NATURAL PROCESSES: THE APPLICATION OF NATURAL SYSTEMS FOR THE RECLAMATION OF DRASTICALLY DISTURBED SITES

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ABSTRACT

Natural processes have been revegetating severely disturbed sites since the beginnings of terrestrial vegetation on Earth over 400 million years ago. Natural systems have developed to address all of the problems associated with unvegetated sites. Bare rock is colonized by lichens while shifting sands are revegetated with stout rhizomatous grasses and mat-forming woody species. Understanding how these natural processes that have evolved over millions of years allows us to use these processes to solve some of the toughest reclamation challenges facing us. Erosion is one of the most significant issues associated with reclamation of disturbed sites. Steep slopes, a subset of erosion issues, are a significant problem at many mine sites. Creation of a number of short steep slopes can reduce the problems of long steep slopes. A lack of plant nutrients is another common problem on disturbed sites. The use of nitrogen-fixing species can provide nutrients for other plants. Providing plants for revegetation of large areas disturbed during mining can present another challenge. Understanding what pioneering plants need to allow them to establish naturally, and creation of the conditions that will allow these species to naturally establish, can greatly reduce the costs of artificially establishing woody species. For every problem faced in mine reclamation, natural systems have a solution; the trick is to identify the solution that will work for the issues at hand. This paper explores the natural solutions to many of the common mine reclamation problems.

KEY WORDS: Keystone species; successional reclamation; filters; successional trajectories; soil surface configuration; and pioneering species.

INTRODUCTION

Reclamation of large mining disturbances can be a costly, complex operation full of unknowns – *Which species should I select for my initial cover? How should I establish these species? Should I be planting other species to provide a specific cover for the designated end land use? What about maintenance?* All of these questions must be set within the ecological context of the site being reclaimed. For instance, the species that might be selected for provision of wildlife habitat would be different in Southeastern British Columbia from those that would be appropriate in the Cariboo. In addition, within any particular site there will be species that will be appropriate on south facing slopes and those that will do better on northern exposures. Similarly, species that will do well on a coarse waste rock dump will be different than those that should be established around the margins of a settling pond. Deciding how to deal with the wide diversity of sites and conditions can be daunting. However, for every condition faced at a mine, natural processes have developed a solution; the trick is to identify what is limiting the natural recovery of the site and then determine how natural processes have overcome this limitation.

The Society for Ecological Restoration International (SERI 2004) defines ecological restoration as the process of assisting the recovery of ecosystems that have been degraded, damaged or destroyed. The key aspect of this definition that we need to keep in mind when we are restoring damaged sites is that at best, all we can do is assist in the recovery process. We cannot make recovery happen any more than we can cause a scab to form on a cut. However, there is a diversity of things that can be done to assist the recovery of damaged ecosystems. This paper explores the things that can be done to help severely disturbed ecosystems recover from degraded conditions. The use of natural successional processes as a model for restoration of difficult sites provides a framework for restoring these sites while observation of how these natural successional processes operate and the filters or limitations that prevent or slow these processes fills in the details. The application of natural processes in the restoration of drastically disturbed sites is presented in this paper.

IDENTIFYING FILTERS

The first step in assisting the recovery of degraded sites is to determine what filters are preventing natural recovery from happening (Clewell and Aronson 2007). At many mine sites steep slopes, compacted substrates, dark substrate colours, adverse chemical properties, including the lack of essential plant nutrients, adverse micro-climatic conditions and excessive erosion can prevent vegetation establishment. Erosion can be an important filter that prevents recovery. Sites that are actively eroding, either because they are too steep, too compacted, too smooth or a combination of these factors may have little chance of recovering and some remedial action may be needed.

There may be a complex series of filters or constraints to recovery. For instance, an angle of repose waste dump may fail to develop a sustainable vegetation cover because the surface is unstable, constantly moving. In addition, this same dump slope may have a coarse substrate that creates severe moisture deficits for young plants. At most mines, re-establishment of the pre-disturbance ecosystems is not an option and a new, novel ecosystem based on the landforms and soil conditions that exist in the post-mining environment will be the most suitable solution (Hobbs et al 2006; Hobbs and Suding 2009). Where large open pit mines create entirely new landforms, there is an opportunity to use restoration to establish new ecosystems, including productive south facing slopes, windswept ridges and in some cases, wetland ecosystems (Polster 1989).

