specific and can be used to restore ecosystem functions and ecosystem services. These should be considered during site analysis. For example, remnant patches of suitable vegetation could be used to facilitate recovery.
    - Threats – site analysis should identify undesirable issues, challenges, or trends that may cause degradation of the reclamation site. These threats, analogous to what engineers might classify as a ‘failure mode’, should be classified according to the severity and probability of occurrence following a comprehensive site assessment. Critical areas of concern should be noted, and once identified, causal relationships should be explored and remediated. A risk analysis may be undertaken if there is uncertainty related to a specific threat.
    - Constraints – constraints represent environmental and socioeconomic limitations, such as: economic resources, human resources, time, stakeholder expectations, political issues, and biophysical factors.

STATE-AND-TRANSITION MODELING

STMs describe changes in ecosystem properties (i.e., composition, structure, and function) by characterizing ecosystem and the mechanisms by which a developing ecosystem transitions from one developmental state to another and have been used for mine-reclamation planning (Grant 2006, Frid and Daniels 2012). STMs consist of a diagram and narratives that describe ecosystem dynamics and supporting evidence for the causes of transitions between states (Stringham et al. 2003). STMs are developed using (1) historical information, (2) local and professional knowledge, (3) general ecological knowledge, and (4) relevant experimental data (Bestelmeyer et al. 2010).

The purpose of STMs in the planning context is to explore mechanisms (‘assembly rules’), track ecosystem recovery trajectories, and anticipate potential interventions. STMs are typically based on empirical data that quantitatively describe the states (typically described in terms of functional traits) and transition probabilities of developing ecosystems but can also be generated from literature. STMs are generally illustrated in the form of compartment models (Figure 2).

The development of STMs for mine reclamation implicitly acknowledges the following:

- there are multiple ecosystem parameters that influence succession and our understanding of ecosystem reassembly is imperfect (Luken 1990);
- broadly categorized succession mechanisms (i.e., facilitation, inhibition, tolerance, random colonization, and stochastic) may change over time, and the changing nature of ecosystem development processes should be considered (Del Moral and Titus 2018); and
- follow-up interventions (aftercare) are often required.

Both abiotic and biotic information sources are used in the development of a STM:

- Abiotic factors include soil/overburden properties and volumes, landform alteration requirements, contaminant concentrations and their respective mobilities. Erosion and sediment control are primarily construction/installation considerations based on the above abiotic factors.
- Biotic factors include plant ecophysiology (e.g., water relations and mineral nutrition), community ecology, plant symbiotic relationships, population ecology and genetics, reproductive ecology (i.e., asexual and sexual reproduction, pollination, seed set, seed dispersal, and germination ecology), seedling ecology, plant species interactions (e.g., competition, facilitation, mutualism), ‘natural’ recovery processes, plant-animal interactions, native species seed collection practices and plant propagation, plant establishment practices (e.g., direct seeding and nursery stock transplanting), spatial context of establishment practices, wildlife populations and habitat use. Reclaimed and reference-condition monitoring are construction/installation and management considerations that incorporate to varying degrees the biotic factors listed.

<u>Steps in Developing an STMs</u>

Information derived from published research, interviews, and field-inventory data is used to develop the diagrams and narratives for each component of the STM for each reclamation planning unit. Bestelmeyer et al. (2010) identified a sequence of eight steps:

- Step 1. Define Plant Communities and States – Identify the states and plant communities of ecologically equivalent sites. In some cases, the plant communities may represent seres.

- Step 2. Define States – Identify the conceptual basis for states and develop the basis for sorting plant communities according to grouping categories such as dominant species, functional groups, and/or surface soil conditions that control feedback mechanisms and ecological processes.
- Step 2a. Reference State – Identify a reference state (or states) that represent historical or natural conditions including the range of natural variability. Within the reference state, the reference plant community should be identified as that which best exhibits the characteristics of the reference state or that is considered to be the most resilient community within the state. At-risk plant communities should be identified as they are the community most vulnerable to transition to an alternative stable state.

