INTEGRATED RECLAMATION: APPROACHING ECOLOGICAL FUNCTION?[1]

Ann L. Hild[2], Nancy L. Shaw, Ginger B. Paige and Mary I. Williams

Abstract. Attempts to reclaim arid and semiarid lands have traditionally targeted plant species composition. Much research attention has been directed to seeding rates, species mixes and timing of seeding. However, in order to attain functioning systems, attention to structure and process must compliment existing efforts. We ask how to use a systems approach to enhance reclamation success. Using a case study example, we discuss ways to target key drivers that return the functional and dynamic nature of western wildlands. Integration of a multitude of abiotic (soil stability, hydrology and nutrient cycling) and biotic processes (plant functional traits, species turnover and regeneration, and wildlife interactions) into reclamation planning will be crucial to uniting research with management experience. Long-term monitoring coupled with tools to unify diverse datasets will be key to future management decisions. Reclamation is constrained by our inability to unify varied experiences with documented evidence. Research should assist managers with integrating spatial and temporal variability of ecosystem processes into long-term management planning. Using an integrated approach, we can more fully comprehend reclamation within the context of ecosystem function. An integrated knowledge base should serve as a communication tool and facilitate more sustainable landscape solutions.

Additional Key Words: functional traits, plant community structure, seeding

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[2] Ann Hild is Professor of Shrubland Ecology, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071. Nancy Shaw is Research Botanist and Team Leader, Great Basin Native Plant Selection and Increase Project, USDA Forest Service, Rocky Mountain Research Station, Boise, ID. Ginger Paige is Assistant Professor and Watershed Hydrologist, and Mary Williams is a Doctoral Student and Instructor of Restoration Ecology, Department of Renewable Resources, University of Wyoming, Laramie.

Introduction

"The repairer of a watch does not need a description or a set of correlations, but a kit of parts and the knowledge of how to fit them together. With this kit and this knowledge, the repairer might hope to reassemble the watch, and if this is done properly the watch will have acquired the emergent property of an integrated whole …" John Harper (1987).

Reclamation efforts in arid and semiarid lands have traditionally targeted plant species composition. Much research attention has been directed to seeding rates, species mixes and timing of seeding. Research in reclamation, by virtue of researcher expertise, often includes controlled studies of one or a few aspects of reclamation at either a precise, small plot scale, or at a more general landscape scale. Although we all recognize the importance of integration in ecology, it is often difficult to clearly visualize how a variety of ecological elements, the knowledge and experience of hands-on managers, and the temporal and spatial characteristics of wildland systems can be integrated into a meaningful synthesis of reclamation outcomes. We discuss an integrated approach to reclamation as a means to advance our science and aid in successful reclamation of arid and semiarid lands following human disturbance.

Elements needed for developing integrated reclamation

Reclamation requires the integration of several ecological components across a range of spatial and temporal scales. Ecological communities and processes are not easily sorted into distinct elements. However, for the purposes of this discussion we distinguish among composition, structure, and function, recognizing that they are synergistically tied to one another and can be considered at a variety of scales.

Composition

Meefe et al. (2002) describe composition as the "what is there" in ecosystems. Composition can be documented at the sub-organismal scale (i.e. genetic composition) to landscape scale (i.e. the arrangement of vegetative communities in a matrix within a watershed). Most common reclamation efforts have targeted composition of ecosystems through inventories documenting pre-disturbance plant species composition, soil textures and profiles of soil horizons, areal extent of vegetation types and sometimes the physical features that may provide wildlife habitat. Often the major focus is on plant species composition (Herrick et al., 2006). These baseline records have provided the laundry list for which reclamation is held accountable. Many difficulties in returning particular combinations of species (plant and animal) to reclaimed lands derive from the desire to replace the composition (i.e. establishing 1 shrub per m^2) irrespective of structural and functional characteristics of the previous landscape (i.e. variation in age structure of shrub populations and shrub cohort recruitment processes).

Seed Selection

The choice between local seed versus widely derived seed sources (Lesica and Allendorf, 1999; Broadhurst et al., 2008) is based on our desire to retain genetic variation of populations (gene flow within cross-pollinated populations) and to limit detrimental effects of out-breeding depression (altering gene flow function by introducing new genetic material that is presumably, less well adapted to specific site characteristics and will die out). Local seed sources (possibly more early successional than were there at the time of disturbance) that include genetic variation may be used for small disturbances when available. Widely derived seed sources may be more applicable to larger disturbances over homogeneous areas because they may include more genetic diversity and thus will be more likely to include seeds that are well suited across the disturbed site. The choices of seed source then, can be best made using tools to consider site conditions, availability and long-term objectives. Availability is often a strong driver of seed selection but may become less so with an integrated approach (for example targeting seed to only restoration applications most likely to be successful would reduce some demand on limited seed sources). In all cases, it is important to consider the seed source (area of collection) and inclusion of adequate variability to obtain adapted materials that will be resilient in the face of environmental stresses (Withrow-Robinson and Johnson, 2004).

