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A database framework was constructed with the purpose of creating a land reclamation decision management tool by compiling oil and gas pad reclamation data to identify successful restoration practices. Pre-existing data were secured from public and private databases from two Wyoming production fields in the Greater Green River Basin from 2005-2012: Jonah Infill and Moxa Arch. The framework includes tables for measurements of reclamation practices (e.g., soil handling methods and amendments, seeding mix and timing, and weed management), geographical and climatological data (e.g., precipitation, slope, aspect, elevation, and temperature) and monitoring data (e.g., vegetation composition and structure along with soil analysis and grazing). Microsoft Access and ESRI ArcGIS 10.1 were used to build the reclamation database for consistent and reliable data storage, manipulation, and retrieval. Querying populated data along with uniting imported data has revealed multiple strengths and weaknesses of the database and data within it. While the initial goal of this project was to identify best management practices in reclamation, several factors limited us from achieving this goal. First, the regulatory criteria for reclamation success vary between and amongst regulatory agencies. Second, there is a limited representation of reclamation practices housed in the database. Third, field technicians, monitoring timing, and monitoring techniques vary across years, making data analysis difficult. Lastly, reclamation of semiarid lands takes many years, so the time-frame of our database has also been limiting. This thesis will outline the construction process of the database, highlight differences in regulatory mechanisms, discuss problems faced in data analysis, and make recommendations for improvement in oil and gas pad reclamation and data collection.

USING DATA MANAGEMENT TO IMPROVE OIL AND GAS PAD RECLAMATION

By

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INTRODUCTION

As of 2010, Wyoming ranked as the second highest energy producing state in the country behind only Texas (USEIA 2013). Wyoming is the nation's leader in coal production, ranked 8th in petroleum production, 26th in electricity production and 3rd in natural gas production behind Texas and Louisiana (USEIA 2013). The amount of known, recoverable natural gas below Wyoming's surface is estimated to be 36.75 trillion cubic feet, ranking behind only Texas in terms of terrestrial sub-surface natural gas reserves (PAW 2012). The magnitude of natural gas reserves in Wyoming has contributed to economic growth in the state and has resulted in an average of about 40% annual growth in new wells throughout the state since 1998, a trend expected to continue in the near future (Anderson and Coupal 2009).

During well pad construction, topsoil is removed from the pad area and stockpiled for later use in reclamation efforts (BLM Gold Book 2007). Since well pad construction involves removing topsoil and native vegetation, land areas where oil and gas pad development occur are considered to be drastically disturbed and require human intervention to aid recovery (Box 1978). Although disturbance caused by an individual well pad may not be considered significant, the combination of many well pads drilled in an area may result in substantial alteration of ecosystems (Nasen et al. 2011). Successful land reclamation efforts help to ensure disturbance is not permanent, possibly resulting in mitigation (Bradshaw 1997, BLM Gold Book 2007).

Many areas where oil and natural gas are extracted in Wyoming are considered to be critical habitat areas for wildlife species such as Greater Sage Grouse, mule deer, antelope and elk (Doherty et al. 2008, Sawyer et al. 2006, Winslow et al. 2009). The success of these species depends greatly on vegetation available in their habitat. Therefore, it is essential that ecosystem restoration processes are well understood and able to be implemented (Holechek 2006, Winslow et al. 2009).

While there is a basic understanding of the importance of reclamation in terms of returning habitat and ecosystem services, there are many challenges with implementing successful reclamation practices in Wyoming. Over half (58%) of active wells are located in sagebrush steppe regions which, due to stressful environmental conditions, are challenging to plant reestablishment after disturbance (Anderson and Coupal 2009). For example, it is estimated 62% of active wells occur in areas receiving 11-15 inches of annual precipitation and 15% of active wells occur in areas receiving 10 inches or less precipitation per year (Anderson and Coupal 2009).

The low and unpredictable precipitation is only one of the natural factors making reclamation difficult in Wyoming. Shallow and salty topsoil, low organic matter and water holding capacity of topsoil, invasive plant species and herbivory add to this challenge (Newhall et al. 2004). Other problems associated with land disturbance in the form of oil and natural gas extraction not common to natural disturbances (e.g., wildfires) are due to soil compaction and degradation of soil structure (Winslow et al. 2009). Identifying efficient best management practices resulting in successful land reclamation on sites disturbed by oil and gas drilling may be essential in regaining the original land use values and ecosystem services of these sites.

