A NEW PARADIGM FOR THE RESTORATION OF DRASTICALLY DISTURBED SITES

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ABSTRACT

Traditional reclamation treatments have generally failed to meet expectations for biodiversity and sustainability. Uniform stands of seeded agronomic grasses and legumes can remain successionally stagnant for decades making forest recovery difficult and severely limiting biodiversity. The failure to re-establish natural successional trajectories on many traditionally reclaimed areas results in degraded ecological conditions that invite invasion by weedy species resulting in weed infested reclaimed areas. Restoration treatments based on the use of natural processes that have been addressing natural disturbances for millions of years can be very effective. Natural successional processes provide answers to species selection and sequencing questions while natural nutrient cycling processes can suggest soil development solutions. Natural erosion control processes can be applied to bare soils to address erosion issues. Understanding the factors that prevent or limit natural recovery can also be important to determine solutions. Compaction, steep slopes and excessive erosion are abiotic factors that can prevent recovery while competition and herbivory are common biotic factors that may limit recovery. This paper presents a new model for treatment of drastically disturbed sites based on the application of these natural processes and the filters (constraints) that limit these processes. Examples are drawn from the author's experience of over 30 years of reclaiming drastically disturbed sites.

KEY WORDS: natural succession, recovery, filters, pioneering species, reclamation, treatments

INTRODUCTION

Reclamation is a critical part of industrial development. Without effective reclamation, social license is lost and the promises made by industry and the permitting part of the government mean nothing. Poor reclamation represents a debt that the creators of the disturbance owe society and the ecosystem (Atwood 2008). Unfortunately most traditional reclamation treatments have failed to achieve the reclamation objectives that were established when the permits were granted. Hyper-abundant ungulates do not equal productive wildlife habitat but rather an unbalanced system that reduces overall biodiversity (Martin et al. 2011). Land that is to be reclaimed must have a capability that is equal to or better than the land capability that existed on the site prior to the disturbance. The established vegetation cover must be self-sustaining. Although these requirements have been part of the statutory code for many years, the ecological implications of these requirements have not been part of the reclamation lexicon. Failure to address the ecological short-comings of traditional reclamation has led to a loss of societal acceptance of reclamation as a tool for mitigating industrial disturbances. Weakened or overly prescriptive legal requirements have contributed to this loss. Regaining societal acceptance will require a significant shift in reclamation treatments.

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). Although reclamation and restoration have traditionally been seen as two distinct activities (Burton 1991) effective reclamation can be considered to be restoration using the concepts of novel ecosystems (Hobbs et al. 2006). By looking at the treatment of drastically disturbed sites as a restoration challenge, the lost social acceptance can be regained. Treatments that are applied to restore degraded or destroyed sites can be used instead of traditional reclamation treatments with significantly improved outcomes.

This paper is organized to provide a synopsis of how drastically disturbed sites can be effectively restored. The model for restoration that is presented here is based on natural recovery systems. Natural recovery processes have been restoring naturally disturbed sites since the advent of vegetation on the earth over 400 million years ago. Evolutionary processes have honed these recovery systems so that now bare ground in temperate regions does not stay bare for long or if it does, it is because of some other factor (filter) that is preventing recovery. The first step therefore in restoring a drastically disturbed site is to determine what, if anything is preventing the natural recovery of the site. Polster (2011) identified eight common abiotic filters and six biotic filters that prevent recovery. Understanding how natural systems address these constraints to recovery allows restoration treatments to be devised that make use of the natural processes, often significantly reducing the cost of conducting restoration.

Drastically disturbed sites are, by definition considerably different than immediately adjacent undisturbed sites. Reference to adjacent sites will be of little use in developing restoration strategies for the disturbed site. Soils may be lost or totally changed. Physical features of the substrate may bear little resemblance to the adjacent natural soils. Vegetation is generally lacking or may be composed of weedy, undesirable species. Ecological processes such as nutrient cycling or carbon sequestration may be lacking. Looking to the adjacent ecosystems as a reference for the reclaimed ecosystems may be inappropriate and may result in the incorporation of unsuitable treatments on the disturbed site. Understanding the successional context of the site to be restored allows natural analogues to be investigated and used as models for the establishment of effective treatments.

FILTERS TO RECOVERY

Polster (2011) listed eight abiotic (non-living) filters to recovery:

1. Steep slopes
2. Adverse texture (too fine or too coarse)
3. Nutrient status
4. Adverse chemical properties
5. Soil temperature extremes
6. Compacted substrates
7. Adverse micro-climatic conditions

8. Excessive erosion.

Six biotic (living) filters are listed by Polster (2011):

1. Herbivory
2. Competition
3. Phytotoxic exudates
4. Propagule availability
5. Facilitation (of one species to the exclusion of another)
6. Species interactions.