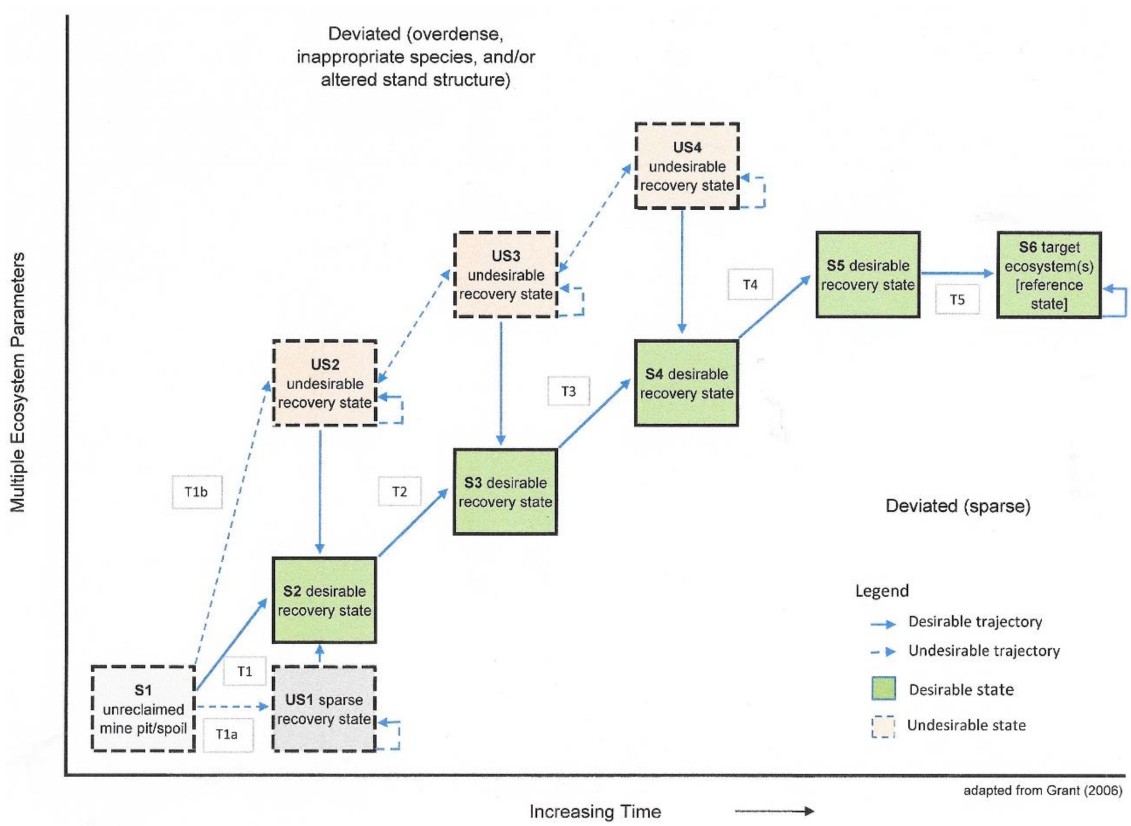

Figure 2. Generic State and Transition Model (STM) for a reclaimed mine

- Step 2b. Alternative States – Identify alternative states that can occupy ecologically equivalent sites. Similar to the reference state, alternative states may represent a group of plant communities comprising the range of variability within the state or may represent only a single community. Alternative states typically feature a distinct set of feedbacks and processes (Suding et al. 2003).

- Step 3. Narrative Description of Each State – Develop narratives that include (1) indicators of states, (2) feedbacks and ecological processes, and (3) management.

- Step 4. Plant Community Pathway Narratives – Community pathway narratives describe the mechanisms of change for plant communities within the same state where present. Once communities are grouped within states based on an understanding of shifts among phases, the specific causes of shifts among communities within a state (e.g., climate, management, disturbance, or changes in resource levels) should be described.

