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Effective reclamation – understanding the ecology of recovery

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Abstract

Recovery processes are complex; understanding them can help make reclamation a success. Many of the things that have been done in the name of traditional reclamation have actually served to slow or even stop the recovery of the disturbed site. In other cases, failure to conduct simple treatments early in the process can lead to the collapse of the reclaimed ecosystem over the long term. Understanding the ecology of recovery can help prevent treatments that work against natural recovery processes. Similarly, understanding the processes involved in ecosystem recovery can allow treatments that enhance these processes. Simple abiotic (physical) treatments can be used to expedite the recovery of drastically disturbed sites. Planting designs that make use of native pioneering species can be used to re-establish successional trajectories that will lead to productive ecosystems that are in accord with the local ecosystems. This paper explores the ecology of recovery processes and the treatments that can be applied to drastically disturbed sites to assist in these processes.

1 Introduction

Most traditional reclamation treatments have failed to deliver productive, self-sustaining ecosystems on sites that have been drastically disturbed. For instance, fields of seeded clovers, alfalfa and agronomic grasses slowly degrade over the years leaving low-productivity stands that become infested by weeds. Late successional woody species planted on these sites perform poorly compared to adjacent natural stands until native pioneering species establish and re-set the successional trajectory. Many of the actions that have been taken over the past 40 years in the name of restoration have actually served to prevent recovery of drastically disturbed sites. In the following sections of this paper we will look at the constraints or filters (Polster, 1989; Walker and del Moral, 2003) and the natural processes that can be used to solve these problems (Polster, 1991).

Natural processes have been revegetating drastically disturbed sites since the advent of terrestrial vegetation on earth about 400 million years ago. Volcanoes, glaciers, floods, landslides, fires, changes in sea level and the activities of animals all create un-vegetated areas. However, in most cases natural processes ensure that these areas do not stay un-vegetated for long. By looking at how these natural processes operate to revegetate drastically disturbed sites (Polster and Bell, 1980) we can use these techniques to enhance our treatments of large mines and other disturbances that we create.

Ecological restoration is defined by the Society for Ecological Restoration (SERI, 2004) as the process of *assisting* the recovery of an ecosystem that has been degraded, damaged or destroyed (author's emphasis). This 'definition' suggests that the best that can be done is to assist the recovery of damaged sites; we cannot cause ecosystems to recover, we can only assist. This is similar to our bodies. If we get a cut on our hand we can assist healing by putting on antiseptic and a bandage or we can constrain healing by going to shovel out the chicken coop and getting the cut infected. The same is true of ecosystems; we can do things that promote recovery or we can do things that constrain recovery. Understanding what these things are and why they either promote or constrain recovery is essential to the development of effective reclamation. These are discussed in the following sections.

Ecosystems come together on a site in a specific way (Temperton et al., 2004) and in a specific order (Walker et al., 2007). Some species may facilitate the establishment of other species (Temperton et al., 2004) or they may constrain the establishment of other species (Polster, 2009). Similarly, sometimes specific physical conditions are required for particular species to establish on a site. Understanding how these processes operate on naturally disturbed sites can provide clues for the establishment of vegetation on drastically disturbed sites that humans have created.

2 Constraints (filters) preventing recovery

Constraints or filters that prevent or limit recovery of ecosystems can be conveniently classed as either biotic or abiotic. As the names imply the origin of these filters are either biological or non-living physical constraints. For instance, a dense thatch of seeded agronomic species may promote the development of high small mammal populations that in turn prevent the establishment of woody species (Green, 1982). This is a biotic filter. Similarly, over-steepened waste dump slopes can prevent establishment of a sustainable vegetation cover (Milligan, 1978) due to the physical ravelling of the slope, an abiotic constraint. The following sections look at common filters that prevent recovery of sites.

2.1 Abiotic filters

Polster (1991) lists five common abiotic filters:

- Steep slopes.
- Adverse texture (too coarse or too fine).
- Nutrient status.
- Adverse chemical properties.
- Soil temperature extremes.

To this list Polster (2009) added:

- Compacted substrates.
- Adverse micro-climatic conditions.
- Excessive erosion.

In many cases these filters interact to prevent recovery of the ecosystem so a site may have coarse textured rock that is unstable and generates acid. Simply treating one of the filters will not solve the problem as the other constraints will come in to play. These filters are discussed individually in detail below although it must be recognised that often there is an interaction between constraints.