Reseeding on a relatively undisturbed soil surface (for example after wildfire) may be best addressed with adapted seed sources, often of the target community, if the hydrologic function and the erosion potential of the site are not severely compromised and if the entry of invasive species is not a threat. In this case, structure will return as the canopy develops (although some structural characteristics may not be present for quite some time). Seeding techniques or use of seedlings to create mosaics of herbaceous and woody material, for example, might be helpful in speeding the return of above and belowground structure and thus function. On more radically damaged sites (e.g. a mine land setting where topsoil and substrate have been removed and replaced) a broader genetic amplitude in the seed source, and perhaps earlier successional species, might increase the chances that some seedlings will be well-suited to at least some of a site's traits (where the 'rules' have changed). But the return of species composition via seeding and immediate reclamation actions is only an initial step. Vegetative communities are defined not only by species composition but also by their spatial arrangement on the landscape.

Structure

Ecosystem structure is the "how it is distributed in space and time" (Meefe et al., 2002). Community structure has been defined by the Society for Ecological Restoration (SER) as "the physiognomy or architecture of the community with respect to the density, horizontal stratification, and frequency distribution of species-populations, and the sizes and life forms of the organisms that comprise those communities" (SER Working Group, 2004). Structure too, occurs in ecosystems at a multitude of scales. Within a single species, genetic make-up varies greatly with geographic location (e.g. the relative representation of a recessive gene). Structure is described by the variety of age groups (demographic structure) or plant growth forms (vegetative structure). At the community scale, plant diversity (richness and abundance combined) is a form of structure, just as vertical arrangement of plant canopies (understory herbaceous layer, combined with a shrub overstory) may be considered structure indicative of say, wildlife habitat characteristics, or regulation of rainfall interception. Given the great amount of reclamation in the western states that is conducted on arid and semiarid shrublands, there is a surprising lack of attention to structure in mine land reclamation seedings.

A search of keywords: 'reclamation, shrub and structure' yields few recent studies in the western states. Structural development in the canopy of vegetation on mine land seedings has not been extensively studied. Often it is assumed that returning the same composition of plant species will provide vegetative structure. However, associated herbaceous species on reclamation sites can limit canopy growth of seeded shrubs and thus slow structural development (Hild et al., 2006). More study is needed to document the return of vegetative structure and its sequential development on reclamation sites. Seeding strategies such as seeding potentially competing species in different rows or patches and mechanical manipulation of vegetative structure, or use of different mixes for parts of the seeding or different mixes from different seed drops in the drill show promise. Although the logistics of such efforts do add expense to projects by requiring additional seeding at different times and equipment to accomplish spatial patchiness (Roundy, 1996) they may ultimately get desired outcomes sooner or avoid reseeding expenses.

Reclamation efforts conducted for wildlife habitat must consider structural vegetation composition and development as well as physical characteristics of the landscape, which provide for wildlife habitat. Rumble (1989), noted that rock structures within reclamation sites provide structural habitat for wildlife in sagebrush grasslands, although vegetation structure was not recorded. Rock structures are commonly added in mine land reclamation. However, inclusion of vegetation structure to favor wildlife, for example by seeding mixes may be less common in mine land reclamation than in wildfire rehabilitation seedings (Roundy, 1996; Stevens, 2004). Roundy (1996) notes that although many attempts to use seeding mixes are intended to increase diversity on reclaimed sites, often interspecific competition can limit the success of these mixes. Stevens (2004) and others suggest patch seeding, seeding species in different rows or creating patchiness via transplanting shrubs into seeded areas as a means of insuring spatial heterogeneity in reclaimed sites. Both authors (Roundy, 1996; Stevens, 2004) target vertical and horizontal community diversity as important vegetative characteristics to consider for wildlife. The use of newer drills with multiple seed boxes that permit seeding different species combinations in separate rows and use of GPS systems to guide planting different mixes within selected project areas are important tools for overcoming these problems. However, the successes of planning for vegetation structure are difficult to directly measure. Lindell (2008) has suggested that wildlife behavior is a more reasonable assessment of habitat quality, urging that we move beyond presence/absence data and quantify animal movement, dispersal, foraging, vigilance and other behaviors as indicators of habitat quality when monitoring reclaimed sites. Designing spatial structure into reclamation programs may speed the return of ecological function and is an important consideration for improving hydrologic processes (Ludwig et al., 2005; Seyfried and Wilcox, 2006).