- Step 5. Transition Narratives – Transition narratives describe the mechanisms of change among states. In contrast to plant community pathways, transitions are associated with changing feedbacks and processes that subsequently limit the recovery of the previous state. Transition narratives and any gaps in understanding of process dynamics should be described.

- Step 6. Restoration Narratives – Restoration pathways describe the technologies, events, and conditions within alternative states (including susceptible plant communities) that can lead to recovery of the former state. Local knowledge linked with previous restoration efforts are valuable.

CASE STUDY

To illustrate the SWOT - C and STM tools described above, a historic underground mine with a small disturbance footprint located in the West Kootenays was selected as a case study.

<u>SWOT - C</u>

The Alpine Mine is a former underground mine that produced silver, lead, and zinc ore from 1938 to 1948. The property consists of 13 mineral claims and 15 Crown grants covering 2,602 hectares (ha). The property is located at the head of Sitkum Creek on Mount Cornfield, approximately 20 kilometers (km) north of Nelson, British Columbia. The focus of the case study is the old mine workings which is an area approximately 0.7 ha in size. A desktop-only SWOT - C analysis was performed for the Alpine Mine (Table 1) using online government and private sector resources readily available to the general public (Lacelle 1990, Mackillop and Ehman 2016, Giroux Consultants Limited and TerraLogix Exploration Incorporated 2018, BCMEMPR n.d.). While only a small underground historic mine, the high elevation of the site imposes environmental constraints in planning for reclamation. The ecosystems impacted by the disturbance are in the ESSFwcw-102 biological ecosystem classification (BEC) forested site series: krummholz (Sk), alpine meadow (Am), and rock outcrop (Ro) (MacKillop and Ehman 2016).

Table 1. Alpine Mine Reclamation Strengths, Weaknesses, Opportunities, Threats and Constraints (SWOT – C) Analysis

Category	**SWOT - C**	**Comments**
General Factors		
Political considerations	Constraint	mine is adjacent to Kokanee Glacier Park, is located at the headwaters of two community watersheds, and is within the traditional territory of the Ktunaxa First Nation (*indirect*)

Category	**SWOT - C**	**Comments**
Historical context	Opportunity	underground silver, gold, lead, and zinc mine developed in 1939 with principal production between 1940-1941 with minor production between 1946-1948 and in 1988 (*direct*)
Hazardous waste	Strength	no known hydrocarbon or contaminant spills (*direct*)
Resource constraints	Constraint	stream flow, short construction season, avalanching (*direct*)
Historical/archaeology	Strength	no recorded archaeological sites within 10 – 12 km radius (*direct*)
Human use patterns	Constraint	recreation (*indirect*)
Identify ecosystem stress points	Weakness	high elevation, short duration and low-temperature growing season, coarse textured soils (*direct*)
Property ownership	Opportunity	Braveheart Resources Inc. (13 mineral claims and 15 Crown grants) (*direct*)
General Constraints	Constraint	road access, availability of revegetation materials (*direct*)
Prior rights	Strength	E. Harrop & Assoc., Alpine Gold Ltd., Hudson Bay Oil and Gas, Cove Energy Corp., Cominco Ltd. (*indirect*)
Land use	Opportunity	recreation, community watershed (*indirect*)
Physical Factors		
Location	Opportunity	22.5 km north-northeast of Nelson, BC (*indirect*)
Mine site defined	Opportunity	roads and 1650 m of underground drifts, cross-cuts, raises, and adits (*direct*)
Landscape ecology considerations	Opportunity	small disturbance with remnant patches of forest and shrub vegetation in close proximity that can be used to enhance off-site/on-site linkages (*indirect*)
Climate	Weakness	short, low-temperature growing seasons, MAT = 0.4ºC, MAP = 1546 mm (*direct*)
Hydrology	Strength	project located at the headwaters of Sitkum Creek, Duhamel Creek, and Lemon Creek – seasonal flows (*direct*)
Groundwater	Opportunity	natural springs feed creeks during low flow runoff (*direct*)
Surface water	Weakness	surface water appears clean and free of debris and sedimentation (*direct*)
Water quality	Weakness	low levels of metals in general but above *BC Water Quality Guidelines* for cadmium (*direct*)
Topography	Weakness	steep, mountainous terrain (*direct*)
Elevation	Weakness	high elevation (2044 – 2166 m) (*direct*)
Slope and aspect	Weakness/Strength	south – southeast (*direct*)
Soil / spoil	Constraint	not characterized – undisturbed soils vary in in depth and stoniness (likely colluvial veneers/blankets and Regosolic and Brunisolic soils) (*direct*)
Soil testing	Weakness	physical and chemical characteristics not available (*direct*)
Biological Factors		
Ecosystems	Opportunity	ESSFwcw BGC variant – rock outcrops (Ro), alpine meadow (Am), alpine heath (Ah), and forested 102 and 103 site series (*direct*)
Successional patterns of existing vegetation	Weakness	natural disturbance type (NDT5), limited information on vegetation development anticipated to be slow (*direct*)
Habitat values and features	Strength	remnant patches of vegetation are present that provide habitat currently and may be employed to assist in revegetation (*indirect*)
Magnitude of degradation	Opportunity	roads, adits, mill site, and spoil – comparatively small surface disturbance footprint (*direct*)