In addition to these challenges, reclamation of oil and gas pads is a relatively new area of concern and best management practices need to be better understood. Soil amendments, fertilizers and herbicides are often applied to the disturbed area in hope of aiding the revegetation process. While previous studies have shown establishment of specific plant species may depend on these individual factors in reclamation efforts (DePuit and Coenenberg 1979, Eldridge et al. 2011, Pierson et al. 2007, Schuman et al. 2001, Simmers and Galatowitsch 2010, Williams et al. 2002, Winslow et al. 2009), more work is needed to gain a better understanding of best management practices across time and space. Identifying best management practices and efficient reclamation procedures is important for ecosystem stability and health. These procedures also have an economic impact in that reclamation failure is costly in the short and long terms (Chenoweth et al. 2010).

The initial objective of this research project was to develop a comprehensive oil and gas pad reclamation database to increase our understanding of best management practices. After obtaining data from BP America Production Company (BP), Conservation, Seeding and Restoration, Inc. (CSR), Wyoming Oil and Gas Conservation Commission (WOGCC), and the Jonah Interagency Office (JIO), a database was created spanning across two natural gas fields in the Greater Green River Basin: the Jonah Infill and the Moxa Arch. During analysis of data within the database, inconsistencies between regulatory agencies were revealed and best management practices were unable to be isolated for a variety of reasons. A modified version of chapter 1 of this thesis has been published in the Journal of American Society for Mining and Reclamation and discusses construction of the database (Curran et al. 2013), as well as strengths and weaknesses and future utility of the database. Chapter 2 of this thesis discusses inconsistencies between regulatory agencies and questions how reclamation success is defined in practice, while Chapter 3 discusses monitoring results from analyzing data housed in the database and calls for improvements in reclamation monitoring data.

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CHAPTER 1: Design and Development of a Land Reclamation Database for Wyoming

Introduction

The amount of proven recoverable natural gas below the surface of Wyoming is 36.75 trillion cubic feet, leaving Texas as the only state in the US with more subsurface, recoverable gas (PAW 2012). The large amount of gas available in Wyoming has contributed to economic growth in the state and has resulted in an average of 41% annual growth in new wells throughout the state since 1998, a trend expected to continue in the near future (Anderson and Coupal 2009). As production fields continue to grow, surface land disturbance will continue to increase.

As the amount of land being disturbed by oil and gas drilling increases in Wyoming, historic land uses (e.g., grazing and wildlife habitat) and watershed protection provided by the natural landscape may decline. Many areas where oil and natural gas are extracted in Wyoming are considered to be critical habitat areas for wildlife species such as greater sage grouse, mule deer, antelope and elk (Doherty et al. 2008, Sawyer et al. 2006, Winslow et al. 2009). Survival of these species depends heavily on vegetation available in their habitat and, therefore, it is essential for revegetation processes to be well understood (Holechek 2006, Winslow et al. 2009). Natural resource development may be curtailed in the future if wildlife habitat and ecological degradation is not mitigated with positive and effective reclamation practices (Stahl and Williams 2010). While there have been many isolated studies to examine seeding and soil handling practices on oil and gas pads, there is much lacking in terms of understanding large-scale restoration efforts of industry practitioners (Hild et al. 2009). Many oil and gas fields of Wyoming exist in ecosystems with challenging environmental conditions and native plant communities with unique adaptations humans have not yet attempted to reclaim or restore.