Although spatial soil patterns are well documented in native shrub stands (Charley and West, 1975; Del Valle et al., 1999 and other studies), little attention has been directed at spatial patterns in returning soil patchiness in reclamation settings. Shachak et al. (1999) provide a useful overview of the links between landscape patchiness in the Negev and its contribution to hydrologic function and nutrient cycles. Mummy et al. (2002) demonstrated differences in microbial populations within shrubland systems beneath Wyoming big sagebrush and associated interspaces. These spatial patterns of soil physical and chemical properties have been documented in many studies in shrubland systems globally (e.g. Del Valle et al. (1999) in Patagonia, Shachak et al. (1999) in the Negev Desert, and Charley and West (1975) in North American sagebrush steppe). In reclaiming shrubland systems especially, spatial structure is particularly crucial to return of ecosystem function even though it is seldom mentioned in reclamation standards. Although this issue is difficult to address in reclamation, patchiness in topsoil replacement (in depth and texture) might be considered along with patchiness in litter derived from variation in stubble seedings. While soil spatial patterns are an issue where topsoil replacement is common such as on mine lands, in wildfire rehabilitation and restoration, soil patchiness in soil fertility patterns often remain following fire.

Functional traits of plant species

Functional traits may be used as predictors of plant performance of seeded species (Violle et al., 2007). The concept of functional trait suggests that species can be grouped by their response to the environment or common effects on ecosystem processes. For revegetation efforts, plants may be selected to meet specific reclamation objectives. Traits of plants selected for erosion control may include strong taproots, fibrous branching root systems, low growing cover, rapid growth, resistance to damage, and high litter production (Morgan and Rickson, 1995). James and Drenovsky (2007) found high variation in relative growth rate among native forbs was related to differences in specific leaf area and leaf area ratios and suggested that species selected for these relatively easily measured characteristics may provide for greater competitive ability against invasives. Identifying and cataloging plant functional traits would provide a valuable tool for aiding reclamation planners to meet specific functional objectives.

Considering Function in Integrated Reclamation

Meefe et al. (2002) refer to ecosystem function as "what it does". Function refers to the flow and rate of turnover in the essential components of an ecosystem: species turnover, energy flow, water and nutrients cycles. Landscape structure can influence function by altering the rate, variability and conservation of resources by these processes (Whisenant, 1999). For example, height and density of shrub species in a landscape might alter animal movement and thus indirectly impact seed dispersal of plant populations and indirectly influence gene flow by altering the exchange of genetic materials in out-crossing species. At the community level, Pellant et al. (2005) describe functioning as the presence and integrity of ecological processes (energy flow, gene flow, water and nutrient cycles) as expected based on the ecological site.

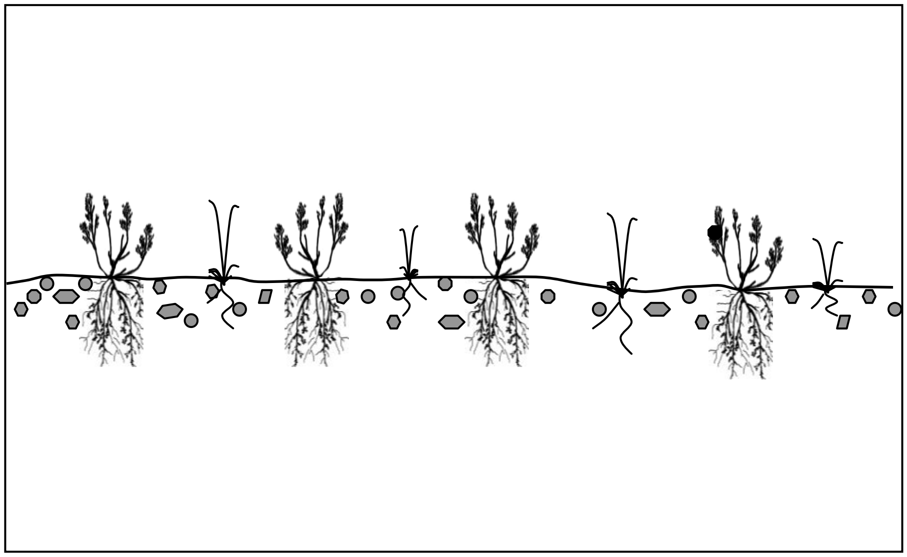
Restoring function and process is essential in restoration planning (Whisenant, 1999). In addition, if we consider integrating biotic interactions, such as response of seeded species to potential attack by an insect herbivore, greater genetic variation may increase seeded species' structural variability. Finally, belowground nutrient uptake may have been altered by soil disturbance, resulting in an altered reclamation environment. Given that in reclamation the 'rules of assembly' are so radically different following disturbance, we must acknowledge that the rules have changed and shift our focus to returning some site functions.

