TOWARDS REVEGETATION SUSTAINABILITY CRITERIA FOR NORTHERN MINE CLOSURE

PREPARED FOR:

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MOSAICS OF NATIVE PLANTS FORM SUSTAINABLE ECOSYSTEMS IN THE NORTH.

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EXECUTIVE SUMMARY

Restoration is the process of *assisting* the recovery of ecosystems that have been damaged, degraded or destroyed (SERI 2004). The best we can do is help the natural processes recover the species and processes that are appropriate for the site being treated (Polster 2009). Natural processes such as succession (Polster 1989) provide a framework upon which sustainable restoration can occur. Monitoring systems to determine if sites have been effectively reclaimed must consider if the site has been re-integrated with the natural successional processes that operate in the region of the disturbance. This requires that the natural successional processes that operate in the region be documented. Although this determination has not been made for many northern areas including most northern mines, there is literature that explores the vegetation patterns on northern disturbances (Polster 2010; Polster and Bell 1980; Bliss and Wein 1972) and thus helps to define the successional trajectories.

Vegetation establishment on drastically disturbed sites requires that the filters or constraints preventing recovery be overcome. These filters include steep slopes, adverse texture (too coarse or too fine), nutrient status, adverse chemical properties, and soil temperature extremes (Polster 1991). In addition, compacted substrates, adverse micro-climatic conditions, and excessive erosion (Polster 2009) can prevent recovery. A lack of plant propagules may prevent some species from establishing (Walker et al. 2007); although in most cases in Canada where fire has played a role in ecosystem development pioneering species have developed effective mechanisms for establishing on distant sites. Species such as Mountain Avens (*Dryas* spp.) and Fireweed (*Epilobium* spp.) have well developed wind-blown seeds that can carry the seeds across vast distances. In some cases reclamation treatments may prevent the recovery of disturbed sites (Polster 2009). Sites where seeded grasses and legumes have established a dense cover of vegetation may preclude establishment of pioneering species that would initiate successional recovery.

Monitoring systems that first identify the appropriate pioneering species that operate in an area and then seek to find these on the reclamation sites will be most effective. Where pioneering species are not occurring on the reclaimed site, the filters that are preventing their occurrence must be determined and rectified. This may entail a significant amount of work including re-contouring the disturbed areas to blend with the natural landforms in the area being restored. In addition, creation of safe sites (Temperton et al. 2003) may be needed to allow pioneering species to establish. If this has been completed and pioneering species have continued to evade establishment, artificial means of establishment (seeding and/or planting) must be considered. It is important not to go to seeding and/or planting until all of the abiotic filters have been addressed and, once the decision has been taken to establish vegetation artificially, that the right species are selected.

1.0 INTRODUCTION

Ecological restoration is the process of assisting the recovery of ecosystems that have been damaged, degraded or destroyed (SERI 2004). Understanding what can be done to assist these natural recovery processes is the first step in development of sustainable restoration. Traditional mine reclamation has not considered sustainability issues (Polster 2007) Unfortunately, traditional reclamation treatments have largely failed to deliver treatments that re-integrate the disturbed area into the local ecosystem processes (Polster 1989). Photographs 1 and 2 show a site that was reclaimed in 1977 using state-of-the-art techniques. The lack of significant woody species ingrowth from the surrounding forest is clear in Photograph 2. Treatments such as the grass and legume seeding that was conducted on this exploration trench have blocked the recovery of this site.

Photographs 1 (left) and 2 (right). This exploration trench was seeded in 1977 (left). By 2009 (right) few woody species had established even though the forest was right beside the trench. The reclamation work conducted on this trench is not sustainable.

What are the factors that make restoration sustainable? This report provides a summary of the elements that create sustainable restoration. The report suggests monitoring strategies that could be used to determine the sustainability of reclamation work that has been conducted at northern mines.

2.0 METHODS

This report is a review report. No actual field work was conducted in support of this study. However, a detailed review of materials on the Ekati Mine that were provided to the author by the Independent Environmental Monitoring Agency was conducted. In addition numerous field assessments of northern mines and other industrial disturbances have been conducted by the author in support of reclamation/recovery studies including studies at the Faro Mine, the Giant Mine, the Colomac Mine and seismic disturbances throughout the Yukon and the southwest corner of the NWT. In addition, demonstration reclamation treatments of alluvial mine disturbances were established in the Klondike region of the Yukon in 2004 and have been followed opportunistically since establishment. All of the studies have provided a context within which restoration/recovery processes and by inference, sustainability criteria can be assessed.