The only effort similar to this took place in Parachute, CO when a comprehensive report about well pad reclamation considered dependent variables as those which measured reclamation success (mainly vegetation cover data) and independent variables as factors and methods used in the reclamation process (e.g., soil handling, revegetation techniques, etc.) (Pilkington and Redente 2006). No project updates have been published since 2006, so this project may have concluded. To further our understanding of oil and gas pad reclamation, a central database to house long-term datasets over large spatial scales would be beneficial. For this reason, a database framework has been created to compile and house oil and natural gas pad reclamation data from public and private sources over a large-scale. The database currently holds disturbance and reclamation information over eight years (2005-2012) of BP America Production Company (BP) well pads from two Wyoming production fields in the Greater Green River Basin: Jonah Infill and Moxa Arch. Keeping in mind the end goal of this project, this database was designed as an operational framework to analyze and isolate trends leading to reclamation success and failure and may eventually serve as a decision management tool for future reclamation projects. In addition, flexibility, sharability and scalability were key ingredients from the initial design, allowing for data input from diverse sources. The objective of this chapter is to outline the construction and design processes of the database framework and provide examples of how the database can be implemented.

Methods

Reclamation data were secured from public and private databases across two Wyoming production fields: Jonah Infill and Moxa Arch in the Greater Green River Basin. Both areas are comprised of sagebrush-steppe habitat, are semiarid, and experience long, cold winters. Oil and gas pad reclamation practice data and soil and vegetation monitoring data were obtained from BP, Conservation, Seeding, and Restoration, Inc. (CSR), and the Jonah Infill Data Management System (JIDMS) over the span of eight years (2005-2012). Data obtained from BP and CSR were received in the form of handwritten data sheets, hard paper copies or portable document format (.PDF) files of annual reports and were then manually entered into the database. Historic and geographic data for each site were obtained from the Wyoming Oil and Gas Conservation Commission (WOGCC). Climate data, including precipitation and temperature, were obtained from Oak Ridge National Laboratory's (ORNL) DAYMET database. In areas where soil surveying has been completed, data tables from Natural Resource Conservation Service's (NRCS) Soil DataMart and Soil Survey Geographic Database (SSURGO) were linked to our database.

Microsoft Access 2002 and 2010 and ESRI ArcGIS 10.1 (ESRI 2012) were employed to build the reclamation database for consistent and reliable data storage, manipulation and retrieval. Since Microsoft Access has a 2GB storage capacity, each production field was built with the same framework but kept in separate databases. The framework includes tables for records for reclamation practices (e.g. soil handling methods and amendments, seeding mix and timing, and weed management), historic well pad data (e.g., spud date, additional disturbances, and plugged and abandoned date), geographical and climatological data (e.g.

precipitation, slope, aspect, elevation and temperature) and monitoring data (e.g. vegetation composition and structure along with soil analysis and grazing). After completion of data input, all databases were checked for the eight characteristics of quality data according to Hoffer, et al. (2009): data accuracy, data consistency, data uniqueness, data completeness, data timeliness, data currency, data conformance, and referential integrity.

The final database framework consists of one master table which is linked by a one-to-many connection to 11 child tables, three of which have look-up tables linked to them (Fig. 1.1).