In some cases the lack of a suitable seed source limits the natural establishment of vegetation, although in most cases this rarely limits recovery, even on large mines. A lack of propagules for colonizing severely disturbed sites may be an issue preventing recovery, although it is more likely that conditions for establishment are not appropriate for the propagules that are available (Braatne and Rood 1998). Many pioneering species produce abundant seeds or other mechanisms for regeneration and with excellent means of distribution. Willows (*Salix* spp.), poplars (*Populus* spp.) and alder (*Alnus* spp.) produce abundant seed that may be blown great distances before settling in an appropriate location for germination and growth. In most cases where these species fail to establish, the lack of suitable receptor sites may be preventing these species from establishing. Elements such as compaction, smooth surfaces or erosion may be causing establishment failures. Identification of the element(s) that may be preventing natural recovery is the initial step in assisting recovery.

IDENTIFYING NATURAL RECOVERY SOLUTIONS

How have natural processes overcome the filters that limit natural recovery? This may be the central question in finding restoration solutions that work. Physical changes to the site (i.e. making seed beds rough and loose; reducing slope angles; adding woody debris) and pioneering species may provide the solutions for overcoming filters (Polster 1991). Seeking out natural conditions that are analogous to the site to be restored can assist in the identification of natural recovery solutions. Observing the details

associated with the establishment of pioneering species can offer clues. Do poplar or alder seedlings establish in the moose prints on the dump surface? Are willow seedlings found around the margins of puddles? Are pioneering grasses found in the old wheel ruts present on the disturbed site? Observations such as these can suggest remedial actions that will foster the establishment of these pioneering species on the disturbed site. Although each situation will provide different clues on establishment patterns some common elements can often be determined.

Many pioneering plants establish most easily where sites are rough and loose and there are an abundance of micro-sites for seeds to lodge in and germinate. Windblown seeds with fluffy "parachutes" such as willows, poplars, fireweed (*Epilobium* spp.) and mountain avens (*Dryas* spp.) may rely on water to trap the seed and provide the moist mud required for germination and growth. Some species with fleshy fruit such as Saskatoon (*Amelanchier alnifolia* Nutt.) or various roses (*Rosa* spp.) benefit from passage through the gut of a bird or animal. Creation of the right conditions for these species may require providing perching locations for birds as they pass through the disturbed area. Application of coarse woody debris may serve this purpose as well as a variety of other restoration purposes.

Mimicking the conditions that allow natural pioneering species to establish assists in the recovery of the site. Creating rough loose surface conditions that encourage establishment of willows, alder and poplars can also assist in establishing later successional conifers. The pioneering deciduous species create conditions that are appropriate for conifer establishment. Observing how these functions are performed in the adjacent undisturbed areas can help define restoration treatments. Natural successional processes can provide powerful models for the design of restoration treatments (Polster 1991; Walker and del Moral 2003; Walker et al 2007).

Steep waste dump slopes can be one of the most challenging limiting factors associated with mine sites. Understanding the processes involved in the natural establishment of vegetation on natural talus slopes (Polster and Bell 1980) can provide clues for the treatment of mine waste dumps. It is clear that although an angle-of-repose talus slope or waste dump may be globally stable, the movement of surface materials as well as the coarse free-draining nature of the mid-slope substrates prevent vegetation growth. Vegetation on natural talus slopes occurs in bands at the top and at the bottom, with little or no vegetation in the middle of the slope (Polster and Bell 1980). Vegetation at the top of the slope relies on the fine textured soil materials that collect at the top of the slope. The vegetation at the bottom of the slope establishes in the organic matter that collects between the large stable boulders that are present at the bottom of the slope (Polster and Bell 1980). However, we know that eventually steep colluvial slopes will support a cover of vegetation (Straker 1996). If we look carefully at the soils on steep colluvial slopes we can determine the processes that are involved in vegetation establishment on these slopes (Polster 1977). Once the surface is sufficiently stable; the slow accumulation of organic matter in the interstitial spaces between the rocks eventually provides ample moisture holding capacity for vegetation to establish. This process does not occur uniformly over the slope as often a single plant will become established in some place where conditions allow and with this establishment the rate of organic matter accumulation accelerates, thus a patchy cover of vegetation establishes that eventually provides the organic matter that leads to a cover of vegetation over the entire slope. Understanding how these processes operate in the natural world can serve as a model for restoration of disturbed mining sites.

Compaction of dump surfaces and haul roads can be one of the most serious limitations to vegetation growth at many mines. Minor surficial loosening such as produced by grader ripping will not provide sufficient de-compaction to support unrestricted plant growth. In natural situations where densely compacted basal till is preventing root penetration, revegetation occurs slowly as the weathering of the till surface creates sufficient loose material to support vegetation growth. Weathering of dump surfaces would loosen the compaction and allow vegetation establishment over many centuries. Vegetation can also help loosen the soil as root systems provide openings that enhance the weathering as well as adding

organic matter. However, this is a very slow process. Mechanical ripping and loosening the soil surface to a depth of at least a 1.5 m will create conditions that will support most natural vegetation types in British Columbia.