Many of these filters operate in concert to prevent the establishment and growth of vegetation. For instance, compacted substrates may prevent establishing plants from reaching nutrients and moisture thus these sites also appear to be nutrient and moisture limiting. Similarly a dense, competitive cover of seeded grasses and legumes may foster establishment of hyper-abundant ungulate populations that limit the establishment and growth woody species that in turn reduce populations of song birds and other species (Martin et al. 2011). Green (1982) identified the problems of small mammals associated with dense grass and legume covers. Trophic cascades (Falk et al. 2006) such as this can have far-reaching consequences for biodiversity and resilience (Holling 1973).

Just as the filters that prevent recovery often act together, the natural solutions to these filters may solve more than one problem. For instance, when trees are blown over in a forest they can turn up large root wads and create open areas that are colonized by pioneering species. This natural process maintains these species in the ecosystem so they are available to address other disturbances in the forests (Straker 1996). In addition, the up-turned soils bring the less mobile nutrients (e.g. P and K and various micro-nutrients) to the surface where they can be accessed by the roots of the pioneering species. The mounds of fresh soil associated with the root wads are located next to the holes from which the root wad came creating topographic heterogeneity (Larkin et al. 2008). Topographic heterogeneity provides conditions that promote species diversity thus the simple process of trees blowing over in the forest ensures the maintenance of diversity in the forest as well as providing successional and nutrient diversity. The following section looks at natural processes that can be applied to solve common filters preventing recovery.

NATURAL PROCESSES TO ADDRESS FILTERS

The following sections describe how natural processes overcome the common filters listed above. The use of these natural processes to address the filters associated with anthropogenically disturbed sites is presented with the filter(s) they address.

Steep Slopes

Angle of repose slopes will not sustain a vegetation cover due to continual sloughing (Polster and Bell 1980). In the absence of material coming from cliffs above a natural talus slope (colluvial slope) this raveling and sloughing will eventually result in a reduced slope angle that will support a vegetation cover. In some cases colluvial slopes are species rich as the freshly available nutrients and the continual deposition of material allow a diversity of species to establish and grow (Polster 1977). Although such sloughing and raveling will eventually allow vegetation to establish, this may take many millennia. Re-sloping waste rock dumps and the use of wrap-around waste dumps has been a standard practice at progressive mines in British Columbia since the late 1970's (Milligan 1978). In addition to reducing the slope angle on waste dumps, re-sloping allows the fine textured materials that collect at the top of the dump to be pushed over the coarser materials found further down the slope, addressing, in part the issue of coarse textured materials (see below).

Adverse Texture

Plants need fine textured soil materials for growth. Fine textured materials hold moisture and nutrients allowing plant roots to extract these materials for growth. Soils that have high clay content may dry and crack and may tightly bind moisture making it unavailable to plants. Coarse rock that will not support vegetation will weather over time to produce finer textured materials that can support plants. Excessively fine soils such as the clays found in old lake beds or ancient marine environments will be slowly colonized by plants that will add organic matter that will eventually ameliorate the adverse conditions of the fine soils. Coarse textured substrates are common on many drastically disturbed sites. As noted above, re-sloping waste rock dumps can be used to spread fine textured soil-like materials over coarse rock thus allowing vegetation to be established. Where large coarse rock fragments exist, organic matter will slowly collect in the interstitial spaces between the rocks. This material will eventually support vegetation (Polster and Bell 1980). In a restoration context, a soil bioengineering technique known of as pocket planting (Polster 1997) can be used to assist pockets of vegetation to become established that will eventually spread to fill between the pockets.

Nutrient Status

Most drastically disturbed sites lack basic plant nutrients. Natural processes provide essential plant nutrients such as nitrogen through nitrogen fixing species. Spawning salmon return to their home waterways bringing marine derived nutrients to coastal forest ecosystems. Weathering of rock provides other, less mobile nutrients (P&K). When trees are blown over in a forest they turn up the soil, renewing these nutrients. Creation of topographic heterogeneity (Larkin et al 2008) mimics these natural processes. Traditionally fertilizers and bio-solids have been used to supply plant nutrients, but these sources favour the growth of non-native agronomic grasses and legumes which have been found to constrain recovery (Polster 2011). Native pioneering species can grow in low nutrient situations and will create conditions where natural processes can provide the needed nutrients for the vegetation that establishes (Walker and del Moral 2003).