Return of function does not necessarily imply return to original plant community and associated processes. Instead different "levels of functionality" need to be acknowledged and defined in reclamation objectives. Ecological function of a reclaimed site will change with time, management, energy input and luck. For example, in a sagebrush steppe reclamation site, return of ecological function (hydrology, nutrient cycling, species composition turnover and demography) may vary with time (Fig. 1). In the first few years following reclamation treatment, minimal reclamation goals are achieved. The soil surface is stabilized, erosion potential is minimal and the vegetative community is comprised of the required or desired plant species. Much later (20-50 years), ecological function of the site is more developed. Extensive interaction and feedback among abiotic and biotic components creates microclimates and heterogeneity of site characteristics and fluxes at multiple scales. However, it is important to note that this level of integration and function does not equate to full 'restoration'. We are not advocating a necessary return to a hypothetical pristine pre-disturbance condition. By full ecological function, we target a state that is inherently integrated and more resilient to future perturbations.

Integrated reclamation, as we envision it, incorporates the elements of composition and structure to examine and facilitate return of functional ecosystems over a variety of temporal and spatial scales within the environmental constraints of the reclamation site. Whisenant (1999) suggests the key to reclamation is to emphasize repair of processes such as hydrology, nutrient cycles, energy capture, propagule production, dispersal and animal interactions. Few examples exist in reclamation literature that demonstrate integration at this level. However, we believe that it is likely that such examples exist in the practitioner knowledge base but have not been well documented. By integrating this knowledge with research we can aspire to describe pathways to improved ecosystem function.

1-5 years:
small uniform sagebrush some herbaceous species homogeneous soil"uniform" hydrologic response

minimal feedback between biotic & abiotic components of the system



20-50 years:
heterogeneity of vegetative cover & structure heterogeneity of hydrologic response development of micro-climates

full feedback among biotic & abiotic components of the system

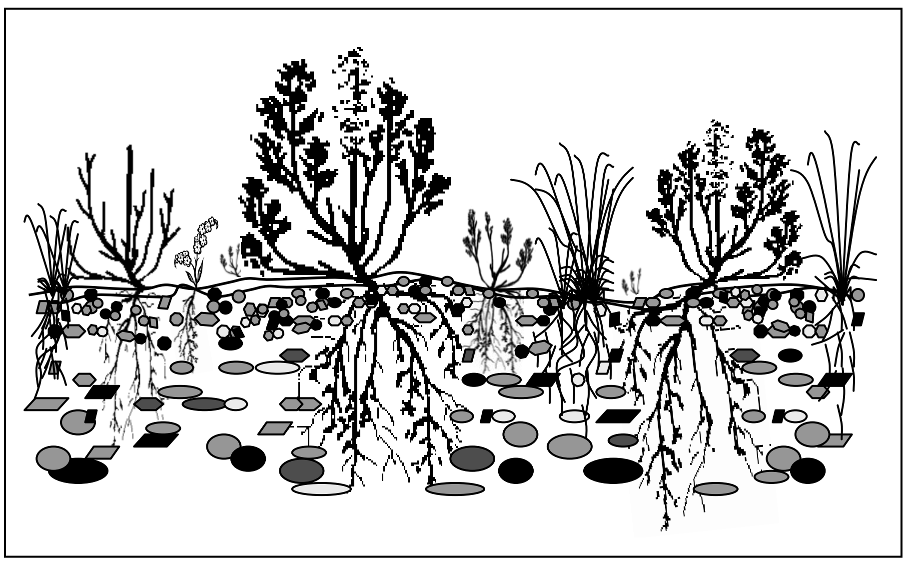


Figure 1. Theoretical example of stages of "ecologic function" in a reclaimed sagebrush steppe system. Minimal reclamation goals are achieved in the first 5 years (above); Ecological function of the site returns via interactions and feedback between year 20 and 50 (below).

