RELATING MINELAND RECLAMATION TO ECOSYSTEM RESTORATION[1]

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Abstract: Evaluation of reclamation success on surface mined lands is based primarily on surface topography reconstruction, characteristics of the reestablished plant community, and soil erosion protection. Restoration of ecosystem functions such as nutrient cycling, organic matter decomposition, soil development, and community dynamics are not directly examined but are assumed to be recovering to the degree that the system will be self sustaining and resilient to environmental stress. Obviously, there are important differences and similarities in the goals of ecosystem restoration and mineland reclamation. We have been collecting data on recovery of ecosystem processeses in reclaimed minelands and adjacent undisturbed sites (reference areas) for almost ten years. This paper reports results of our findings on recovery of ecosystem functions on reclaimed surface mined lands and relates characteristics of successfully reclaimed surface mined land to attributes of restored ecosystems.

Additional Key Words: land reclamation, ecosystem restoration, ecosystem sustainability

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Introduction

Historically, in the field of disturbed land remediation, the terms reclamation and restoration have been defined quite differently. The National Academy of Sciences, in their 1974 report on rehabilitation potential of western coal lands (NAS, 1974), defined restoration as returning a disturbed site to the exact condition it was in before disturbance and reclamation as reconstructing a disturbed site to be habitable by the same organisms (or similar organisms in terms of ecological niche) present before disturbance in approximately the same composition and density. In his textbook, Disturbed Land Revegetation, Munshower (1994) defines restoration as return of a degraded site to the exact ecological condition it exhibited prior to disturbance and reclamation as construction of topographic, soil and plant conditions which may not be identical to the pre-disturbance site, but which permits the degraded land to function adequately in the ecosystem of which it was and is a part. In this author's opinion, these definitions of restoration are impractical because some ecosystem components cannot be returned to exact pre-disturbance condition. Soil, for example, is a highly structured, complex and heterogeneous mixture of mineral particles, organic matter, gases and organisms that cannot be reconstructed by humans even when soil is salvaged prior to a disturbance.

In 1994, the Society for Ecological Restoration adopted a more practical definition of restoration: the process of repairing damage caused by humans to the diversity and dynamics of indigenous ecosystems (SER, 1994). This definition is still problematic, however, because indigenous ecosystems do not exist in many areas with long histories of human habitation. The current definition of ecosystem restoration according to the Society for Ecological Restoration (2004) is quite broad: the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. A more recent definition of reclamation posted on the University of Alberta Land Reclamation website is: the process of improving disturbed land to achieve land capability equivalent to the pre-disturbed condition (University of Alberta, Department of Renewable Resources, 2005).

Considering the changing definitions of land reclamation and ecosystem reclamation, in this author's opinion the meaning of these two terms have become more similar over the past 30 years. An operational difference may be that the term reclamation is preferred or more commonly used in regard to remediation of planned disturbances by whose remediation work must meet certain standards and is subjected to evaluation by regulatory agencies as required by law, e.g. highway right-of-way reclamation, surface mine reclamation. Restoration is more often used in regard to remediation of unplanned or unintentional disturbance or degradation where results are not required to meet strict regulatory requirements. This usage may be a result of the historical definition of restoration to mean returning a site to its exact pre-disturbance condition. Reasons for increasing similarity in the definition of these terms may be the realization that a disturbed site cannot be returned to its exact pre-disturbance condition (think about soils as mentioned above) and that legal requirements for remediation of planned disturbances have become stricter, e.g. requirements for use of native species and reestablishing certain levels of diversity.

Objectives of Mineland Reclamation and Ecosystem Restoration

In addition to the broad objectives stated in the definitions discussed above, specific objectives of mineland reclamation and ecosystem restoration seem very different. In reclaiming

mined land to a capability equivalent to its pre-disturbance condition, the specific objectives of concern to the reclamationist are the legal requirements or performance standards dictated by the regulatory agency evaluating reclamation success. In Wyoming these requirements are given in Wyoming Coal Rules and Regulations (WCRR), Chapter 4: Environmental Protection Standards for Surface Coal Mining Operations (WYDEQ, 2005). The first performance standard stated in this chapter supports the definition of reclamation from the University of Alberta: "Reclamation shall restore the land to a condition equal to or greater than the highest previous use" (University of Alberta, Department of Renewable Resources, 2005).