Adverse Chemical Properties

Acid rock drainage (ARD), salinity, sodic soils or soils contaminated with metals can severely limit plant growth. Although there are some native species (e.g. Tufted-hair grass, *Deschampsia cespitosa*) that are tolerant of high metals levels (Cox and Hutchison 1980), most plants are excluded where excessive metals are present. Natural sites with toxic metals levels are colonized by species that are tolerant that in turn provide organic matter that eventually chelates the metals, allowing other plants to grow. Salinity naturally moves down the soil column where it does not impact plants. Some natural areas where salts accumulate due to low rainfall and high evaporation rates remain un-vegetated. Typically adverse chemical properties are dealt with by covering the offending materials with sufficient material to allow plant growth without influence of the adverse material. Specific cover designs that will be effective for millennia are needed but are relatively uncommon.

Soil Temperature Extremes

Dark coaly shale on south facing slopes can become lethally hot to plants in the summer sun. Similarly, in northern areas, permafrost can create conditions that are too cold for plants to grow. Natural systems bury dark materials under a litter of organic matter while layers of organic matter (active layer) insulate permafrost from growing plants. Making sites rough and loose (Polster 2011) or topographically heterogeneous creates warm and cool slopes and wet and dry conditions, overcoming soil temperature extremes.

Compacted Substrates

Naturally compacted substrates weather until there is sufficient material that is not compacted to allow plant growth. Making sites rough and loose can be used to de-compact sites. Simple ripping is insufficient to eliminate compaction on dump surfaces where large trucks have been running.

Adverse Micro-climatic Conditions

Frost pockets, hot dry knobs and other sites where the micro-climatic conditions limit plant growth may occur. Naturally these sites are vegetated by tolerant vegetation. Making sites rough and loose can ameliorate adverse micro-climatic conditions by creating warm slopes as well as cool slopes.

Excessive Erosion

Erosion is a problem with anthropogenically disturbed sites. Although natural landslides may inject large quantities of sediment into aquatic systems, they also provide sediments that are important for various natural processes such as fish spawning. There are a variety of natural processes that serve to reduce the potential for erosion. Up to 30% of the rain that falls on a natural forest is caught in the canopy and re-evaporated. Funnel shaped plants such as Swordferns (*Polystichum munitum*) channel rainfall into the groundwater system. Leaves (deciduous and coniferous) that are deposited on the ground protect the soil surface from raindrop erosion and promote infiltration. Making sites rough and loose and promptly establishing pioneering woody species can protect the site from erosion and promote recovery. There are a variety of simple soil bioengineering treatments (e.g. live silt fencing) that can be used to control erosion.

Herbivory

Excessive herbivory can occur where predators have been reduced or where large stands of seeded grasses and legumes promote population explosions. The dense thatch of seeded grasses and legumes can shelter small mammals from predation, allowing these animals to destroy woody species. Natural systems such as burned areas where pioneering species (willows and poplars) might be expected to dominate and attract large herbivores (moose, elk and deer). However, in many of these sites, the accumulations of coarse woody debris prevent easy access by ungulates. Scattering woody debris or building temporary fences can reduce the impacts of excessive herbivory.

Competition

Competition is a complex topic (Falk et al. 2006). A species that might be competitive to one species might facilitate another (Temperton et al. 2004). Typically one species is more efficient at using resources than another. For instance, alfalfa tends to be able to extract moisture from the soil more effectively than most woody species so will create a competitive barrier to establishment of those woody species. Seeded grasses and legumes can create a dense competitive cover that prevents establishment of woody species (Polster 2010).

Phytotoxic Exudates

Some invasive species are successful because they produce chemicals that prevent the establishment of other species. Knapweed and Scotch broom are two examples of such plants. These plants can create successionally stagnant conditions (Kimmins 1987) that prevent further development of the vegetation. Western redcedar leaf litter can restrict the growth of understory species, although often mosses can tolerate these conditions and will initiate growth of other species. With the exception of alien invasive species, the issues with phytotoxic exudates are not generally significant.

Propagule Availability

Another biotic filter that may be important on large disturbances is a lack of plant propagules. On large sites or on sites where the surrounding vegetation is in a late successional stage and there are no pioneering plants nearby, the ability of plants to colonize the bare ground may be so slow that erosion and other problems might arise before the pioneering plants can establish an effective cover. Establishment of pioneering species can be important in situations such as this. Seeding in pioneering woody species such as alder can be an effective treatment on large sites.