Suggestions for Integrating Reclamation Knowledge and Research

Standardized Ecological Units for Planning and Monitoring Reclamation Efforts

One example of an attempt to unite information on revegetation efforts is the US Forest Service Burned Area Emergency Response (BAER) program, which targets emergency watershed rehabilitation on western wildlands impacted by wildfire. BAER teams commonly weigh revegetation treatments (cover layers, road treatments and physical barriers) to limit erosion, in effect-targeting tactics that begin to restore hydrologic function. An assessment of the effectiveness of BAER treatments in the Western States provides an overview of reclamation effects on 5.4 million acres over a 30 year period (Neary et al., 2000). Use of such information into a larger reclamation framework could more effectively document trends and predict risk associated with reclamation tactics (Robichaud et al., 2000).

If for example, we unite BAER, coalmine, natural gas and other reclamation project records into a western states reclamation database, we may be able to develop predictive tools for understanding risks and potential windows of optimum success. This task requires some standardization of monitoring and site delineation. Standardization of site delineation throughout western wildlands is already well underway with the implementation and delineation of Ecological Sites (ES), an undertaking led by the National Resource Conservation Service, in conjunction with the Bureau of Land Management, Agricultural Research Service and several other public land agencies. An Ecological Site is a kind of land that differs from other kinds of land in its specific physical characteristics, its ability to produce distinctive kinds and amounts of vegetation and in its response to management (Pellant et al., 2005). Development of ecological site descriptions (ESDs) for western wildlands is currently underway on public lands. Ecological Site Descriptions provide a standardized characterization of basic landscape units for management, based upon soil and site stability, hydrologic function and biotic integrity. They describe not only plant species composition (the baseline vegetative composition that many reclamationists already document) but they add quantitative measures of site soil and physical characteristics. If reclamation professionals and researchers join this effort by recording and designing reclamation based on Ecological Sites, we believe that trends in reclamation would become much more easily recognized. The replication of reclamation efforts in comparable units (the same ES) would allow a more precise vision of the outcomes of management decisions and yield more statistically powerful tests of hypothesized relationships.

Monitoring Effectiveness

In addition to use of ESDs, reclamationists should begin to monitor their impacts on structure and function and must target temporal trajectories. Temporal trends in changing hydrologic function, return of vegetative structure and other ecosystem traits will greatly enhance our ability to project the effectiveness of reclamation actions into the future. Some managers already hold long-term reclamation records for specific sites. If these datasets were combined with other long-term datasets and detailed climatic records, and stratified by common ecological sites, we might be able to discern long-term trends not apparent to individual managers. In this way, temporal variability due to climatic influences and spatial variability associated with geographic location of reclamation sites may be more easily documented and isolated from impacts of reclamation treatments. Herrick et al. (2006) call for monitoring of three key ecological processes: soil and site stability, hydrologic function, and biotic integrity in order to document potential long-term success of restoration efforts. They suggest ecological processes should be monitored in reclamation using the 17 indicators used in Rangeland Health Assessments (Pellant et al., 2005). However, for use in integrating reclamation datasets (see below) we suggest inclusion of quantitative measures (the 17 indicators are qualitative) of function where feasible.

Uniting Research with Management Experience in Online Datasets

Coupling long-term monitoring with standardized ecological units will provide a foundation for uniting diverse datasets and will be crucial to clarifying future management decisions. Thus far, reclamation has been constrained by our inability to unify information derived from the varied experiences of practicing reclamationists with documented evidence in scientific research. Wirth and Pyke (2006) describe a common system for monitoring post-fire BAER and Emergency Stabilization and Rehabilitation projects on non-forested lands including measures of vegetation establishment and erosion control to provide for comparison with control sites. Data can be analyzed and filed online for use by other researchers and managers. We suggest uniting datasets held by the reclamation industry, and interagency groups working in wildfire rehabilitation and restoration, into a central repository, standardized by ecological site. Analyses can be developed to predict potential outcomes (or the probability of returning function) associated with particular reclamation treatment choices. Managers whose ultimate goals are to facilitate effective restoration for all practitioners cannot realize this form of integration without considerable effort. Public land agencies and universities should take the lead in developing the tools to facilitate this kind of integrated project although funding sources for this sort of effort are limited and do not provide the long-term stability needed to maintain and continue to develop such a knowledge base. But their success hinges entirely on the support and cooperation of knowledgeable managers in the field. As an example, the NRCS Ecological Site Inventory database (http://esis.sc.egov.usda.gov/ESI_Rangeland/frmMain.aspx) facilitates entry of rangeland records based upon the Ecological Site and other restoration sites house monitoring guidelines for post-fire rehabilitation (Wirth and Pyke, 2006).