2.1.1 Steep slopes

On natural talus slopes (loose rock slopes) the gradual erosion of the slope materials reduces the angle until eventually plants can establish. Similarly, where substrates are too coarse such as at the bottom of such slopes, the collection of organic matter and dust in the crevices between the rocks provides a safe site (Temperton et al., 2004) and allows vegetation to establish. There are several factors at play on talus slopes. At the tops of the slopes, where there is fine textured material, the availability of moisture supports plants that can tolerate the constant bombardment of stones from above. In the middle of the slope where there are coarse textured, mobile stones, the abiotic threshold (Hobbs and Suding, 2009) is so severe that in most cases, this portion of the slope remains un-vegetated. At the bottoms of the slopes where rocks are large and stable organic matter collects between the rocks allowing vegetation to establish (Polster and Bell, 1980).

2.1.2 Adverse texture

Soils that are too fine may become compacted. Here the slow freezing and thawing cycles or the extension of root systems can assist in ameliorating these conditions. In some cases, where soils are silt sized, excessive erosion can be a problem. Sites that are too coarse tend to be free-draining and droughty. Here, natural processes add organic matter to fill in the interstitial spaces and provide a substrate upon which vegetation can grow.

2.1.3 Nutrient status

Many severely disturbed sites lack essential plant nutrients. Natural sites that lack essential plant nutrients, mainly nitrogen, such as alluvial gravel bars or recent lava flows are colonised by species that have the ability to fix atmospheric nitrogen making it available in plant-useable forms. Pioneering species such as alder (*Alnus* spp.), Mountain Avens (*Dryas drummondii*) and a variety of lichens have the ability to contribute nitrogen to nutrient-poor sites. Nutrient cycling can also be an issue on severely disturbed sites (Fyles, 1984). Some common pioneering species such as willows (*Salix* spp.) and poplar (*Populus* spp.) can tolerate the poor nutrient conditions of drastically disturbed sites.

2.1.4 Adverse chemical properties

Many metal mines with sulphide ore bodies may develop acid rock drainage (ARD). Where natural ARD occurs, weathering over many centuries provides an oxidised crust that then prevents further oxidation of the sulphides. The volume of oxidation that would be required and the length of time that this would take at most mine sites makes this an unacceptable means of dealing with ARD so a diversity of capping strategies have been applied (Morin and Hutt, 1997). High sodium content (sodic soils) and salinity can be significant problems at some sites. Natural processes serve to weather these materials driving them down in the soil column although where groundwater reaches the surface; these constituents may reappear, resulting in specific species responses (Clewell and Aronson, 2007).

2.1.5 Soil temperature extremes

Soil temperature extremes can occur with dark coloured substrates or where freezing temperatures persist in the soils into the growing season. Dark coaly shale may create substrates where soil surface temperatures exceed 60°C, a temperature lethal to vascular plant seedlings. Leaf litter and other organic matter will slowly change the albedo of these sites and ameliorate the temperature extremes. Areas where permafrost occurs can be difficult for vegetation to establish. Vegetation only grows in the active zones of these soils.

2.1.6 Compacted substrates

Compaction can be a significant constraint to ecosystem recovery (Clewell and Aronson, 2007). Compaction can limit root growth, prevent moisture infiltration and add to erosion problems. Glacially compacted basal tills can prevent root penetration and create a slip plane that results in landslides when root strength is lost following timber harvesting (Pike et al., 2010). Waste rock dump platforms can become extremely compacted. Simple ripping with a large bulldozer is insufficient to reduce this compaction. The hooves of animals can also compact soils, restricting plant growth.

2.1.7 Adverse micro-climatic conditions

Micro-climatic conditions may influence the establishment of some species. South facing slopes can become very hot in northern latitudes while northern exposures can be excessively cold. A lack of micro-sites may reduce seed capture and seedling growth. Similarly, smooth hard surfaces contribute to overland flow and excess erosion (see below). Shade such as may occur on northern exposures may be an important part of the micro-climatic conditions that foster the growth and development of some species.

2.1.8 Excessive erosion

Excessive erosion may prevent establishment of plants. Seeds and seedlings may be washed away on sites that are actively eroding. In addition, erosion may result in degradation of adjacent aquatic habitats. Understanding erosion processes is the first step in developing effective erosion control treatments. With the exception of raindrop erosion, all water erosion processes result from water moving across a soil surface. Raindrop erosion occurs when raindrops hit a bare soil surface and lift soil particles in the air. From there they can be transported down the slope with sheet flow and/or rill and gully erosion. Mass movements, or landslides, can cause a significant loss of vegetation.

2.2 Biotic filters

Biotic elements may create conditions that prevent the recovery of degraded sites. The following biotic elements may be constraining recovery on reclamation sites:

- Herbivory.
- Competition.

- Phytotoxic exudates.
- Propagule availability.
- Facilitation (of one species to the exclusion of another).
- Species interactions.

