PROCESSES AND FUNCTIONS: A NEW APPROACH FOR MINE RECLAMATION

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ABSTRACT

Natural processes and ecological functions have been restoring natural disturbances since the advent of terrestrial vegetation over 450 million years ago. Understanding how these processes operate can allow these recovery forces to be harnessed for the reclamation of mining disturbances. Identification of the filters or constraints that are preventing recovery is the first step in defining an effective restoration program. Compaction, erosion and steep slopes are three of the most common filters at large mines. Once these are addressed, selection of revegetation species can be undertaken. Determining the species that are naturally establishing around the edges of the mine will narrow the list. Pioneering species such as willows, poplars and alder are common pioneering species throughout British Columbia. These species initiate recovery processes and functions in disturbed areas. In addition to filters and species, identification of the structures that may have been lost in the mining process will help to re-establish the functions that may be related to this lost structure. Large woody debris (old logs) in piles or individually either standing or lying on the ground, can help to restore nutrient cycling functions as well as enhance wildlife diversity. Rock piles can be used to create structure, enhancing diversity on otherwise flat areas (e.g. tailings ponds). Making surfaces rough and loose, modeled on trees turning up root wads in the forest, creates instant topographic heterogeneity while addressing issues of compaction and erosion. Application of natural processes and the re-establishment of recovery functions can reduce the cost of reclamation while re-integrating the site to the natural systems that have served to maintain vegetation on the earth for millennia, creating sustainable mining.

Key Words: Natural processes; succession; recovery; restoration; filters; rough and loose.

INTRODUCTION

Restoration of terrestrial ecosystems is a complex process as the intricacies of how ecosystems operate is poorly understood (Gonzales 2008). The ecology of drastically disturbed sites such as mines and other major disturbances has only recently drawn the attention of scientists (Walker 2012). Understanding how the biological part of these ecosystems interacts with the physical, non-biological part is essential for the development of effective recovery strategies. Understanding how natural systems 'reclaim' disturbed sites can provide important clues in the development of restoration strategies for sites disturbed by humans. Restoration is defined by the Society for Ecological Restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SERI 2004). For the purposes of this paper, the words reclamation and restoration are used interchangeably since reclamation in British Columbia seeks to re-establish productive, self-sustaining ecosystems on lands disturbed by mining. Effective reclamation therefore is ecological restoration. Providing effective restoration of mining disturbances is essential for the maintenance of social license. Public acceptance of large scars on the land caused by mining is waning.

The first step in designing an effective restoration program for a disturbed mine site is to determine the factors that are preventing the recovery of the site. The term filters is used to describe the factors that prevent recovery (Clewell and Aronson 2013). This term implies that the constraining factor will allow some species to occur but not others. Consider the edge of a compacted roadway where only a few weedy species occur. The compaction of the roadway coupled with lack of nutrients, possibly salt from the road and the disturbance of grading may all contribute to preventing non-weedy species from occurring. Filters can be abiotic (non-living) such as compaction and steep slopes, or biotic (living) such as a lack of propagules or excessive herbivory. The concept of ecological filters within the context of mine reclamation is discussed below.

Natural systems have evolved a variety of ways of addressing the filters that prevent vegetation establishment. For instance, glacially compacted tills underlie many areas of British Columbia. These tills are at least as compacted as mine haul roads, and yet productive forests have established on compacted tills in the ten thousand years since glaciation. How does this happen? What can be done to mine haul roads so that it does not take ten thousand years for regrowth? Natural strategies for addressing filters are discussed further below.

The species that colonize disturbed sites provide functions and processes that assist the recovery of disturbed sites (Polster 1989). What are these functions and processes and how can they be used to assist in the recovery of sites mining disturbs? These aspects of restoration of disturbed sites are discussed below.

FILTERS TO RECOVERY

Polster (1991) listed five abiotic filters common in the mining industry. **Steep slopes** are one of the most common filters on mine waste rock dumps. The continual movement of angle-of-repose (37^{o}) slope surfaces prevents the establishment of plant seedlings (Polster and Bell 1980). The adage 'A rolling stone gathers no moss' is true from a social perspective as well as in restoration ecology (Polster 2008). In addition, the lower portions of waste rock dump slopes and natural talus slopes are composed of coarse rock fragments with few fine textured materials to hold plant-available moisture and nutrients. **Adverse texture** is therefore a common filter at many mine sites. Most mine wastes are low in plant nutrients so **nutrient status** is another common filter. At some mines **adverse chemical properties** such as acid rock drainage or high salinity levels restrict the growth of plants. At coal mines the often dark substrates creates **soil temperature extremes** that can limit plant growth. Polster (2009) listed three additional filters common to mines in British Columbia, **compaction**, **adverse micro-climatic conditions** and **excessive erosion**.