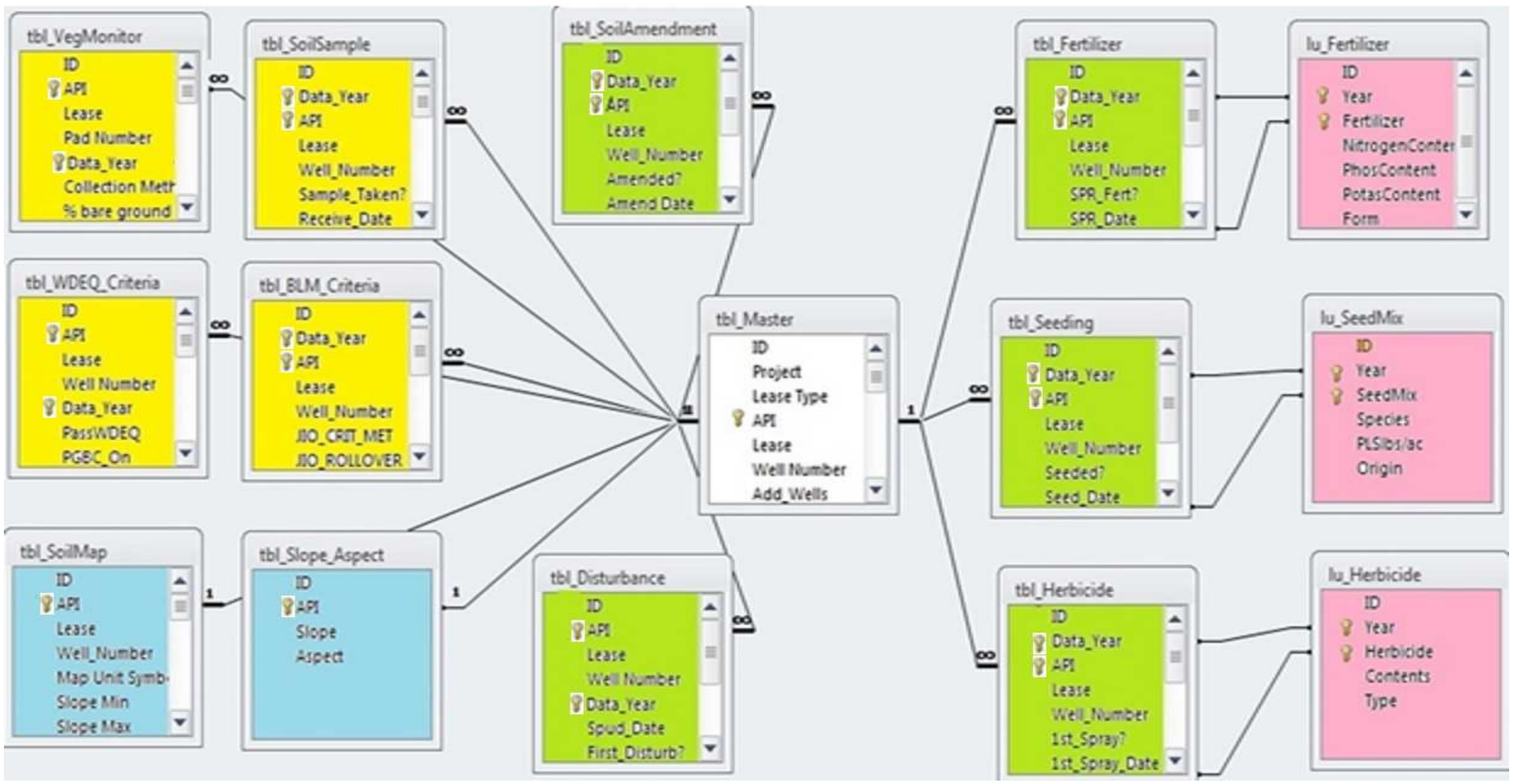

Figure 1.1. Database Framework and Relationship.

In the master and all child tables, American Petroleum Institute number (API) is used as the primary key or as part of the composite key. Tables in yellow represent monitoring tables, tables in green represent reclamation practice tables, tables in blue are geographic tables, and tables in pink are look-up tables.

The master table contains historic well data, including the American Petroleum Institute permit number (API) for the initial well on a pad, well operator, spud date of initial well, plugged and abandoned date for the final operational well, latitude and longitude coordinates, elevation, state and county, and Bureau of Land Management (BLM) district field office with regulatory jurisdiction. Well pad API numbers do not change over time, and are used as unique identifiers for each pad, serving as the primary key in the master table and either the primary key or part of the composite key in all related child tables. Child tables are broken into three groups: (1) monitoring data, (2) geographic data, and (3) reclamation methods data. Four child tables are used to describe monitoring data: (1) one table contains quantitative vegetation cover measurements for all well pads and their undisturbed reference sites, (2) one table contains binary data showing whether or not sites passed Wyoming Department of Environmental Quality (WYDEQ) requirements, (3) one table contains binary data showing whether or not sites passed BLM field office or interagency reclamation requirements, and (4) one table shows results of any soil sampling done on well pads. Two child tables are used to provide additional geographic data: (1) one provides slope and aspect data from a 10 meter resolution digital elevation map (Gesch 2007, Gesch et al. 2002), and (2) one provides NRCS soil map units where applicable. Five child tables were used to house reclamation practice data: (1) a seeding table contains information about seed mix used, seed timing, and seed methodology, (2) a soil amendment table contains information about any type of soil amendment (e.g., sulfur or gypsum) used including the rate, acreage applied to, and timing, (3) a fertilizer table contains information about any fertilizers or compost teas including rate, acreage treated, and timing, (4) a disturbance table contains information about additional disturbances to wells since the reclamation practices first initiated, (5) an herbicide table contains information related to herbicides sprayed on site, including herbicide used, rate, acreage applied to, and timing. The seeding, fertilizer, and herbicide tables all have look-up tables linked to them to include specific information to elaborate upon content of child tables themselves (e.g., seeding look-up table includes the pure live seed per acre and origin for each species included in a given seed mix). Since the master table and child tables are linked through API number, this database can be considered to be a relational database with a queryable nature. This database framework enables particular geographical, climatological, reclamation practices, or monitoring data to be isolated or grouped together in queries to identify trends leading to reclamation success or failure. Since the database also contains vegetation monitoring data from undisturbed reference sites, queries can be run to compare reclamation sites to undisturbed sites or to isolate information about reference sites in different geographical locations.