Biotic filters can be significantly more complex than abiotic filters as there are often interactions between biotic elements in an ecosystem and these interactions can change with changes in the ecosystem. So a relationship between two species that may start out as facilitation may end up as competition. The salient features of biotic filters relative to restoration are discussed below.

2.2.1 Herbivory

Herbivory can be a major player in the development of ecosystems (Gonzales, 2008). Hyper-abundant ungulates associated with predator removal can significantly change the successional trajectories of recovering ecosystems. Similarly birds, small mammals and invertebrates can play a major role in the survival of seeds and seedlings. Herbivores may seek out specific species and thus change the balance in ecosystem development (Aronson et al., 2007).

2.2.2 Competition

Competition is one of the major areas of study in ecology (Poole, 1974). It is therefore not surprising that competition has become a major topic of study in restoration (Clewell and Aronson, 2007). Competition may be responsible for determining the composition of many ecosystems including restored ecosystems (Temperton et al., 2004). Seedling competition may be particularly severe with annual species that germinate simultaneously in response to environmental conditions. Competition can exert an influence on plant community development at a variety of different stages of development. Alfalfa (*Medicago sativa*), one of the commonly used reclamation species is particularly competitive. Alfalfa can out-compete trees such as Red Alder (*Alnus rubra*) for moisture if the trees have not closed canopy sufficiently to shade-out the alfalfa (Polster, 2010). Dense sod-forming grasses such as Creeping Red Fescue (*Festuca rubra*) can create a competitive cover of vegetation that prevents other species from establishing.

2.2.3 Phytotoxic exudates

Some species have the ability to exude phytotoxic substances (allelopathy) that prevent other species from establishing. Knapweeds (*Centaurea* spp.) have been particularly successful in taking over heavily grazed lands in western North America because of the phytotoxic substances produced by the roots of these plants. Scotch Broom (*Cytisus scoparius*) can dominate open ecosystems for decades due to the allelopathic effects of this species.

2.2.4 Propagule availability

Sometimes the seeds or other propagules of plants that might colonise a new site are simply not available at the site (Temperton et al., 2004). This may be because the site is too large for seeds to move in from surrounding areas, or because the species that might be appropriate for colonisation of the disturbed site are not part of the adjacent flora. This may be the issue when disturbances are located in an area of late successional vegetation and early seral species that might colonise the disturbed area are not common. Where seeds are moved by specific organisms (see Section 2.2.6) and it is either too far or otherwise unsuitable for that other organism, the seeds will not be delivered. This may be the case for species that are moved by birds. If there are no perches where birds can land, then the seeds will not show up on the recovering site. Seeds and propagules may be moved by a variety of organisms and other means (e.g. floating), but if those means are not available, the plants will not arrive.

2.2.5 Facilitation

Facilitation is usually considered the beneficial effects of one species on others. However, in some cases, the benefits ascribed to one species come with detrimental effects on other species. For instance, beneficial mycorrhizal interactions between some species (Temperton et al., 2004) may reduce the competitive ability of other species.

2.2.6 Species interactions

Species interactions refer to the importance of other species to the species in question (Temperton et al., 2004). For instance, some plants may require specific pollinators without which they cannot set viable seed. Mycorrhizal symbionts are another example of species interactions. Without these important components, the species involved will fail thus ecosystem recovery is constrained.

3 Overcoming constraints – fostering recovery

The key to effective reclamation is to understand what is constraining the natural recovery processes and to develop effective methods for overcoming these filters. The following sections describe effective treatments for addressing constraints. Most of the treatments described below will address a number of different constraints. Again, the treatments can be conveniently broken into abiotic and biotic treatments on the basis of whether they entail living or non-living treatments.

3.1 Abiotic treatments

One of the simplest, most effective treatments for overcoming several common abiotic constraints is to make the soil surface rough and loose (Polster, 2009). Rough and loose surface configurations can be achieved by using an 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 toothed 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.

Rough and loose surface treatments eliminate compaction and prevent erosion (by preventing overland flow). The rough and loose surface provides an ideal site for seeds of pioneering species to be trapped. With a diversity of micro-site exposures as well as moisture conditions, the rough and loose configuration encourages invasion by a wide variety of pioneering species. In addition, because these treatments leave the soil loose, planting is easy. Costs for creation of rough and loose surface features have been found to be a fraction of the cost of traditional hydroseeding. A reasonably large machine (Komatsu PC300 series) can cover a hectare of surface with a rough and loose treatment in about 4 hours (Georgia Lysay, pers. comm.).