In order to be sustainable, restoration treatments must re-integrate the disturbed lands with the natural recovery processes that operate in the area in question. Although many criteria have been suggested for the level of productivity that reclaimed lands should achieve, from detailed agricultural productivity levels established in the requirements for reclamation in some parts of Alberta to the more general requirement in British Columbia to achieve a level of productivity equal to or better than that which existed at the site prior to mining. In general most jurisdictions require that reclamation meet or exceed productivity values associated with the pre-disturbance conditions. At northern mines and drastically disturbed sites, re-integration with the natural recovery processes that will return productivity values in a reasonable time frame can be considered appropriate. The following criteria are based on this framework.

3.0 SUSTAINABILITY CRITERIA

Sustainable restoration must be able to re-integrate the disturbed lands with the surrounding lands. Ecosystem processes that operate on non-disturbed adjacent areas should eventually operate on the restored lands. These would include soil-forming processes, nutrient cycling processes, vegetation replacement processes and resiliency. Understanding the way ecosystems establish (assembly rules) can help define treatments and techniques for putting them back together once they have been destroyed (Temperton et al 2004). Similarly, understanding the natural successional trajectories that operate in the areas in question can help in the design of restoration strategies (Walker et al 2007). Pioneering plants such as willows, alders, poplars and others can initiate the natural successional processes that lead to sustainable restoration. In northern areas within the forested zones, species such as willows, alder, aspen and other poplars dominate the early successional stages that lead to recovery. Above the tree line processes are similar but the species may change. Mountain Avens (Dryas spp.) and a variety of species with wind-borne seeds such as fireweeds (*Epilobium* spp.) may be more important (Polster, 2009). Treatments that can be shown to re-establish natural successional trajectories can be considered sustainable (Photographs 3 and 4) while those that do not result in the re-establishment of natural successional trajectories (Photographs 1 and 2) are not considered sustainable.

Photographs 3 (left) and 4 (right). Seeding Sitka Alder on this 0.8:1 rock cut in October, 1986 (left) resulted in re-establishing the natural successional processes that by August, 2009 resulted in a cover of healthy conifers on the rock cut.

Species such as Sitka Alder in the Roger's Pass (between Golden and Revelstoke, BC) can serve as facilitators (Walker and del Moral 2003) as it creates conditions that allow other species to move in and 'facilitates' the establishment of ecosystems even though it is only one species. Similar species, possibly Mountain Avens (*Dryas* sp.) will occur at northern mines. Willows are commonly facilitators of drastically disturbed sites and can often be found as early colonizers of mines and other drastically disturbed sites. Identification of the facilitators that operate in the region is the first step in developing sustainable ecosystems. The specific species that will serve as the facilitators at specific mine sites may differ although they will all be common on disturbed sites and will be seen to create conditions that foster invasion by other species. At the Faro Mine, willows and alder both serve to facilitate recovery and thus can be used as indicators for recovery.

2.1 Landforms

Natural ecosystems form on naturally shaped landforms. Eventually erosion processes will create naturally shaped landforms from shapes human activity leaves. We can assist this process by re-contouring waste rock dumps so that they fit in the landscapes they are located in. By creating naturally shaped landforms, the physical structures that are essential for the re-establishment of ecological processes are in place. Photograph 5 shows a waste rock dump that remains in stark contrast to the natural landforms, while Photograph 6 shows a waste rock dump that has been re-contoured to blend with the surroundings. Creating naturally shaped landforms provide the foundation for the re-establishment of natural processes on the disturbed lands. Failure to provide this basic restoration treatment will lead to a failure to re-integrate the disturbed lands with the natural successional processes and thus a failure to meet sustainability goals. Since landforms change very slowly, the re-shaping of mining landforms is the critical first step in restoring lands disturbed by mining.

Photographs 5 (left) and 6 (right). The flat tops and angle-of-repose slopes shown on the right will remain for many millennia, precluding effective ecosystem development. Re-contouring waste rock dumps to fit with the surrounding landscape will allow them to re-integrate into the natural ecosystem processes easily.