Low nutrients and/or adverse chemical composition can limit vegetation establishment and growth at some sites. Low nutrient status typically revolves around the lack of ample plant available nitrogen to support healthy vegetation growth (Errington 1978). Traditionally agronomic legumes have been used to address this problem (Polster 2007). Unfortunately, some of these species have turned out to become aggressively invasive (Polster et al 2001) and can prevent the natural successional advancement of vegetation on the site, resulting in a successional stagnation (Kimmins 1987). Native pioneering nitrogen fixing species, such as alder, do not create these same competitive conditions and can foster growth of later successional species (Polster 1985).

Adverse chemical composition of some mining related substrates can severely restrict plant growth. The generation of acid rock drainage (ARD) associated with many sulphide ores is well known in British Columbia (Morin and Hutt 1997). Salinity, high sodium levels, extreme carbonate levels and in some cases the presence of process chemicals, hydrocarbons or hydrocarbon derivatives can restrict plant establishment and growth. Natural solutions to these problems revolve around either sealing the offending material from the surrounding environment or diluting the material to the point where the phyto-toxicity is diminished. A wide variety of covering (isolation) techniques have been applied in British Columbia (Gardiner 1977). The currently favoured technique is to isolate the offending material using a capping with loose sufficient materials on top of the capped wastes to support plant growth (O'Kane et al 2001). Care must be taken to ensure there is ample loose material to support the vegetation growth as well as to store the annual moisture volumes. Failure to account for the successional changes in the vegetation from the seeded grasses and legumes to the surrounding forest vegetation can result in failure of the cover system with subsequent increased costs for treatment of contaminated drainage water. Table 1 summarizes the common filters that limit recovery as well as the natural solutions to these.

Table 1
Filters and Solutions

Limiting Filter	Natural Solution
Steep slopes	a) Erosion to reduce slope angles b) Pocket plant establishment in collected organic matter
Rapid erosion	a) Evergreen ground covers b) Rough loose soil surfaces c) Scattered large woody debris
Compaction	Weathering through freeze-thaw cycles
Low nutrients	Nitrogen fixing pioneering vegetation
Adverse chemical composition	a) Isolating materials from surrounding environment b) Dilution of offending materials
Lack of seed sources	Pioneering species with widely disbursed seed
Dark coloured substrates	Mulching leaves or other materials
Lack of micro-sites	Rough and loose soil surfaces

IMPLEMENTING RESTORATION TREATMENTS

Once the natural solutions to revegetation problems have been identified, it is simply a matter of implementing these on the restoration site. The following paragraphs outline measures that can be used to

implement the natural solutions to limiting factors. Although the solutions presented below are based on limiting filters that commonly occur in mining situations and thus solutions that can be implemented on the scale of most mining projects, in many cases these solutions can be scaled to fit a variety of circumstances.

Steep slopes can be treated by mimicking natural erosion processes and flattening the slope using machines. A wide variety of treatments and techniques have been developed over the years to address the issues of slope flattening. Wrap around dumps, where stable angles are achieved by placing subsequent waste dumps across the face of the dump have been used to reduce the costs associated with re-contouring large dump faces (Milligan 1978). On steep slopes that are stable but cannot be accessed by machines, establishment of pockets of vegetation on the slope can serve to initiate the processes of organic matter collection that will eventually revegetate the slope. Of course where the slopes are unstable and the surface is continually moving, pockets of vegetation will be unsuccessful.

Rapid erosion of exposed surfaces can limit vegetation establishment. Making the surface rough and loose to prevent overland flow and encourage infiltration can make a significant difference in the rate of erosion. Similarly, placement of large woody debris (not chips) can protect the surface from raindrop erosion and slow overland flow. On smaller sites where erosion control is critical such as along a stream bank or other sensitive area, planting evergreen species such as swordferns (*Polystichum munitum*) Oregon grape (*Mahonia* spp.) or kinnikinnick (*Arctostaphylos uva-ursi*) can dampen the impacts of raindrops and thus slow erosion rates. In addition a blanket of mulch, such as partially decomposed leaves, can help maintain soil moisture in the summer while reducing erosion during the rainy times of the year.

Vegetation and weathering can slowly de-compact sites but the rates are so slow that in most situations allowing these natural processes to treat mining related sites is unacceptable. Mechanical ripping or covering dump surfaces with loose, free-dumped material is the most effective way of dealing with compacted mining sites. If sites are left to de-compact naturally, care must be taken to ensure that weathered materials are not lost from the site by erosion. This process is very slow and some areas where vegetation has established on compacted basal till only a meter or less of mineral soil has accumulated since glaciation.