Results

Simple queries have revealed inconsistencies in monitoring methods and timing across years in each field. For example, modified Daubenmire quadrats were used to monitor vegetation at sites in the Jonah Infill in 2008 and 2009, whereas in 2010 and 2011 sites were monitored using a line-transect method. In 2011, all sites in the Jonah Infill were monitored between July 6 and July 10, whereas in 2010 most Jonah sites were monitored between June 1 and June 7.

Other simple queries have allowed us to quantify reclamation efforts in each field. For example, in 2007, 10 well pads with a total of 60 acres of disturbance were seeded with an early seral mix and 20 well pads with a total of 75 acres of disturbance were seeded with a late seral mix in the Jonah Infill. Using our seeding look-up table, we are able to determine the amount of seed per species used in each seed mix for reclamation in the Jonah Infill (Table 1.1).

Table 1.1. Seed Mixes Used in Jonah Infill in 2007.

In 2007, two seed mixes were used in the Jonah Infill. Early Seral mix was seeded on 60 acres across 10 well pad locations, while Late Seral mix was seeded on 75 acres across 20 well pad locations. This information can be found in look-up tables housed within our database framework.

Species Early Seral 2007	Pure Live Seed/Acre	**Species Late Seral 2007**	Pure Live Seed/Acre
Bluebunch Wheatgrass	2.00	Gardner Saltbush	4.00
Needle and Thread	3.00	Wyoming Big Sagebrush	1.00
Western Wheat	3.00	Rubber Rabbitbrush	0.50
Sandberg Bluegrass	0.75	Needle and Thread	1.00
Indian Ricegrass	3.00	Indian Ricegrass	2.50
Bottlebrush Squireltail	1.00	Bluebunch Wheatgrass	2.00
Blue flax	1.00	Black Sage	0.40
White Yarrow	0.20	Blue Flax	0.75
Penstemon Strictus	0.50	White Yarrow	0.20
		Penstemon Strictus	7.15

More complex queries have revealed inconsistencies in regulatory requirements between and among agencies and will be discussed further in chapter 2. In 2011, 0 of 102 monitored sites in Jonah Infill were considered to pass the Jonah Interagency Office's (JIO) situational reclamation criteria, while 67 sites passed the WYDEQ's Storm Water Pollution Prevention Plan (SWPPP). In the Moxa Arch, 317 of 619 monitored sites passed Kemmerer BLM district field office's situational reclamation criteria, while 340 passed WYDEQ SWPPP criteria. Queries to evaluate JIO versus Kemmerer BLM standards were conducted and revealed that all 317 sites passing Kemmerer BLM requirements in Moxa Arch would be considered failures against JIO criteria, while 63 sites in Jonah Infill (61.8%) would be considered successful against Kemmerer BLM criteria.

Statistical analyses of best management practices in reclamation have been difficult to conduct for several reasons. Since our current database is limited in the number of seed mixes and other reclamation practices it contains and accounts for only seven years of data, we are limited in our ability to compare success rates between practices. However, as we continue to receive additional data, we hope to compare success rates among reclamation practices over a longer period of time. Our ability to do so accurately and effectively will rely on improvement and consistency in data collection across space and over time. Some findings from initial examination of our database should help guide reclamation practitioners to improve monitoring in the future (see chapters 2 and 3).