Once landforms have been effectively re-established, application of available soil materials can greatly enhance the recovery of degraded ecosystems. Although natural recovery of ecosystems can occur without soil replacement, the replacement of soils can speed up this process by many thousands of years. Photograph 7 shows a landslide site where natural soil development is allowing pioneering species to move in from the edges. Where sites are stable, the collection of organic matter in the spaces between large rocks provides a site where pioneering species can become established (Polster and Bell 1980). These pioneering species create additional soil and facilitate the invasion by later successional species, re-establishing the natural successional trajectory that leads to sustainable plant communities. Adding soil to cover waste rock greatly speeds up this process as natural organic matter collection can take many centuries.

Soil brings with it the potential for erosion. Seeding in a cover of grasses and legumes is often cited as the best way to control erosion. However, as has been suggested above, seeding in a cover of grasses can prevent invasion by native species and arrest successional processes. Therefore, alternative erosion control treatments are needed. Making the surface rough and loose is a simple, cost-effective way of eliminating erosion caused by water running across the surface of the ground. In addition to preventing erosion, making a site rough and loose creates safe sites (Walker and del Moral 2003) where seeds of pioneering species can land and grow. In addition, rough and loose sites trap winter snow and allow moisture to soak into the soil so that it is available for plants. Also, by creating a diversity of exposures, rough and loose terrain provides opportunities for a diversity of plants to establish. Creation of habitat diversity is the key to creating ecological diversity which in turn creates greater stability and resilience.

Photographs 8 and 9 show some of the attributes of rough and loose surfaces in industrial situations.

Photograph 7. Organic matter and dust that collects in the pockets between the rocks provides a rooting medium for pioneering species, in this case Balsam Poplar. These then facilitate the invasion by conifers until eventually this rock slide (Frank Slide) is re-covered by forests.

Photographs 8 (left) and 9 (right). Rough and loose terrain traps winter snow (left) and prevents erosion on steep slopes (right) by preventing water from running down the slope.

Rough and loose surface configurations can be achieved by using a large excavator to open holes on the slope, dumping the material that is generated from the holes in mounds between the holes. The excavator, using a digging bucket (not clean-up), takes a large bucket full of soil and places it to the left of the hole that was just opened, half a bucket width from the hole so it is half in and half out of the hole. A second hole is then excavated half a bucket width to the right of the first hole. Material from this hole is then placed between the first and second holes. A third hole is now opened half a bucket width to the right of the second hole, with the excavated soil placed between the second and third holes. Care should be taken when excavating the holes to shatter the material between the holes as the hole is dug. The process of making holes and dumping soil is continued until the reasonable operating swing of the excavator is reached. The excavator then backs up the width of a hole and repeats this process, being sure to line up the holes in the new row with the space between the holes (mounds) on the previous row. Photograph 10 shows an excavator making a rough and loose surface on the Kemess Mine tailings dam face (whole dam shown in Photograph 9.

Photograph 10. Rough and loose surface configurations are easy to construct using a large excavator and cost about one-third the cost of traditional hydroseeding.

2.2 Plant Communities

Establishment of appropriate plant communities can be the trickiest part of restoring a site. Although the tendency is to look around and see what is growing in undisturbed areas adjacent to the site to be restored and to focus on those species, often these are late successional species and will not perform well on the early seral sites that are being treated. The species that are coming in on the edges of roads and on older areas that have been abandoned can give useful indications since these are the pioneering species. Check to be sure that these species are not just responding to a compacted surface or some other constraint (filter). Most pioneering species will have wind-blown seeds so that the seeds can travel great distances between recently disturbed sites. In addition, they may be associated with nitrogen fixation or have the ability to live in nutrient poor situations. Species such as Lupines and Mountain Avens are nitrogen fixing while species such as Cotton-grass and various sedges (*Carex* spp.) can tolerate low nutrient conditions.