Angle of repose slopes need to be flattened before they can be expected to recover. Resloping methods have been well established (Milligan, 1978). Natural landform shapes provide the context for the establishment of natural ecosystems. Providing swales and a diversity of slope configurations will allow a diversity of species to establish. In most cases, pushing fine textured materials from the crest of the slope over the coarse materials that are found in the middle and at the bottoms of waste rock dump slopes will eliminate the problems associated with the free draining rocks found in the middle and bottom of a dump slope.

Adverse chemical composition problems need to be addressed using treatments that are specific to the site where the problems occur. In most cases, providing a cover of inert materials is the most effective treatment for soil chemical problems. The cover that is provided should be thicker than the deepest native species root system so that the problems of native woody species establishment on a thin cover and root puncture of the cover are avoided.

Nutrient issues are most effectively dealt with through vegetation as described below. Applications of leaf litter and coarse woody debris, including stumps and root systems can help re-establish nutrient cycling processes by introducing soil micro-organisms to the disturbed site. Woody debris (any non-merchantable material) including stumps, brush and other woody materials can provide substantial benefits to the restoration site. This is further discussed below as a biotic treatment.

Fencing may be an important part of the restoration treatment on some sites. Where herbivory is expected to be extreme, installing a fence to keep animals out of the reclaimed area until the plants are well established can be a cost-effective treatment. In riparian areas, protection of newly planted riparian vegetation from beavers may be very important. Many of the pioneering plants used in successional reclamation (Polster, 1989) are particularly favoured by herbivores and must be protected as they become established.

3.2 Biotic treatments

Traditionally, the main reclamation treatments applied to drastically disturbed sites was to seed the site with agronomic grasses and legumes, possibly with planting of late successional forest species. This approach has failed to provide ecologically appropriate, sustainable vegetation covers. The use of early successional, pioneering species as the initial cover on the disturbed sites appears to be the most effective means of providing a sustainable vegetation cover that re-integrates the disturbed site with the surrounding natural successional trajectories (Polster, 1989; Walker et al., 2007).

Pioneering species such as willows (*Salix* spp.), poplars (*Populus* spp.) and others that root readily from cuttings can be used in soil bioengineering treatments (Polster, 1997) that address many of the abiotic filters (steep, unstable slopes). Soil bioengineering treatments such as simple live staking can be used to create an immediate cover of pioneering species on drastically disturbed sites, reducing reliance on natural establishment and creating conditions that encourage re-establishment of natural successional trajectories.

Direct seeding of nitrogen fixing pioneering species on drastically disturbed sites can be a very effective way of establishing these species on these sites. Alder (*Alnus* spp.) and Mountain Avens (*Dryas drummondii*) can be directly seeded on disturbed sites, starting the natural successional processes. Planting seedlings of pioneering woody species can also be an effective way of establishing these species. Nitrogen fixing pioneering species can be planted as facilitators with an understory of later successional species to ensure successional movement towards these later successional species. Using a cover of pioneering species can improve the growth of later successional species. The pioneering species create shade and increase relative humidity in the understory in addition to the nitrogen in some cases, allowing the later successional species to grow more quickly than those without the pioneering cover. This is particularly important on drastically disturbed sites where the amenities of a previous vegetation cover are not usually available.

Some species are tolerant of high metals content or salinity and can be used in these extreme conditions. Tufted hair-grass (*Deschampsia cespitosa*) is well known for its tolerance of high metal levels and low pH (Watson et al., 1980) and can be found growing in very severe locations. Alkali saltgrass (*Distichlis spicata*) as the name implies, is tolerant of saline conditions and can be used to initiate succession and ameliorate the harsh conditions of saline or sodic sites. Capping the offending materials avoids the need for specialised species and allows recovery to follow locally appropriate successional trajectories.

4 Conclusions

Natural processes have been restoring drastically disturbed sites for millions of years. Understanding how these natural processes operate, the constraints to recovery and the treatments that can be applied to address these constraints allows development of effective strategies for the restoration of drastic disturbances caused by humans. The first step in this process is to identify the filters that are preventing the recovery of the ecosystems that have been destroyed. These constraints can be classed as either abiotic or biotic. In general, abiotic constraints are ones that can be addressed by machinery while biotic constraints require biological solutions. Observing how natural systems have overcome natural constraints that are similar to those caused by humans provides clues for finding effective solutions that are inexpensive and effective.

Pioneering species provide the initial vegetation cover on most natural drastically disturbed sites so it makes sense to use these same species to treat drastic disturbances that humans create. These species have qualities such as the ability to fix nitrogen or to grow in marginally stable situations making the site where they grow more stable. Treatments such as soil bioengineering treatments that make use of these species can initiate the successional processes that will lead to productive ecosystems that re-integrate the disturbed site with the natural successional processes that operate in the area.

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