Discussion

The framework of this database system is sound and will allow for advancements in the field of oil and gas pad reclamation in the future as more data are gathered over longer time periods. The framework is flexible and sharable to allow for incorporation of additional data from diverse sources. Although this framework has strong potential to be used as a decision management tool in the future, we have found several weaknesses in the database and data sources that need to be addressed to increase performance and reliability. Currently, the most limiting factors to our database are: (1) the storage capacity of Microsoft Access, (2) the minimal amount of reclamation practice data, (3) inconsistent monitoring data, and (4) the limited time frame accounted for by our dataset.

Since Microsoft Access is compatible with larger databases, such as SQL Server, the storage capacity problem can be eliminated by upgrading to a larger server, at which point our databases can be combined into a single database and allow input of large amounts of additional data entry from diverse sources. Currently, a multi-tiered database system is being developed with hopes to allow for electronic forms to be used to populate the database on the front-end to be used by field technicians, while a password protected back-end to be used by data managers will ensure data quality and protection. The use of forms on the front-end will save time and money associated with data entry and labor, and may improve data accuracy by eliminating multiple steps presently necessary to transfer data from hard paper copies and .PDF files into the database.

Combining our databases into a single database and increasing the amount of reclamation practices being used by additional practitioners should allow for better understanding of best management practices across geographic space. By including reclamation practice and monitoring data from additional production fields, we may also increase our understanding of how different climates, soil types, and land forms affect reclamation success. While this database currently focuses solely on oil and natural gas pad reclamation, the framework allows for reclamation data from other projects (e.g., roads, pipelines, coal mines) to be added to the database system. Although this database has focused on reclamation, it is capable of incorporating wildlife data if geospatial information is available for certain populations. Additionally, successional trends on drastically disturbed sites will be better understood as spatial and temporal scales of this database system increase if consistency improves in data collection methods to improve data quality.

More studies should be conducted to improve monitoring techniques and timing. Without consistent monitoring techniques and timing, our ability to effectively evaluate reclamation success, perform statistical analysis and identify best management practices is limited. Inconsistent monitoring timing is, at least in part, due to lack of man-power and the spatial scale of oil and gas fields. The Wyoming Reclamation and Restoration Center at University of Wyoming (WRRC) is currently attempting to develop a predictive model to aid in determining best monitoring timing to capture data during the peak growth stage of a given growing season. This may prove beneficial for regulatory agencies, operators, and reclamation contractors to schedule monitoring during periods best suited to measure success based on current regulatory criteria. It may also guide monitoring to be conducted at times outside of peak growing season to account for periods of the year that are paramount to wildlife.

While the database currently contains only vegetation density and species richness measurements, vegetation structure measurements (e.g., biomass production, plant height, etc.) have not been thoroughly studied (Hild et al., 2009). Incorporating this type of data along with reclamation practice, climate, and geographic information may aid in future decision making by improving our understanding of best reclamation management practices in specific areas. Identifying areas where reclamation can be achieved using proper management practices versus areas where reclamation success is difficult or improbable to occur due to problematic environmental factors can also be used as risk management in the future. For example, determining areas likely and unlikely to achieve reclamation success prior to disturbance in large natural gas fields can be a useful risk management tool in critical wildlife habitat areas, as future land disturbance decisions can be proactive to prevent development on land where reclamation is unlikely to mitigate disturbance in a reasonable time (e.g., Kiesecker et al. 2009).

During a time when natural resource exploration and development are increasing at record levels, our ability to understand and identify best management practices of land reclamation is paramount. With improved data collection, additional data, and more time, the framework of this data management system has potential not only to enhance our understanding of reclamation (see chapters 2 and 3), but also to serve as a decision management and risk assessment tool for operators, reclamation contractors, and regulatory agencies. The flexible and sharable nature of our database framework will allow for increased data from additional sources to be input rapidly and immediately. Increasing the data content in our database system will enhance our overall understanding and ability to quantify the amount of land disturbance and reclamation efforts, as well as evaluate the status of reclamation over a broad scale.

Since inception of the database, the United States Fish and Wildlife Service (USFWS) has demonstrated interest in using it as a means to evaluate industry-wide reclamation efforts when making their listing decision for the greater sage grouse as an endangered species. Currently, thirteen operating oil and natural gas companies have shared or have agreed in principle to share reclamation data with WRRC. After thoroughly examining all data, modifications to the current framework may be necessary. The contributions from all companies may potentially broaden our knowledge of reclamation and enhance future management decisions.