Natural nitrogen fixing species such as alder are common constituents of pioneering vegetation and can be very important additions to reclamation programs. In dry areas species such as soopolallie (*Shepherdia canadensis*) and the blue-green algae of the cryptogrammic crusts may provide ample nitrogen for the growth of the dryland vegetation. Although there has been little study on the establishment of crusts, establishment of alder and soopolallie has been routinely conducted for many years. Alder (all species) is relatively easy to establish from nursery grown plugs that have been grown from seed. In addition direct seeding of alder on prepared (rough and loose) sites has been very successful. In some situations, alder will establish without intervention on appropriately (rough and loose) prepared sites. Soopolallie can be grown from stratified and scarified seed. In some cases seed collected from bear droppings has been successfully used to grow soopolallie plugs. Large scale planting of pioneering nitrogen fixing species has been undertaken at large industrial disturbances, including mines in British Columbia.

Adverse chemical conditions can be addressed by isolating (covering) the offending materials; finding tolerant species if the adverse condition are not too severe; or through dilution. Covering is most often used to address ARD or other toxic mine wastes. Care must be taken to ensure full operation of the ecosystems that will establish on the capped surface. Failure to provide an adequate depth for rooting of all potential vegetation will ensure continued maintenance needs as the natural vegetation seeks to establish on the capping. In some cases where adverse chemical conditions are not too severe, tolerant

species such as tufted hairgrass (*Deschampsia cespitosa*) or alkali saltgrass (*Distichlis spicata*) can be used to initiate successional processes. In some cases dilution of the offending material can provide relief and allow establishment of tolerant species.

The lack of suitable seed sources is rarely a problem as most pioneering species have seed dispersal mechanisms that allow seeds to be spread over great distances. The one exception can be where alpine areas are being revegetated by alpine species (Polster 1977). Planting pockets of vegetation to serve as seed sources for adjacent areas can be an effective means of revegetating these harsh sites (Bittman 1997). Planting pockets of vegetation on severe sites can also be used to change the conditions of the site. For instance, on a site with a generally dark substrate, planting clumps of vegetation can change the albedo in the area of the clump allowing other vegetation to establish and expanding the area covered by vegetation.

Mulch, including hydroseeding mulch and roughening the surface can change the albedo of dark substrates thus allowing vegetation to establish. Roughening the surface creates mini north and south facing slopes. The north facing slopes can be revegetated and can serve as shade for the south facing areas, thus allowing vegetation to establish on the whole surface. Large woody debris can also be used to provide shade and shelter on sites with dark substrates. In addition to the shade and shelter provided by large woody debris, the slow decomposition of this material can serve as a nutrient source for many years. Woody debris also creates substrate diversity that encourages invasion by a variety of other organisms including fungi, bacteria, viruses and micro and macro-invertebrates.

Making restoration sites rough and loose is the simplest way to create a variety of microsites for seeds to lodge in and seedlings to germinate. In addition to the erosion control benefits of rough and loose soil surfaces, the uneven texture of the surface helps to trap wind-borne seed and to provide crevices and small places where seed can lodge. The establishment of seedlings is one of the most sensitive stages in the life cycle of plants. By creating a rough loose substrate, a variety of micro-habitats is provided that helps protect the young plants at this tender stage of growth.

Monitoring is an essential part of any restoration treatment. There are a wide variety of monitoring systems that can be applied depending on the information that is desired. In many cases simply documenting the changes in the treatment site over the years is sufficient to illustrate the success of the restoration program. Sometimes collection of information on the spontaneous establishment of later successional species can be used to document the success of the program. Many restoration systems change very slowly so a band of planted pioneering species may remain for many decades before seedlings of later successional species start to establish. In these cases success can be measured by the stability of the pioneering ecosystem.

CONCLUSIONS

Natural processes can be used for the restoration of severely disturbed sites. The key is to determine what factor(s) or filter(s) is preventing the natural recovery of site and to provide treatments that mimic the natural processes for overcoming these factors. Where slopes are steep and unstable, physical changes in the site may be needed prior to attempts to restore the site. In many mining situations new landscape elements are established, thus novel ecosystems can be substituted for the original ecosystem. Where the natural solutions to addressing problems in vegetation establishment are slow, there may be an opportunity to accelerate the process by providing suitable plants or structures that help the recovery process. Care should be taken to avoid introducing elements that might compromise the recovery over the long term. Non-natural structures such as impermeable membranes, concrete or other non-natural material can solve an immediate issue, but create a profound future problem. The application of natural

solutions avoids this common mistake. The use of natural processes as models for recovery of degraded sites allows restoration of severely damaged ecosystems.

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