Identification and tracking of native invaders is important in defining the sustainability of the reclaimed site. As sites age there should be an increase in the numbers of species that are found up to a point where the number of species on the reclaimed site is slightly below the number of species found in the native ecosystems around the site (Hobbs and Suding 2009). Eventually, species numbers should equilibrate, but this may not happen for many centuries as soil conditions need to mature. The Island Copper Mine illustrates the processes that can be used for monitoring for sustainability at northern mines. Of course the species will differ and would need to be determined specifically for each mine in question. Figure 1 shows a graph of Swordfern and Salmonberry invasion onto reclaimed areas at the Island Copper Mine near Port Hardy, BC. This BHP Billiton mine closed in 1995 with the major planting on the Beach Dump and North Dump being undertaken in 1996. The data for Figure 1 was derived from assessments conducted on the Beach Dump and the North Dump. Assessment methodology is discussed in Section 3 of this report.

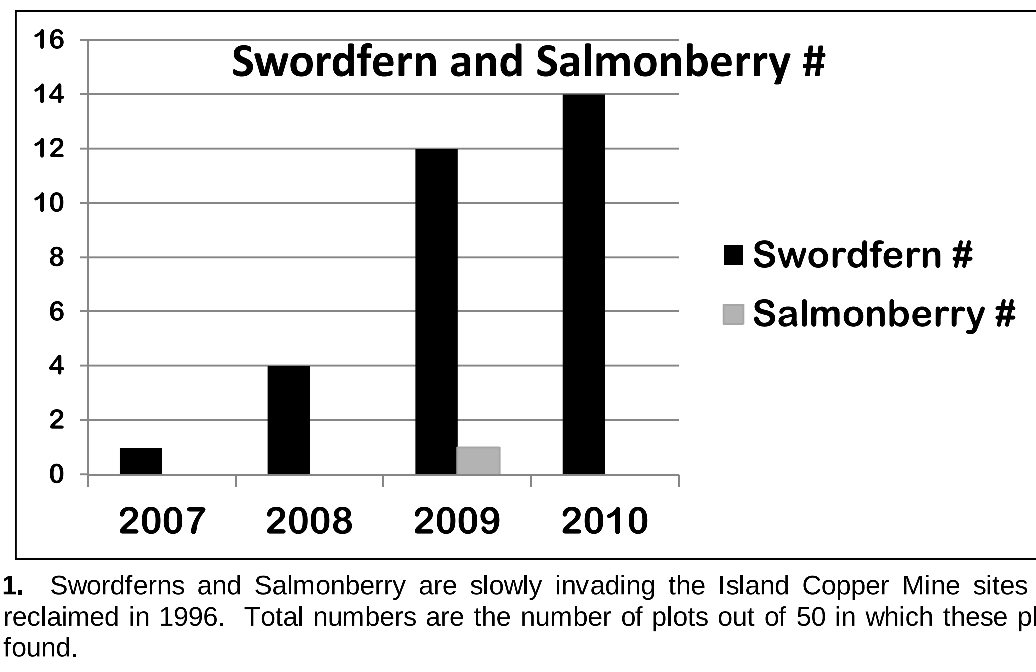

Figure 1. Swordferns and Salmonberry are slowly invading the Island Copper Mine sites that were reclaimed in 1996. Total numbers are the number of plots out of 50 in which these plants were found.

Creating conditions that foster invasion by pioneering species is essential to ensure reclaimed sites are sustainable. Preventing conditions that prevent invasion is another way of looking at providing appropriate opportunities for plant community establishment. Vegetation requires ‘safe sites’ to establish and grow (Hobbs and Suding 2009). These sites may need to be free of competition or moist during the germination and early growth period. They may need to be shaded or sunny or free of herbivores. Areas that are continually windy may need sheltered locations where seeds can land and plants can establish. There are a wide variety of conditions that may need to be provided to allow plants to establish and grow. Many of these conditions are provided by creation of rough and loose surfaces. Photographs 11 and 12 show two different types of ‘safe sites’.

Photographs 11 (left) and 12 (right). This crevice in the rock face provides a safe site for the germination and growth of Stonecrop while the moist mud at the edge of the puddle creates a safe site for Balsam Poplar seeds to germinate and grow.