There are biotic filters that can prevent recovery as well (Polster 2011). These include excessive **herbivory** (Green 1982), **competition** (Temperton et al. 2004), **propagule availability** (Temperton et al. 2004), **phytotoxic exudates** (GOERT 2011), **facilitation** and **species interactions** (Temperton et al. 2004). In addition to the operation of these filters independently, they may combine with abiotic filters to create complex filters. For instance excessive erosion (abiotic filter) can be a problem on bare slopes. Seeding with an agronomic grass and legume cover has been the standard approach to deal with this problem. However, creating a dense stand of grasses and legumes can create habitat for mammals that then causes excessive herbivory and competition (Polster 2010). Care must be taken so that solving one problem does not create others. The following section presents solutions to common filters that can be used at mines in

British Columbia. These solutions are based on the strategies that are found in natural systems for addressing these filters. By observing how natural systems solve common filters solutions for mining problems can be found.

STRATEGIES FOR ADDRESSING FILTERS

Angle-of-repose rock slopes consist of fine textured materials at the top of the slope grading into progressively coarser textured materials down the slope until the bottom of the slope where the coarsest materials are found (often large boulders). These patterns are true on natural talus slopes (Polster and Bell 1980) as well as on mine waste dump slopes (Milligan 1978). How do natural systems address these problems? At the tops of the slopes the steep slope and fine textured materials results in excessive erosion so in addition to the steep slope, erosion is an issue. Natural systems slowly colonize the fine textured materials and eventually control the erosion allowing other species to establish. This is a very slow process and one that is governed by chance events. There are a variety of soil bioengineering methods that can be used on steep slopes to address the slope / erosion issues (Polster 2008). Although these may be considered too expensive to use in a mining context, the option of re-sloping large waste rock dumps can involve excessive machine time and be far more costly in the long run.

The coarse textured materials in the middle of a natural angle-of-repose slope are slowly revegetated by fine textured soils that wash from the slopes above through erosion or through the accumulation of organic matter that collects in the interstitial spaces between the rocks (Polster and Bell 1980). These natural processes are very slow. A soil bioengineering technique called pocket planting (Polster 2008) can be used to initiate (assist) the recovery processes on coarse textured substrates. This treatment uses fine textured soils brought from elsewhere to fill the voids between the rocks and create pockets of vegetation that then expedite the recovery processes on the remainder of the slope. The coarse materials at the bottom of the slope recover by the collection of organic material without contributions from above. Again, pocket planting can be used to expedite this process. Mechanically resloping waste rock dumps provides the fine textured materials from the top of the slope to cover the coarse materials lower on the slope. The use of wrap-around waste dumps can significantly reduce the costs of resloping (Milligan 1978).

Filters such as compaction, dark substrates, erosion and a lack of micro-sites can all be addressed through the use of a technique called ‘rough and loose’ (Polster 2011). 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.

As the name implies, making sites rough and loose addresses compaction by breaking up the surface down to approximately one meter (depending on excavator size). This allows the soil to absorb moisture therefore help with erosion. In addition, since the ground surface is rough, water cannot flow over the surface, further reducing erosion. North and south facing slopes are created so the dark substrates associated with coal mines can be ameliorated by planting on the north slopes. Conversely where cool temperatures limit plant growth the south-facing slopes can be used. The loose substrates allow roots to freely penetrate the soil and access moisture and nutrients. Rough and loose substrates have an abundance of micro-sites where seeds can lodge and seedlings can grow. Rough and loose treatments can be applied to the upper covering on covers designed to control acid rock drainage or other adverse chemistry. The ‘sponge’ cover system (O’Kane et al. 2001) allows a forest to be developed on top of a cover that seals reactive wastes. Using the rough and loose treatment on this cover provides excellent growth of forest species thus enhancing transpiration and the effectiveness of the cover.

The nutrient status filter is common if one compares mine wastes to agricultural soils. However, when compared to natural substrates on disturbed sites such as might occur following a landslide or on a river gravel bar, the nutrient status of mining wastes is equivalent. How then do natural systems address nutrient deficiencies on these sites? Natural disturbances are colonized by pioneering species (Walker and del Moral 2003). Many pioneering species such as alder are associated with nitrogen fixing organisms (Binkley et al 1982). Red Alder is the most common pioneering species in coastal British Columbia. Alder is often found colonizing forest landslides (Straker 1996) and is an important contributor to the nitrogen balance in forest ecosystems (Peterson et al 1996). Sitka Alder is an important species in Interior locations (Sanborn 1997). In both cases, alder contributes nitrogen to the local recovering ecosystems. Other pioneering species such as Balsam Poplar have been implicated in the enhancement of nitrogen status of recovering ecosystems (Peterson et al 1992). Lichens also fix nitrogen and contribute to the nitrogen status of forest ecosystems, especially in the north (Henriksson and Simu 1971).

Downed woody debris is an important source of nutrients in recovering forests. In addition, woody debris provides an important function in the control of erosion. Woody debris also provides habitat for a variety of plants and animals. Red Huckleberry, an important forest species in coastal British Columbia is often found growing on rotting logs and old stumps. Birds may play an important role in distributing this species on woody debris as they perch on the debris. Similarly, woody debris forms important habitat for many small mammals, reptiles, amphibians and invertebrates. Including woody debris as piles and/or single pieces either standing or on the ground can contribute immensely to the creation of habitat and the cycling of nutrients on restoration sites. In addition, the cost of woody debris placement can be far less than the cost of chipping or burning.