Specific objectives of ecosystem restoration are not legal requirements or performance standards dictated by legislation and most restoration projects are not required to meet legislated performance standards. In fact, in searching for objectives of restoration projects, we found that most restoration projects had their own specific objectives developed as part of the project. These restoration objectives, in general, were much more site and project specific than performance standards associated with mineland reclamation. The Society for Ecological Restoration International (2004) has published a list of nine attributes to provide a general basis for determining when restoration is accomplished. In the next section of this paper, we will relate these nine Attributes of Restored Ecosystems (SER, 2004) to our observations of reclamation on surface coal mines in Wyoming, reclamation performance standards as stated in WCRR (WYDEQ, 2005), and research on recovery of ecosystem structure and function we have conducted surface mine reclamation sites.

Comparing Attributes of Restored Ecosystems to Reclaimed Surface Coal Mines

To relate the attributes of Restored Ecosystems as stated by the Society for Ecological Restoration International (2004) to reclamation sites on surface coal mines in Wyoming, we will first state the attribute, and then relate it to reclamation practices at surface coal mines, WCRR, and finally to our own research. The Society for Ecological Restoration International (2004) points out that full expression of all 9 attributes is not essential to demonstrate restoration. Rather it is only needed to demonstrate a suitable trajectory of ecosystem development toward the intended goals or reference ecosystem (SER, 2004).

1. *The restored ecosystem contains a characteristic assemblage of species that occur in the reference ecosystem and that provide appropriate community structure.*

Reclaimed coal mines are generally seeded with an assemblage of native plant species (many species may not be available as seed), however, in some places, the resulting reestablished plant community may have a very different structure than the reference area. For example, reestablished plant communities on reclaimed sites in the Powder River Basin have a much greater cool season grass component, higher productivity and lower plant diversity than undisturbed reference areas.

WCRR (WYDEQ, 2005) state that “the operator shall establish on all affected lands a diverse, permanent vegetative cover of the same seasonal variety native to the area or a mixture of species that will support the post mining land use in a manner consistent with the post mining land use. This cover shall be self-renewing and capable of stabilizing the soil”. In regard to community structure, WCRR state “species diversity and composition are suitable to the approved post mining land use and the revegetated area is capable of withstanding grazing pressure at least comparable to that which the land could have sustained prior to mining”. Or, if

using the Control Method (Reference area), "Control or Reference areas shall be sampled for cover, productivity, species diversity and composition in the same season that the affected area is sampled for baseline data. Quantitative pre-mining and post mining vegetation data from the control areas shall be used to mathematically adjust pre-mining affected area for climatic change. Pre-mining affected area cover and productivity data will be directly compared by statistical procedures to data from the reclaimed vegetation type when evaluating revegetation success for final bond release. Species diversity and composition data will be quantitatively of qualitatively evaluated as determined by the Administrator".

In regard to organisms other than plants, our research on microbial community recovery in reclaimed minesoils indicate the indigenous species of arbuscular mycorrhizal (AM) fungi are reestablishing on surface mine reclamation sites (Frost et al., 2001). Like the plants, however, community structure among the AM fungi is very different in reclaimed soil than in undisturbed soil. The methodology we are currently using to characterize microbial communities in reclaimed soils (phospholipid fatty acid analysis, PLFA) does not allow us to monitor specific species of microbes but does indicate that microbial community structure is returning to that found in undisturbed reference soils (Mummey et al., 2002a; 2002b).

2. The restored ecosystem consists of indigenous species to the greatest extent possible.

Reclaimed landscapes on most surface mines are dominated by indigenous species, however, older reclaimed areas exist that were reclaimed using introduced species such as Crested Wheatgrass.

WCRR (2005) state: Introduced species may be used only to establish a quick, temporary, stabilizing cover to control erosion, or to achieve a post mining land use as approved by the Administrator.