Category	SWOT - C	Comments
Soil-plant-microbe	Weakness	unknown (*direct*)
Pollinator networks	Weakness	unknown (*direct*)
Wildlife resources	Threat	wide ranging carnivores (*indirect*)
Construction and Installation / Management		
Grading	Opportunity	resloping, recontouring required for surface disturbances, and adits closed off (*direct*)
Soil import/export	Threat	unknown soil resource potential (*direct*)
Drainage/flood control	Constraint	sediment fencing may need to be installed depending on grading and contouring requirements (*direct*)
Buffer requirements	Strength	potential timing window for equipment work due to wildlife species (*direct*)
Revegetation	Constraint	unknown 'natural' revegetation potential, site-specific collection of plant materials necessary for revegetation (*direct*)
Access/access control	Constraint	adits permanently closed, roads decommissioned, fencing around revegetation may be necessary (*direct*)

The parent materials for the regosolic and brunisolic soils consist of colluvium and decomposed bedrock, so overburden and/or cover soil materials will be stony and limited in volume. Placement of the cover soil materials will likely involve the strategic placement of the available cover soil resource. The absence of soil physical and chemical characterization for any surficial materials will necessitate soil sampling and analysis to best determine soil amendments and cover depths.

The revegetation goal is the reestablishment of native species dominated ecosystems; therefore, fertilizer formulations and application rates will need to be chosen carefully to accommodate the mineral nutrition of these species. Soils will likely be deficient in macronutrients.

The site is subjected to cold temperatures, frost, high snowpack, and a short growing season, all of which will limit vegetation recovery and productivity. The short growing season means that collection of plant materials (e.g., seed, seedling, and transplant sods), and revegetation establishment will take more than two growing seasons. Seeding will likely be best just before snowfall following site preparation, but transplant establishment may need to be undertaken, if necessary, just after snow melt.

A review of the provincial site guides indicates that there are several native herbaceous and woody species with known horticultural properties that could be established via direct seeding or seedling transplantation. The remnant patches of forest and shrub vegetation can be used as donor populations for plant ingress. A detailed site plan will need to be developed to fully design the spatial arrangement of revegetation activities.