Leaf litter is an important contributor to ecosystem health. The litter of Red Alder contributes substantial amounts of nitrogen to ecosystems where it occurs. Leaf litter can also protect bare soils from raindrop erosion. Leaf litter provides habitat for a variety of organisms important in the nutrient cycling processes of ecosystems. Leaf litter adds carbon to the soil providing an important carbon sequestration role. In some cases invertebrates need leaf litter to complete stages in their life cycles. There are opportunities to bring the spores and propagules of important soil organisms (e.g. mycorrhizal fungi) from forests to restoration sites by collecting leaf litter from the adjacent forest and scattering it on the restoration sites.

Establishing species that will provide structure for the developing ecosystem can expedite the recovery processes. The winter branches of Red Alder catch the spores of Swordferns as well as supporting the perching of frugivorous birds and soon the species they eat such as Salmonberry, start to show up in the understory (Polster 2010). Similarly, providing habitat for squirrels and chipmunks encourages the growth of mycorrhizal fungi as these small mammals collect the fruits of the fungi and cache them in various places in the forest. Understanding how these processes operate allows simple measures to be implemented during the restoration of the disturbed area that will build on the simple treatments that have been applied (e.g. planting pioneering woody species and scattering woody debris). In some cases, supplying nest boxes for key species can bridge the gap between the open mining disturbance and when the pioneering species reach a level of maturity to provide the habitat.

A lack of propagule availability can be an important filter to ecosystem establishment, especially on large disturbed sites (Walker 2012). Many pioneering species have developed effective means of distributing over large distances. The fluffy seeds of Balsam Poplar can be seen floating around at certain times in the spring. Similarly, the seeds of Sitka Alder can be found on the first winter snow in the fall. Although these seeds may travel long distances, in situations where parent plants are not available near the disturbed site or where the distances are too great, the lack of seeds of pioneering plants may be the limiting factor in the establishment of these species. Collection of the seeds of pioneering species and the application of these on disturbed sites can help overcome this filter. In some cases, animals can move the seeds of plants onto reclaimed areas. Providing perching sites or denning sites such as woody debris piles or rock piles can assist in this process.

Herbivory can be an important filter preventing recovery of some species. Small mammal (Green 1982) populations can explode under the cover of grasses and legumes that have been traditionally been used for reclamation. Similarly, populations of ungulates (deer and elk specifically) have responded positively to the extensive areas of grass and legume seeding at many mines. This has resulted in excessive herbivory and changes in the recovering ecosystems. Competition is another factor that can limit recovery. Careful study over sixteen years at the Island Copper Mine have identified that dense stands of seeded grasses and legumes can compete with planted woody species for moisture during periods of dry weather (Polster 2010). In some cases, seeded grass and legume species facilitate the establishment and growth of non-native weedy species (Polster 2010). This further complicates the establishment of productive, self-sustaining ecosystems as species such as Scotch Broom can inhibit tree growth by exuding a phytotoxic material. In some cases, specific species interactions such as between a plant and a pollinator can limit vegetation establishment. Wind pollinated pioneering species avoid this issue.

Incorporating biodiversity enhancements into the restoration of drastically disturbed sites can greatly improve the restoration work that is undertaken. Resilience (Holling 1973) is built on redundancy. Providing a suite of nitrogen fixing species from trees and shrubs such as Red Alder and Sitka Alder to a diversity of shrub species including Soopolallie, Ceanothus and Wolf Willow (*Elaeagnus commutata*) as appropriate to the site being treated, that can all provide a similar ecological function, will ensure the restored site is prepared for future uncertainty. Similarly, the creation of rough and loose surface configurations ensures a level of topographic heterogeneity (Larkin et al. 2008) that will enhance diversity since it creates a variety of different habitats.

CONCLUSIONS

Natural systems have been restoring disturbed ecosystems for millions of years. Observing how these natural processes operate and the functions that various components provide can greatly enhance restoration operations and significantly reduce costs. Rather than spending money on seeding a cover of grasses and legumes that has been shown to limit recovery, seek to integrate natural processes into the restoration of disturbed sites and allow these natural processes to 'pay' for the recovery. Identification of the filters that are preventing recovery is the initial step in providing a site that restores itself. In some cases, all that is needed is to create the appropriate surface conditions (e.g. rough and loose), add some woody debris and rocks as structure and apply some forest litter to re-establish nutrient cycling pathways. In other cases, planting of pioneering species will be required to provide the recovery functions associated with nitrogen fixation and the creation of ecological structure.

Effective reclamation of mining disturbances is essential to maintain social license. Expectations for the reclamation of new mines are significantly greater than in the past. The days of lakes being used as tailings disposal areas or that creek valleys could be used for the deposition of waste rock, exiting the rock drain as a selenium contaminated stream, are past. Similarly, the thought that hyper-abundant ungulates wading in belly deep alfalfa can serve as a surrogate for biodiversity has been debunked (Martin et al. 2011). Restoring mining disturbances to enhance biodiversity is the future of mining. Natural processes and functions can provide that pathway.

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