Research from our laboratory indicate the indigenous species of AM fungi and many bacteria do reestablish after soil conditions begin to return to pre-mining conditions (i.e. reduction of salt content, redevelopment of pore space, etc; Stahl et al., 1988; Frost et al., 2001; Mummey et al., 2002a). Our vegetation data suggests that plant community diversity also increases with time after reclamation (Wick et al., 2006).

3. All functional groups necessary for the continued development and/or stability of the restored ecosystem are represented or, if they are not, the missing groups have the potential to colonize by natural means.

Other than certain functional groups of vegetation (i.e. shrubs, warm season grasses, forbs) in some regions, there are no obvious indicators of missing functional groups retarding ecosystem development or inhibiting stability. In most mineland reclamation sites, there do not appear to be significant limitations on the potential of missing functional groups of plants, animals and microbes to re-colonize reclaimed areas. One exception observed on a number of mines in Wyoming, however, is the difficulty in reestablishing Wyoming Big Sagebrush due to heavy grazing of seedlings by rabbits, deer, and antelope (Partlow, 2003).

WCRR (2005) do not address functional groups of organisms other than requiring establishment of a diverse vegetative cover and similar species diversity and composition when using the reference area method for evaluation.

Data we have collected thus far on belowground ecosystem structure and function have not revealed any indicators of missing functional groups of organisms. Our data on this topic

indicate that a number of functional groups of soil organisms are reestablishing in reclaimed soils (Ingram et al., 2005; Stahl et al., 2002) however, this dataset is by no means complete. See attribute 5 for further discussion.

4. *The physical environment of the restored ecosystem is capable of sustaining reproducing populations of the species necessary for its continued stability or development along the desired trajectory.*

In surface coal mine reclamation sites, the physical component of the environment most significantly altered is the soil and subsurface environment. In most situations, the belowground environment does not appear to be inhibiting reproduction of species. It is possible, however, that surface soil physical factors are contributing to poor reestablishment of certain plant species. We are currently in the initial stages of examining diversity of soil biota in reclaimed soils.

WCRR (2005) call for handling or redistribution of topsoil in a manner that avoid degradation of this resource. There are no requirements for testing or matching of soil physical, chemical or biotic properties in the WCRR (2005).

In general, most soil physical characteristics we have examined in our research (i.e. pH, electrical conductivity, and texture) are capable of sustaining reproducing populations of necessary species.

5. *The restored ecosystem apparently functions normally for its stage of development, and signs of dysfunction are absent.*

In general, no signs of ecosystem dysfunction are obvious at surface mine reclamation sites.

Other than observation and analysis of soil stability, plant community characteristics (cover, production and diversity), surface and subsurface hydrology, ecosystem functions (e.g. decomposition, energy flow, N fixation, etc.) are not monitored in evaluation of reclamation success.

Our lab has been studying a number of ecosystem processes on surface coal mine reclamation sites such as soil organic matter accumulation, soil structure redevelopment, litter decomposition, N mineralization, mycorrhizal development, microbial productivity, and microbial community recovery. Although our data is not conclusive, they indicate that ecosystem functions are reasonable for stages of development examined. Work we have recently published on N-mineralization in reclaimed mine soils (Ingram et al., 2005) suggests that N-mineralization in these reclaimed soils is occurring at greater or equal rates to that in nearby undisturbed soils. A study published in this volume (Wick et al., 2006) indicates that structural redevelopment in reclaimed soil begins shortly after soil replacement. Other studies on reclaimed mine soils in arid and semiarid regions have reported recovery of various functional groups of microbes, often in relatively short periods of time (Fresquez and Aldon, 1986; Parker et al., 1987; Stahl et al., 1988)

6. *The restored ecosystem is suitably integrated into a larger ecological matrix or landscape, with which it interacts through abiotic and biotic flows and exchanges.*

Surface mine reclamation sites appear to be well integrated into the landscape in regards to watersheds, fauna, vegetation, and nutrient flows.