2.3 Ecosystem Processes

Re-establishing ecosystem processes can be difficult. Large quantities of thatch that occur on some reclaimed sites are indicative of limited decomposition and nutrient cycling. Seeding with grasses and legumes in ecosystems that are not grasslands may create conditions of excessive thatch (Photograph 13). In addition, the traditional practice of adding fertilizers because the seeded grasses and legumes are doing poorly can result in excessive thatch that further slows the re-establishment of ecological processes. Establishing appropriate micro-organisms on recently reclaimed areas may be difficult in areas where biomass generation and turn-over is slow such as in the Ekati region. In more temperate areas, the use of leaf litter collected from adjacent undisturbed areas or the use of large woody debris can be effective in bringing these organisms onto reclaimed sites. Looking at the health and vigour of the vegetation that establishes can be a good indicator of the ability of the ecosystem to cycle nutrients. If the vegetation looks sickly and stunted, do not add fertilizer, instead consider creating conditions that foster nutrient cycling.

Small mammals can be important in moving the spores of fungi and bacteria onto reclaimed areas. Creating habitat that attracts these animals can be an effective way of bringing these organisms onto the reclaimed areas. Providing habitat links between natural areas and the reclaimed areas can assist in bringing soil micro-organisms onto reclaimed sites. Similarly making a 'tea' using organic matter from adjacent natural areas can help to introduce appropriate fungi, bacteria and viruses to otherwise barren sites. Lichens and mosses can be important contributors to the early stages of nutrient cycling on bare sites.

Photograph 13. Dense thatch caused by heavy grass growth, often assisted by maintenance fertilization and a lack of appropriate decomposers can tie up nutrients and result in the stagnation of successional processes.

3.0 MONITORING STRATEGIES

Monitoring to determine if reclamation work is sustainable is far different than monitoring that might be conducted to ascertain plant health or cover. The following points must be considered when looking at sustainability of restoration:

- Is the vegetation on a sustainable successional trajectory?
- Are ecosystem functions being re-established?
- Is soil being developed?

- Is ecosystem structure being re-established? and,
- Can the established ecosystem withstand perturbations (is it resilient)?

These components of the monitoring systems are discussed below.

3.1 Measuring Successional Trajectories

Successional trajectories are measured by documenting the changes in species composition and cover that occur in the ecosystem. For instance, in the example given in Photographs 3 and 4, the initial cover of Sitka Alder has been replaced by a cover of conifers. There are still some alder plants on the site, but a diversity of conifer species has established. Unfortunately this site is on a very steep rock cut and detailed assessments are not possible. However, visual monitoring of this location can reveal a lot about how ecosystems recover. Assessments are conducted by photographically monitoring the treated areas. The graph shown in Figure 1 is from the Island Copper Mine. Here the area was seeded with grasses and legumes and planted with Red Alder. Assessment methods consist of transects with plots spaced along the transects. Each transect is about 300 m long (depends on if a plot is located at the start or not) with plots established every 30 m for 10 plots/transect. Five transects have been established, although the fifth transect was only established in 2004. The other four transects were established in 1997, one year after the major reclamation work was completed at the mine.

Each plot along the Island Copper transects consists of a circle 5.62 m in radius, giving a plot area of 100 m^2. In the early years data recorded in the plots consisted solely of the number of planted trees (alder or pine) that were surviving, the percent cover of legumes and the total vegetation cover. More recently in addition to the number, size and cover provided by the woody species and a listing of all of the species that occur in the plots along with an estimate of their combined cover and abundance is collected. Data are analysed using simple parametric statistics (means and variance). Figure 2 shows a graph of the alder numbers at the mine.

The graph of alder numbers shows interesting patterns. Up until 2007 or 2008 if the question about sustainability arose, the answer would have to have been, ‘We don’t know’. The trend in alder numbers for a number of years was downward. It turns out that the seeded grasses and legumes were out-competing the alder and killing it, leaving large open areas where alfalfa dominated, ringed by dead alder (Photograph 14). In recent years, however, the planted alder have matured to the point where they are producing seeds and the heavy seed rain is allowing additional alder plants to establish. It is also interesting to note that the numbers of alder in the pine area (Transects 3 and 4) are increasing as well. Here the natural recovery processes are moving the ecosystem into alignment with the appropriate natural successional trajectory. Red Alder is the major pioneer on disturbed mineral soil sites. The roots of this species are associated with nitrogen fixing bacteria so this species adds nitrogen to a site. In addition, leaf litter from this species is full of nitrogen so every fall the soil is improved by the deposition of leaves. The pine that was planted in this area is inappropriate and natural processes are trying to fix this so therefore there is an increase in alder numbers.