Integration of Biotic and Abiotic Processes to Return Ecological Function

Integrating knowledge from a variety of reclamation efforts throughout the western US would greatly advance our success, understanding and estimates of risk in reclamation. Individual reclamationists have in-depth knowledge and experience with reclamation approaches that have succeeded on mine lands, but are challenged by many of the same gaps in knowledge as other land managers restoring disturbed ecosystems. Two important gaps are how to return ecosystem function and how to assess the uncertainty and risks associated with different restoration approaches for a given location and situation.

These gaps in knowledge could be more readily addressed by the development of an integrated knowledge base. The knowledge base would incorporate *not only what was done on a given site*, but would define the constraints and detail the results (both successes and failures) over time, given a distinct set of inputs (Fig. 2). The potential framework for the proposed knowledge base defines ecological sites as the constraints. Ecological sites are a reasonable constraint for the proposed system in that by definition, they integrate soils and topography, vegetation communities, and climate at a management scale and are hypothesized to have a uniform response to management and climatic inputs. The inputs include what was done (reclamation choices and approaches used) and can include a suite of management alternatives (a few examples are presented). In addition to the planned management choices, other considerations that may influence the outcomes are addressed. Often, other considerations are site- or time-specific influences or events such as adjusting to a prolonged drought or responding to a new invasive species. The outcomes, results of the reclamation project, would be documented over time (Fig. 2). The true power of an integrated knowledge base is realized by joining reclamation outcomes into a unified, searchable, relational database. The database would include outcomes achieved over time, given the initial constraints and the inputs.

An example: wildfire rehabilitation project for inclusion in a knowledge base (Figure 2). A sagebrush seeding project was initiated to conduct wildfire rehabilitation on the 2006 Humboldt and Gopher fires in northern Nevada. The managers joined forces with researchers to examine return of a number of species and to document impact of different seeding methods.

Constraints: Pre-fire vegetation was Wyoming big sagebrush, bluebunch wheatgrass, bottlebrush squirreltail, and Sandberg bluegrass. Soils were loam to fine sandy loam, 60 inches deep on 2-8 slopes. The area occurs in MLRA 025 Owyhee High Plateau in a Loamy 8-10 P.z. ecological site. Two sites, Gopher and Humboldt fires, within 45 miles of each other.

Management Choices: A seeding mix that included local sources Wyoming big sagebrush and native grass and forb species. Seeding treatments were drill type (minimum-till or rangeland drill) at high or low seeding rates in November 2006. Inputs into the site were identical in seed mix, seeding methods, drills and even the tractor driver. No irrigation or fertilization.

No effort was made to treat cheatgrass that was present as seed on one site (Gopher), due to more moderate fire conditions.

Outcomes: for minimum till treatments

Humbolt: Wyoming big sagebrush 4/m^2 year 1; 0.2/m^2 year 2.

Density of all drilled species 80-100/m^2 year 1; 4.5-5.0/m^2 year 2

Density of cheatgrass: <10/ m^2 year 1; < 20/ m^2 year 2

Gopher: Wyoming big sagebrush 2-3/ m^2 year 1; 0.1-0.25/ m^2 year 2.

Density of drilled species 30-40/ m^2 year 1 and 2-3/ m^2 year 2.

Density of cheatgrass: 80-100/m^2 year 1, 120-14/ m^2 year 2.

Year 1-2, the outcomes differed between the 2 sites. On one site, the presence of cheatgrass influenced desired seedling establishment

It is unclear what the two sites will look like in 5-10 or 20-50 years, given their very different initial two years.