WCRR (2005) require reestablishment of pre-mining stream channels in most situations.

Our observations of integration of reclaimed mine sites indicate that they are well integrated into the larger ecological matrix.

7. *Potential threats to the health and integrity of the restored ecosystem from the surrounding landscape have been eliminated or reduced as much as possible.*

Other than invasive plant species that cannot readily be eliminated, no potential threats to the health and integrity of reclaimed mine lands are obvious. Other difficult situations may exist but probably do not constitute threats to the health and integrity of reclaimed coal mines as much as problems that must be overcome to meet objectives. A good example of this type of situation is the herbivores that feed on sagebrush seedlings and reduce establishment of this important species. Partlow (2003) showed that rabbit, pronghorn antelope and mule deer feeding on sagebrush seedlings can lead to high rates on sage mortality (50-70%). Successful establishment of high densities of sagebrush at a number of mines demonstrate that this problem can be overcome.

8. *The restored ecosystem is sufficiently resilient to endure the normal periodic stress events in the local environment that serve to maintain integrity of ecosystems.*

Surface mine reclamation sites appear to be enduring normal periodic stress events. For example, most reclaimed areas in Wyoming seem to have endured the drought of 1999-2003 without significant failure.

WCRR (2005) do not appear to address this issue specifically.

In general, reclaimed surface mine sites we have been conducting studies on appear to have withstood normal periodic stress events such as drought and grasshopper infestations.

9. *The restored ecosystem is self-sustaining to the same degree as its reference system, and has the potential to persist indefinitely under existing environmental conditions.*

This is an extremely difficult attribute to assess.

WCRR (2005) call for establishment of a diverse, permanent vegetative cover. This was the only reference to a self sustaining system we found.

Our research on recovery of ecosystem structure and function have not revealed any information that indicate reclaimed coal mine sites will not be self-sustaining. Our investigations into soil organic matter and nutrient cycling suggest that these reclaimed systems are cycling nutrients to the same degree as the nearby undisturbed systems within a few years after reclamation (Ingram et al., 2005).

Conclusions

Using the current definition of ecological restoration (SER, 2004), surface coal mine reclamation is definitely a type of restoration; that is, mine reclamation is assisting or facilitating the recovery of an ecosystem that has been degraded, damaged or destroyed. While attributes of restored ecosystems used in ecological restoration focus more on reestablishment of pre-disturbance community structure and ecosystem function, surface mine reclamation performance standards may be more difficult to meet in that they are legal requirements and must be fulfilled to a legal standard. Attributes of Restored Ecosystems (SER, 2004) are guidelines and full expression of all attributes is not essential to demonstrate restoration (SER, 2004). In terms of

reestablishing a stable, functioning, self-sustaining ecosystem, it is our opinion that it will take time to determine which approach will be more effective. While devoting attention to ecosystem functions, the ecosystem restoration approach (SER, 2004) acknowledges that measurement of most ecosystem functions is beyond the capabilities and budgets of most restoration projects and these functions must be assessed indirectly. Redevelopment of ecosystem function is implied in the reclamation approach and is also indirectly assessed, e.g. health of the vascular plant community. Most scientists have come to realize, however, that vegetation indicators alone do not provide sufficient information to properly evaluate ecosystem function or sustainability and must be used cautiously (Blum and Santelises, 1994; NRC, 1994; Larson and Pierce, 1994; Karlen et al., 1997).

Literature Cited

Blum, W.E.H. and A.A. Santelises. 1994. A concept of sustainability and resilience based on soil functions. P. 535-542. In: D.J. Greenland and I. Dzabolcs (eds), Soil Resilience and Sustainable Land Use, CAB International, Wallingford, England.

Fresquez, P.R. and E.F. Aldon. 1986. Microbial reestablishment and the diversity of fungal genera in reclaimed coal spoils and soils. Reclamation and Revegetation Research 4:245-258.

Frost, S. M., P.D. Stahl and S.E. Williams. 2001. Long term reestablishment of arbuscular mycorrhizal fungi in a drastically disturbed semi-arid surface mine soil. Arid Land Research and Management 15:3-12. http://dx.doi.org/10.1080/15324980119429.