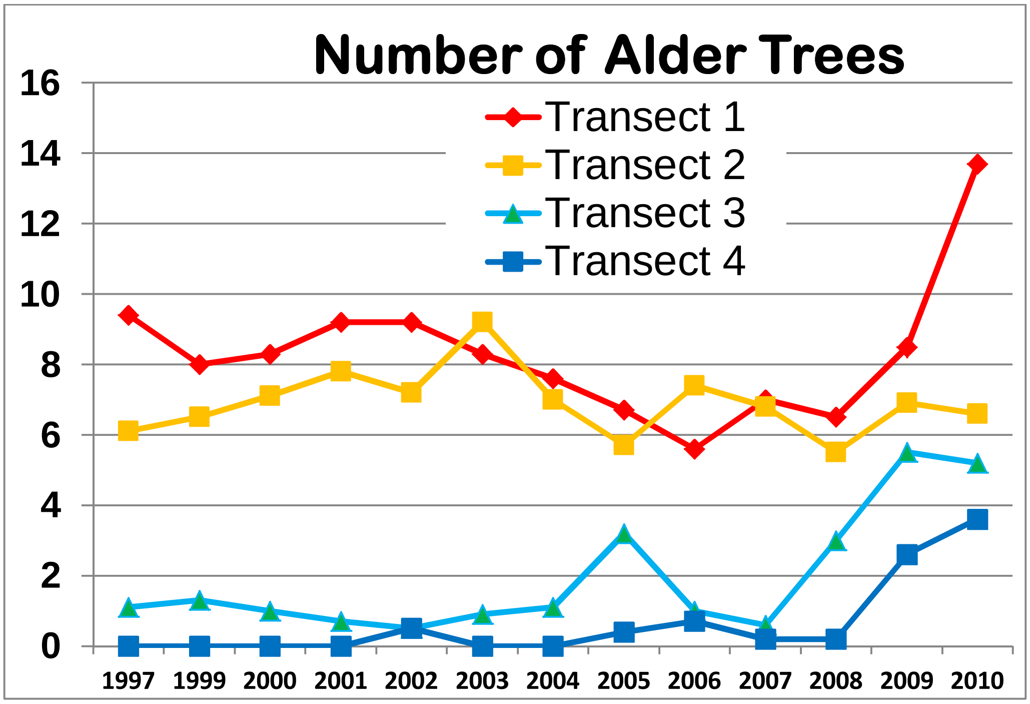

Figure 2. Numbers of alder trees along four of the transects at the Island Copper Mine.

Photograph 14. Dense stands of seeded grasses and legumes have been out-competing the planted alder at the Island Copper Mine. This area was fully stocked with alder at the time of planting in 1996.

The question of sustainability at the Island Copper Mine is complicated by the fact that the area was seeded with grasses and legumes. This creates a filter or barrier to recovery that may be difficult for the natural successional forces to overcome. Without the seeded grasses and legumes, it is probable that the recovery would be faster and could be guaranteed at this point. Figure 3 shows a model of how ecosystem degradation occurs. This model suggests there are thresholds across which it is difficult to move an ecosystem. When restoration occurs some effort must be made to re-cross the threshold(s). Mining sites have crossed a substantial abiotic threshold. When seeding with grasses and legumes is added, both an abiotic and a biotic threshold must be re-crossed. This can be clearly seen in the Island Copper example where the abiotic threshold of mining wastes has been crossed by capping with till. But the biotic threshold is more problematic.