Facilitation

Facilitation (Temperton et al. 2004) is often considered a beneficial ecological process. Pioneering species may facilitate the growth of later successional species. However, facilitation can promote the growth of one species over another so for instance invasive nitrogen fixing species might promote the growth of nitrogen-loving plants at the expense of other more thrifty species. Within the context of restoration however, the facilitation effect of pioneering species on later successional species is an important attribute of these systems (Walker et al. 2007).

Species Interactions

There may be specific interactions between species such as between a vascular plant and a pollinator without which the plant in question will suffer. Enhancing the diversity of the restored ecosystem will help to ensure that beneficial species interactions are available. In many cases redundancy in these interactions helps to promote development of the ecosystem (Falk et al. 2006). Having many pollinators available by creating a diversity of appropriate habitats can help ensure redundancy and hence resilience (Holling 1973).

SUCCESSION AS A MODEL FOR SUCCESS

Natural successional processes provide an excellent model for the restoration of drastically disturbed sites (Polster 1989). Pioneering species such as willows, poplars and alders can be used to initiate successional processes on bare soil / waste rock sites. These species produce large quantities of biomass that can quickly create soil like materials amenable to later successional species. Alders produce nitrogen and can increase biodiversity through a process known as niche complementarity (Kahmen et al. 2006). The role of pioneering species in taking sites from bare ground to a vegetated condition that initiates successional trajectories is well known (Polster 1989; Walker et al. 2007).

Providing pioneering species as the initial stage in restoration of drastically disturbed sites has benefits in a world with uncertain climate futures (IPCC 2007). These species have broad ecological amplitude so can provide recovery services under a broad range of climatic conditions. In addition, by avoiding the temptation to try to guess the species composition of later successional stages decades in advance of their establishment, the use of pioneering species initiates successional processes that do not dictate the specific species composition of later successional stages. The appropriate later successional species composition will establish naturally when the time comes.

Using natural successional processes as a model for the restoration of drastically disturbed sites is cost effective. The pioneering species that are used are often easy to propagate and are designed to spread into un-vegetated areas. In addition, propagules of these species (seeds or cuttings) are often available for the cost of collection in the project area. Pioneering species often show remarkable survival and growth on very harsh sites as these are the conditions to which they are adapted. Leader growth of a meter or more per year is not uncommon for many of these species. The ability to grow rapidly and occupy the disturbed site quickly helps to reduce problems with invasive species as well as providing evidence to stakeholders that the restoration is effective. By following the natural recovery processes, successionally based treatments can take advantage of many recovery elements that happen without costly interventions.

CONCLUSIONS

Restoration programs can be modeled on the natural processes that have been restoring natural disturbances for millions of years and are ideal for re-establishing the ecological functions, goods and services that have been lost when the degradation occurred. Because the actual processes that formed the ecosystems initially are used to assist in the recovery of the ecosystems; the use of natural processes such as succession and nutrient cycling are very effective in returning the ecological values associated with the ecosystem.

Identification of the filters or constraints that are preventing recovery of the ecosystem is the first step in the restoration process. In most cases, once the filters have been identified and addressed, the recovery of the site is simple. Avoid creation of additional filters as part of the treatment. For instance, seeding a site with agronomic grasses and legumes, except where a tame pasture or hayfield is desired, can establish a successionally stagnating cover of these species. Excessive grading and smoothing sites serves to increase compaction and creates conditions that open the site to erosion. Making sites rough and loose (topographically heterogeneous) can eliminate compaction; reduce erosion; create micro-sites for the seeds of native pioneering species to lodge in and a diversity of edaphic conditions. Inclusion of large woody debris, brush piles, boulder piles and other such features can greatly enhance recovery processes by providing ecological heterogeneity in the site conditions. Increased diversity is the reward for a heterogeneous site.

Native pioneering species that operate in the area are selected as the species of choice for the initial vegetation establishment. These are generally readily available in the local area for the cost of gathering the propagules (seed or cuttings). Pioneering species are generally easy to establish and need little or no maintenance. Growth rates of pioneering species are generally exceptional on the adverse substrates that are common with drastically disturbed sites. These species will quickly build soils on barren sites and create conditions that will foster the growth of later successional species.

The use of natural processes can greatly reduce the costs associated with recovery of drastically disturbed sites. By harnessing the power of natural recovery, the natural processes model greatly reduces the cost of treatments and generally eliminates the need for costly maintenance or re-treatments. Allowing the established pioneering species to create conditions appropriate for subsequent species accommodation for changes in climate is built into the use of the natural processes model. Following natural processes creates ecosystems that are appropriate for the conditions of the area and the end land uses that might be applied.

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