Ingram, L.J., G.E. Schuman, P.D. Stahl, and L.K. Spackman. 2005 Microbial respiration and organic carbon indicate nutrient cycling recovery in reclaimed soils. Soil Science Society of America Journal 69:1737-1745. http://dx.doi.org/10.2136/sssaj2004.0371.

Karlen, D.L., M.J. Mausbach, J.W. Doran, R.G. Cline, R.F. Harris, and G.E. Schuman. 1997. Soil Quality: A concept, definition, and framework for evaluation. Soil Science Society of America Journal 61:4-10.

http://dx.doi.org/10.2136/sssaj1997.03615995006100010001x.

Larson, W.E. and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. P. 37-52. In: J.W. Doran, D.C. Coleman, D.F. Bezdicek and B.A. Stewart (eds), Defining Soil Quality for a Sustainable Environment, Soil Science Society of America, Madison, WI.

Mummey, D.L., P.D. Stahl, and J.S. Buyer. 2002a. Soil microbiological and physicochemical properties 20 years after surface mine reclamation: comparative spatial analysis of reclaimed and undisturbed ecosystems. Soil Biology and Biochemistry 34:1717-1725. http://dx.doi.org/10.1016/S0038-0717(02)00158-X5.

Mummey, D.L., P.D. Stahl, and J.S. Buyer. 2002b. Microbial biomarkers as an indicator of ecosystem recovery following surface mine reclamation. Applied Soil Ecology 21:251-259. http://dx.doi.org/10.1016/S0929-1393(02)00090-2.

Munshower, F. F. 1993. Practical Handbook of Disturbed Land Revegetation. Lewis Publishers, Boca Raton, FL.

National Academy of Sciences, Study Committee on the Potential for Rehabilitating Lands Surface Mined for Coal in the Western United States. 1974. Ballinger Publishing Company, Cambridge, MA.

Parker, L.W., N.Z. Elkins, E.F. Aldon, and W.G. Whitford. 1987. Decomposition and soil bota after reclamation of coal mine spoils in an arid region. Biology and Fertility of Soil 4:129-135. http://dx.doi.org/10.1007/BF00256986.

Partlow, K.A. 2003. Wildlife impacts on Wyoming big sagebrush in reclaimed mined lands. M. Sci. Thesis. University of Wyoming, Laramie, WY.

Society for Ecological Restoration International . 1994. Society for Eclogical Restoration Project Policies. Restoration Ecology 2:132-133.

Society for Ecological Restoration International Science & Policy Working Group. 2004. The SER International Primer on Ecological Restoration. www.wer.org & Tuscon:Society for Ecological Restoration International.

Stahl, P.D., Williams, S. E. and Christensen, M. 1988. Efficacy of native vesicular-arbuscular mycorrhizal fungi in drastically disturbed soil. New Phytologist 110: 347-354. http://dx.doi.org/10.1111/j.1469-8137.1988.tb00271.x.

Stahl, P.D., B.L. Perryman, S. Sharmasarkar, and L.C. Munn. 2002. Stockpiling vs. exposure to traffic: Best management of topsoil on in-situ uranium wellfields. Restoration Ecology 10:129-137. http://dx.doi.org/10.1046/j.1526-100X.2002.10114.x.

University of Alberta, Department of Renewable Resources. 2005. Land Reclamation, Remediation and Restoration. Retrieved 19 January 2006 from http://www.rr.ualberta.ca/Research/Index.asp/Page=LRRR.

Wick, A.F., P.D. Stahl, L.J. Ingram, G.E. Schuman, and G.F. Vance. 2006, Aggregate size distribution and stability under a cool season community chronosequence on reclaimed coal mined land, Proceedings America Society of Mining and Reclamation, 2006 pp 806-815 http://dx.doi.org/10.21000/JASMR06010806

Wyoming Department of Environmental Quality, Land Quality Division. 2005.Wyoming Coal Rules and Regulations. Soswy.state.wy.us/Rule_Search_Main.asp