<u>STMs</u>

Three STMs were developed for the site ecosystems: (1) krummholz/forest (Sk/102), (2) ‘alpine’ meadow (Am), and (3) rock outcrop (Ro) (Figure 3). The states described are primarily structural/functional categories (e.g., MI – mine, MZ – rubbly mine spoil, and RY – reclaimed mine) and could be refined with a detailed site inspection. The assumed successional trajectories (state transitions) will be dominated by facilitation and random colonization initially and later by a combination of the inhibition and tolerance mechanisms. The rate of change will likely be faster in more sheltered areas or on the cover soil ‘environmental resource’ patches.

Issues related to hydrology and water quality appear to be limited although protection of the stream/riparian areas below the surface operations will be necessary to prevent siltation effects during site preparation. No unique habitat features will need to be created for the wildlife species expected to use the reclaimed habitat. Online information sources indicated that there are no known archaeological signs, and the current land-use values are primarily recreation and watershed management which will be addressed through the reestablishment of native ecosystems.

Monitoring will need to be conducted for an extended period due to the short growing season at the site.

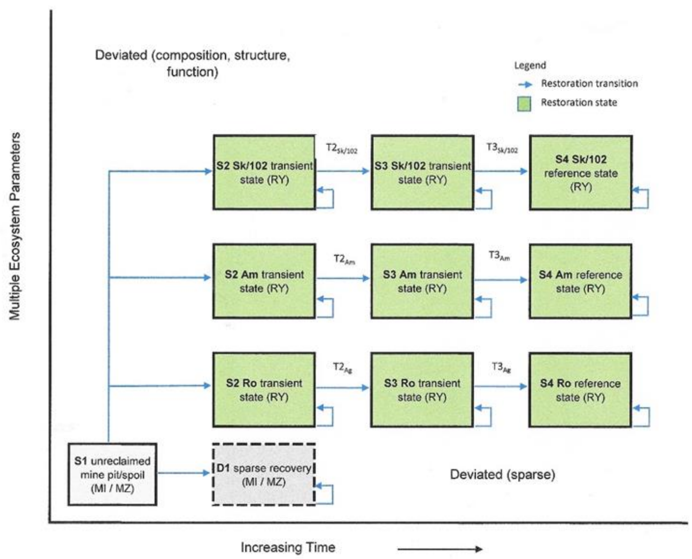

Figure 3. Alpine Mine State and Transition Model (STM) diagram

SUMMARY

SWOT-C analysis as a structured planning method and STM narratives as a description of the dynamics of ecosystem recovery, when combined, can be effective in developing ecologically based mine reclamation plans. These tools are used in an attempt to comprehensively document all potential factors influencing a mine reclamation program and to identify the mechanisms by which ecosystems recover following mining and their states or stages of development. STMs are also useful in developing an adaptive management frameworks and monitoring program. Data are typically collected prior to the completion of a SWOT-C analysis and the preparation of a STM. In the absence of site-specific empirical data, site assessment information for SWOT-C analyses and STM narratives can be generated from species and community literature.

REFERENCES

Bestelmeyer, B.T., K. Moseley, P.L. Shaver, H. Sanchez, D.D. Briske and M.E. Fernandez-Gimenez. 2010. Practical guidance for developing state-and-transition models. *Rangelands*, 32, 6, 23-30.

Bradshaw, A. 2000. The use of natural processes in reclamation – advantages and difficulties. *Landscape and Urban Planning*, 51, 89-100.

British Columbia Ministry of Energy, Mines and Petroleum Resources (BCMEMPR). n.d. *Alpine Gold*. Minfile Detail Report. British Columbia Geological Survey, Ministry of Energy, Mines and Petroleum Resources, Victoria. 3 pp.

Burton, C.M. and P.J. Burton. 2003. *A Manual for Growing and Using Seed from Herbaceous Plants Native to the Northern Interior of British Columbia*. Symbios Research and Restoration, Smithers. 179 pp.

Cooke, J.A. and M.S. Johnson. 2002. Ecological restoration of land with particular reference to the mining of metals and industrial minerals: A review of theory and practice. *Environmental Review*, 10: 41-71.