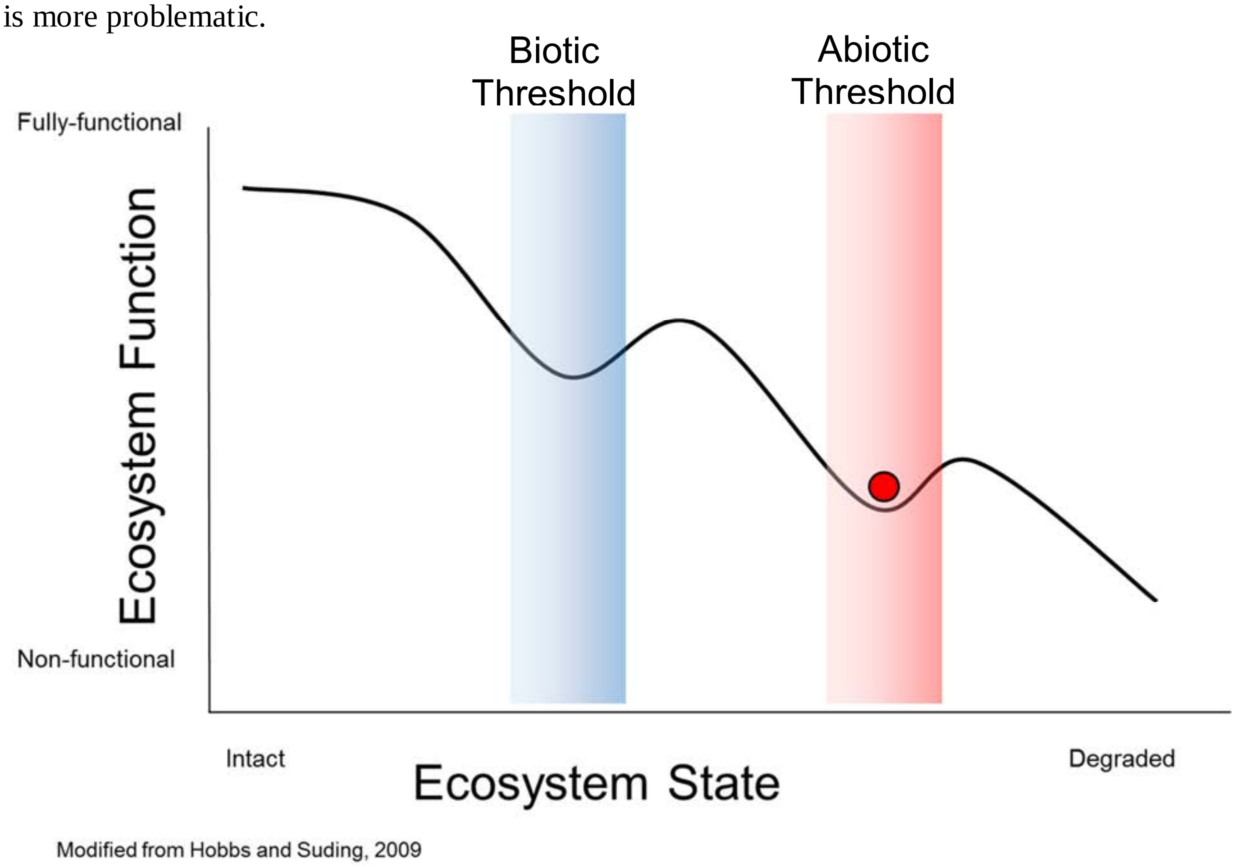

Figure 3. Model of how ecosystems unravel suggesting that the state thresholds (biotic and abiotic) require substantial effort to overcome. The red ball represents an ecosystem, in this case caught in the trough of an abiotic threshold, possibly compaction or lack of nutrients.

The monitoring system that has been developed for the Island Copper Mine is proving to be very useful in assessing the ecological trajectory of the minesite vegetation. The results that are arising from this monitoring, however, are not providing the expected answer. The standard practice when the mine site was reclaimed was to seed with grasses and legumes under the mistaken impression that doing so would assist in the recovery of the site. It is clear from the monitoring that has been undertaken that this is not the case and that rather than helping the recovery of the site; the seeded species are actually hindering recovery by forming a biotic threshold that the restored ecosystem must now go through.

3.2 Monitoring Ecosystem Functions

Ecosystem functions are difficult to measure so surrogates are used. Nutrient cycling can be particularly difficult to follow directly. However, vegetation is a very good indicator of how effectively nutrient cycling systems are operating. Photographs 3 and 4 show a 0.8:1 rock cut in the Roger's Pass where vegetation was established directly on the rock by seeding in the pioneering species Sitka Alder (too steep to plant seedlings). The alder provided the initial pioneering cover that fixed nitrogen and added leaf litter (nutrient rich organic matter). This facilitated invasion by conifers and now, 23 years later, a healthy stand of conifers has established. The conifers have good colour and are growing well. No fertilizer or other management treatments have been applied since the alder seeding in 1986 so one must assume that nutrient cycling processes are operating effectively. Photographs 15 and 16 taken from the 2010 Ekati Revegetation Report show the Misery Topsoil Stockpile where a dense thatch of vegetation has established from the seeded vegetation. Native species, Cotton Grass (*Eriophorum*) and willows have invaded in moist depressions where the competition from the seeded species is reduced, suggesting that as is the case with the Island Copper Mine, natural processes are trying to do the right thing but are blocked by the biotic threshold of the seeded species.