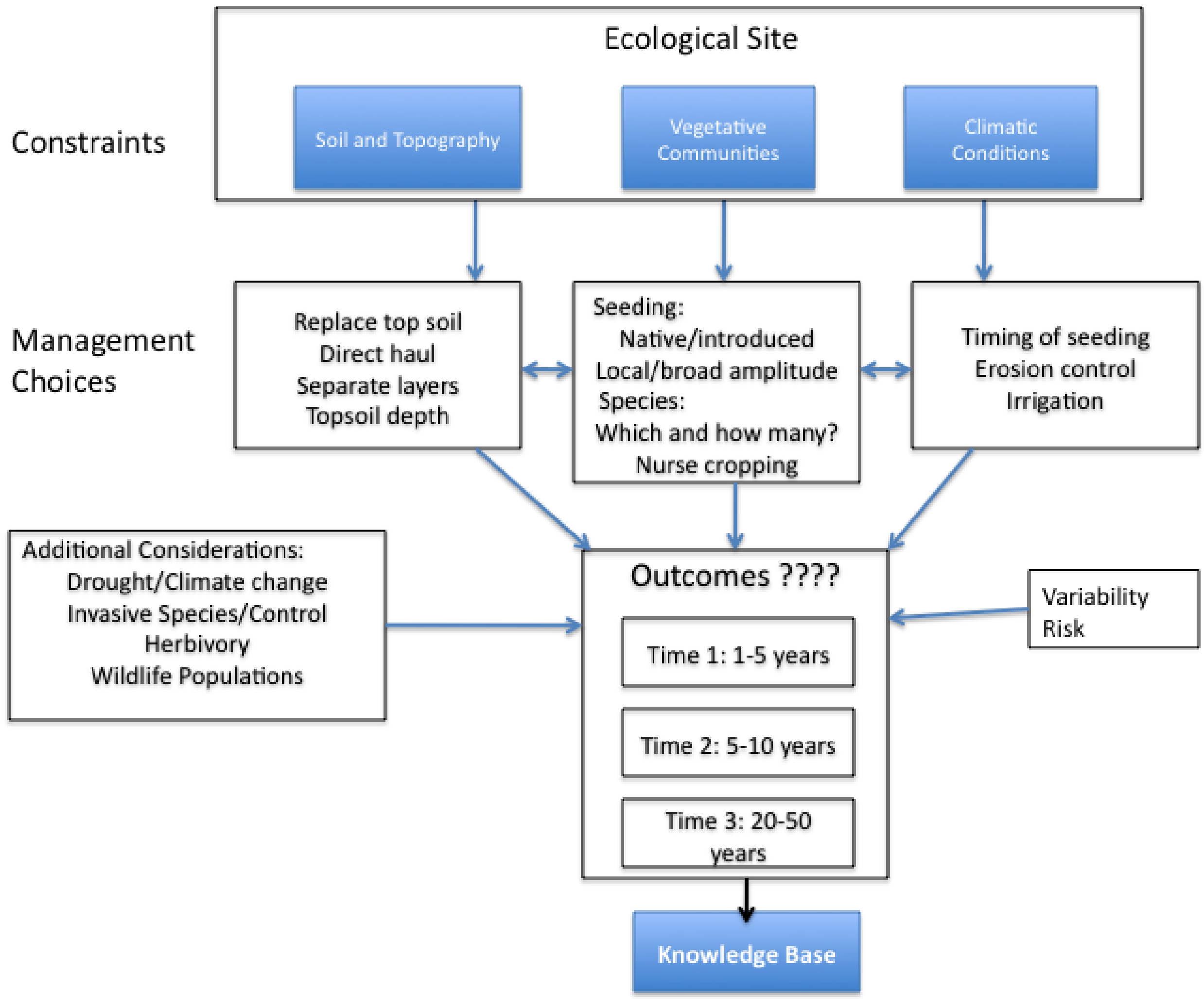


Figure 2. Hypothetical decision matrix to incorporate and integrate restoration decision-making for identifying the relationships between management choices and short- and long-term reclamation outcomes (1-5, 6-10, and 20-50 year time scales). An integrated database would unite known site constraints including soils, climate, disease, and presence of exotic invaders with management choice such as topsoil handling, cultural treatments, seed choice, nurse crops, and timing to determine pathways to desired restoration outcomes. Based on knowledge from experienced practitioners and long-term monitoring, the database can be used to examine pathways to particular outcomes and trends among many reclamation projects.

We propose that this sort of experience, collectively, can provide useful tools for understanding reclamation, and restoration ecology. By recording these impacts and comparing such examples across a wide range of sites, climatic conditions, or use histories, we more fully understand how often the presence of such uncontrollable factors dramatically alter outcomes.

Eventually we should be able to estimate when outcomes are influenced enough to warrant additional management input. If we continue to follow the trajectories of these two sites and others like them, over a longer term, we will learn too, when additional management is required to attain function, and perhaps how to recognize indicators of risk- when a seeding on may never attain a functional sagebrush community. If managers report these findings only in a publication or an oral session at a meeting, it might get out to some reclamationists. If it is recorded and filed in an agency office somewhere it may never be understood well in the larger context of similar results on other sites. However, if these datasets are united with other such data, we can begin to ask if a particular sequence of climatic conditions, or wildlife presence or recreational traffic may have introduced the exotic species onto one site. That is to say, we can observe trends that may be helpful to managers in the future.