Del Moral, R. and J.H. Titus. 2018. Primary succession on Mount St. Helens: determinism and alternate states. *Ecological Responses at Mount St. Helens: Revisited 35 Years after the 1980 Eruption*. C.M. Crisafulli and V.H. Dale, Editors. Springer Nature, New York. pp. 127-148.

Fire Effects Information System (FEIS). 2019. *Fire Effects Information System*. United States Forest Service, Department of Agriculture, Washington DC. https://www.feis-crs.org/feis/

Frid, L. and C. Daniels. 2012. *Developing a State-and-Transition Model in Support of Reclamation Planning. Final Report*. Contract 2012-0005. Prepared for the Cumulative Environmental Management Association by Apex Resource Management Solutions Limited, Ottawa. 97 pp.

Giroux Consultants Limited and TerraLogix Exploration Incorporated. 2018. *NI 43-101 Technical Report for the Alpine Property British Columbia, Canada*. Prepared for Braveheart Resources Incorporated by Giroux Consultants Limited and TerraLogix Exploration Incorporated, North Vancouver/Cranbrook. 84 pp.

Grant, C.D. 2006. State-and-transition successional model for bauxite mining rehabilitation in the Jarrah forest of Western Australia. *Restoration Ecology*, 14, 1, 28-37.

Hardy BBT Limited. 1989. *Manual of Plant Species Suitability for Reclamation in Alberta*. Second Edition. Alberta Land Conservation and Reclamation Council Report No. RRTAC 89-4. Queen’s Printer, Edmonton. 436 pp.

Kumar, N.P, and I. Rathore. 2015. The need of mining industry – a SWOT analysis. *International Research Journal of Earth Sciences*, 3, 8, 32-36.

Lacelle, L.E.H. 1990. *Biophysical Resources of the East Kootenay Area: Soils*. Wildlife Technical Monograph TM-1. Report No. 20. British Columbia Soil Survey. Habitat Inventory Section, Wildlife Branch, British Columbia Ministry of Environment, Victoria. 359 pp.

Luken, J.O. 1990. *Directing Ecological Succession*. Chapman and Hall Publishers, London. 251 pp.

MacKillop, D. and A.J. Ehman. 2016. *Field Guide to Ecosystem Classification and Identification for Southeast British Columbia*. The South-Central Columbia Mountains. Land Management Handbook 70. British Columbia Ministry of Forests, Lands and Natural Resource Operations, Kootenay-Boundary Region, Nelson. 491 pp.

Premier Pacific Seeds. 2019. *Product Guide*. Premier Pacific Seeds Incorporated, Surrey. 20 pp.

Province of British Columbia (BC). 2019. *British Columbia Data Catalogue*. https://catalogue.data.gov.bc.ca/dataset?download_audience=Public.

Rieger, J., J. Stanley and R. Traynor. 2014. *Project Planning and Management for Ecological Restoration*. Island Press, Washington DC. 313 pp.

Stringham, T.K., W.C. Krueger and P.L. Shaver. 2003. State and transition modeling: an ecological process approach. *Journal of Range Management*, 56, 106-113.

Suding, K.N., K.L. Gross and G.R. Houseman. 2003. Alternative states and positive feedbacks in restoration ecology. *Trends in Ecology and Evolution*, 19, 1, 46-53.

Tongway, D.J. and J.A. Ludwig. 2011. *Restoring Disturbed Landscapes. Putting Principles into Practice*. Island Press, Washington DC. 210 pp.

Tripathi, N., R.S. Singh and C.D. Hills. 2016. *Reclamation of Mine-Impacted Land for Ecosystem Recovery*. John Wiley and Sons, Chichester. 201 pp.

Wang, T., A. Haman, D.L. Spittlehouse, T.Q. Murdock. 2012. ClimateWNA – high resolution spatial climate data for western North America. *Journal of Applied Meteorology and Climatology*, 51, 16-29.