Photographs 15 and 16. Two permanent transects at the Misery Topsoil Stockpile showing a dense thatch of seeded species with poor colour and a lack of decomposition suggesting poor nutrient cycling (photos from 2010 Ekati Revegetation Report.

Monitoring ecosystem function should be based on visual assessments of plant health. Established plants will show how well ecosystem processes are functioning. If the plants look poorly, then the ecosystem is functioning poorly. However if the plants look healthy and detritus is being decomposed and recycled then it can be assumed that ecosystem functions are doing well. Care should be taken to avoid mistaking a fertilizer response for a health ecosystem.

3.3 Monitoring Soil Development

Soils develop slowly so monitoring soil development is difficult within short time frames. In addition, soils can be very heterogeneous so the composition of soils as measured by standard soils analysis methods in one area may differ markedly from those in an area immediately adjacent to that area. Therefore soil monitoring is tricky and it is better to look at the results of a healthy soil, healthy vegetation, than to get involved in detailed soil sampling.

3.4 Monitoring Ecosystem Structure

Ecosystem structure can play an important role in the ecology of recovering ecosystems. At the Island Copper Mine, Swordferns did not start showing up until the alder trees were big enough to catch the wind-borne spores 10 years after planting. Similarly, species such as Salmonberry show up when trees get large enough to provide perches for birds carrying seeds. In the Ekati area, trapping winter snow may be an important function of structure in the community. To some extent, this could be addressed by making a site rough and loose so that winter snows get trapped in the hollows (see Photograph 8). Monitoring the development of structure in the restored ecosystem can be conducted by simply noting the height of the species that are encountered during the monitoring of successional trajectories (discussed above).

3.5 Resiliency

Resiliency is another ecosystem attribute that is hard to measure. Consideration should be given to the natural disturbance regimes that are anticipated at the site and the ability of the established ecosystems to recover from these disturbances. There may be relatively few natural disturbances associated with northern mine areas, although the impacts associated with caribou herds moving through should be considered. The study of resiliency in restored ecosystems is in its infancy so detailed procedures for such studies have not been developed (Hobbs and Suding 2009). Further consideration of this topic can be developed within the context of the successional trajectory monitoring.

4.0 CONCLUSIONS

What makes a restored ecosystem sustainable? It may be easier to answer this question by eliminating those factors that make an ecosystem un-sustainable. For instance, a grassland within a forest as is shown in Photographs 1 and 2 is clearly not sustainable. Similarly, sites where nutrient cycling and soil forming processes are thwarted such as those shown in Photographs 14, 15 and 16 are clearly not sustainable. What about restored sites that may be sustainable such as the Island Copper Mine example presented above, but might lapse into a condition where nutrient cycling and soil forming processes are stymied by a dense cover of seeded species? In these cases, it may be that the answer will come with continued monitoring. Sites such as the Roger's Pass site shown in Photographs 3 and 4 are clearly sustainable; monitoring is not needed to see this. Monitoring programs are therefore needed on sites where the question of sustainability remains un-answered.

Monitoring systems such as the one used for over a decade at the Island Copper Mine can be very effective. In this case, large plots (1/100th of a hectare) strung out over a large area provide an effective sampling of the vegetation. Nested plots such as the Daubenmire method where a smaller detailed sampling plot is located within a larger plot where less detail is collected can be used to collect detailed vegetation information (Photograph 17). However, within the context of mine reclamation, this detail may serve to obscure the obvious. The key issue at some northern mines may be a lack of sufficiently large areas that have been reclaimed to sample, although this may be beneficial as restoration strategies may need to be modified to achieve success.

Photographs 17. Detailed sampling using a Daubenmire frame in a Garry Oak ecosystem provides information at a very fine scale and may not be appropriate for mine sites where areas are large and heterogeneous.

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