Simulation models coupled with shared databases can be useful tools to facilitate an integrated approach to reclamation. The Office of Surface Mining (OSM) lists several modeling tools on its website (http://www.tips.osmre.gov/) including RUSLE2 for estimating erosion potential, HEC-RAS4 for simulating surface runoff processes, Geospatial tools from ESRI and AutoCad software. Though very effective, these tools do not directly integrate biotic and abiotic processes to address ecological function. Most of these tools either predict soil erosion potential or hydrologic response based on static soil and site characteristics. There is a clear need to expand the suite of decision tools available and document their potential use for reclamation. To truly return ecologic function to a disturbed area, a multitude of processes and considerations (e.g. soil stability, hydrology and nutrient cycling, plant functional groups, species turnover and regeneration, wildlife interactions) should be integrated into reclamation planning and management processes (Fig. 2).

Although there are many successes in mine land reclamation, the science of reclaiming wildlands following disturbance is continually assailed with new challenges that cannot be addressed in the same manner. Repair of damaged wildlands is a larger issue that must be addressed with ecological understanding of mechanisms and processes that determine outcomes. Functionality is obtained in degrees (Fig. 1). If management objectives are to attain surface mining standards then reclamation can commonly attain these goals within a 10-year bond-release period. Applying the same techniques to gas wells in another region may not meet with the same success. If we understand the mechanisms that allow us to get to ecological function, then we may identify mechanisms that are more universally applicable. Will this help reclamationists on mine lands? We argue that developing more detailed understanding of process-based reclamation will also allow mine land reclamationist to more precisely attain their goals. If, for example, sagebrush seedings can be more effectively timed within the constraints of climate change, then limited seed sources may be more effectively used.

The dynamics of the system response and the time frame for post-wildfire reclamation can differ from those of other reclamation efforts, however many of the management objectives are the same. Robichaud et al. (2007a) and others have used process-based soil erosion modeling tools (ERMiT and WEPP http://forest.moscowfsl.wsu.edu/engr/software.html) to estimate erosion on seeded hillslopes following wildfire. Erosion potential estimates provide a means for land managers to assess risk and plan mitigation measures. ERMiT is a web-based application that uses Water Erosion Prediction Project (WEPP) technology to estimate erosion, in probabilistic terms, on burned and recovering forest, range, and chaparral lands with and without the application of erosion mitigation treatments. By using a well-developed database to develop model input parameters, ERMiT not only predicts erosion potential, such as predicted by RUSLE, but also mitigation effectiveness using a process based probabilistic erosion model (Robichaud et al., 2007b). Instead of determining an annual average erosion rate, ERMiT provides a distribution of erosion rates along with the probability of their occurrence. This approach incorporates both risk assessment and an understanding of the uncertainties associated with post-fire mitigation techniques. The ability of a tool such as ERMiT to provide a distribution of erosion rates along with a probability of occurrence in response to a fire severity or a management treatment, results in a much stronger management decision tool. Similar tools and approaches can be developed for assessing reclamation approaches and techniques on other disturbed ecosystems. Coupled with vegetative cover and spatial connectivity of overland flow, integration of soil and plant composition with vegetative structure and spatial patterns can produce characterization of hydrologic recovery (Pierson et al., 2008; Seyfried and Wilcox, 2006), a functional attribute of the system and important predictor of reclamation success.

Uncertainty in reclamation efforts comes from encountering situations that are unique from environmental variability (climate) and from variability in resources (such as seed source availability). The goal of a well-designed reclamation effort is to limit uncertainty. Researchers can make use of management experience and unite a variety of datasets which, when compiled provide truer estimates of risk associated with variable conditions. Though there is some reluctance, shared databases from both mine land reclamation and other wildland restoration efforts can be integrated to significantly improve our decision-making. Such integration will help all to better address trends in restoration and clarify pathways to return ecosystem function. The database also will aid planning efforts, allowing us to more directly consider management alternatives, reclamation successes and understand reclamation failures. Integrating datasets and results from reclamation efforts will allow us to incorporate probability of success into reclamation decision processes.

Conclusions

An integrated approach to reclamation was proposed more than 20 years ago (Harper, 1987). The premise presented here is not new. However, many significant advances in plant ecology have occurred since that time. We have a much greater understanding of ecological function, feedback pathways and the interactions between biotic and abiotic components of ecosystems. Significant advances in seeding techniques and timing, cultural treatments and mechanical action to enhance success of post-mining reclamation and wildfire rehabilitation have been documented. In addition, we have decades of experiential learning in reclamation upon which we can draw. We propose that the time is ripe to move forward with an integrated approach to reclamation that unifies all that has gone before. Advances in simulation and decision modeling will allow us to synthesize the many components that entail reclamation success. Integrating our experience and data sets will allow us to improve our ability to assess a variety of reclamation actions and detail the uncertainty and risks associated with each. Embracing this effort will require the collaboration of all members of the reclamation community.

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