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CHAPTER 2: Different Requirements for Reclamation Success in Wyoming

Introduction

Due to increased requirements for remediation of anthropogenic land disturbances related to natural resource extraction, the science and practice associated with land reclamation and ecosystem restoration have experienced increased attention and undergone rapid advancements in recent decades (Suding 2011, Wortley et al. 2013). Setting realistic and attainable goals for reclamation projects is considered to be an essential component for achieving restoration success (Allen et al. 1997, Dickens and Suding 2013, Ehrenfeld 2000, Higgs 1997, Hobbs and Harris 2001, Hobbs and Norton 1996, Parker 1997, Suding 2011, White and Walker 1997). While goals and needs may vary among stakeholders, there has been agreement in the scientific community that reclamation projects should aim to reestablish a sustainable and resilient ecosystem similar to, or on the same trajectory as, an undisturbed reference community or the intact ecosystem if measurements were made prior to disturbance (Clewell 2009, Ruiz-Jaen and Aide 2005, SER Primer 2004, Suding 2011). Even with goals in place, evaluation indicators of reclamation success vary and may be controversial (Ruiz-Jaen and Aide 2005, White and Walker 1997, Zedler 2007). In a practical sense, goals of reclamation projects and standards for success are defined by the regulatory body or bodies with jurisdiction over disturbed land.

On federally owned Bureau of Land Management (BLM) lands in Wyoming, oil and gas pad reclamation is regulated by both Wyoming Department of Environmental Quality (WYDEQ) and the BLM district field office or interagency office with jurisdiction over a given site. WYDEQ's Storm Water Pollution Prevention Plan (SWPPP) criteria emphasizes early erosion control and site stabilization, while BLM field offices and interagency offices mandate a range of vegetative cover and soil protection requirements which may vary among field offices. While restoration criteria differ among field offices, each office requires disturbed sites to meet vegetation criteria based on comparison to a single, undisturbed reference site.

A database was constructed to house reclamation data for BP America Production Company (BP) well pads in the Jonah Infill and Moxa Arch natural gas fields (Curran et al. 2013, Chapter 1). Analysis of data within this database revealed problems in regulatory requirements and selection of reference sites. The objectives of this chapter are: (1) to evaluate WYDEQ and Wyoming BLM regulatory standards for reclamation success and compare reclamation success criteria for oil and gas pads on different district field offices of BLM lands in Wyoming, and (2) to make suggestions in the way reference sites are used as standards of comparison for reclamation success.

Methods

A restoration database was populated using data gathered from practitioners and regulatory agencies across two Wyoming natural gas fields in the Greater Green River Basin: Jonah Infill and Moxa Arch (Curran et al. 2013). At current, the Jonah Infill contains data from BP America Production Company (BP) between 2006 and 2012, while the Moxa Arch contains BP data between 2006 and 2011. The database houses quantitative vegetation monitoring data from both reclaimed well pads and undisturbed reference sites, as well as tables to measure binary (i.e., pass/fail) criteria for regulatory success criteria as defined by the Jonah Interagency Office (JIO, which includes specialists from Wyoming Department of Agriculture, Wyoming Game & Fish Department, WYDEQ, and Pinedale BLM field office), Kemmerer BLM district field office, and WYDEQ. The queryable nature of this database allowed for quantitative vegetation monitoring data to be compared to criteria of various regulatory groups. These criteria were obtained from various Record of Decision documents from BLM district field offices and from a Conservation, Seeding, and Restoration, Inc. report (CSR 2013) which summarizes all reclamation regulatory requirements in Wyoming, Colorado, and Utah.

Since we were only able to obtain data in Moxa Arch until 2011, we used the year 2011 to compare reclamation data and success criteria between Jonah Infill and Moxa Arch. In the Jonah Infill in 2011, CSR monitored a total of 102 well pads and their respective reference sites between July 6 and July 10 using a step-point method in accordance to BLM Technical Reference 1734-4 (BLM 1999). This method involved either one 100 m or two 50 m transects being placed on representative area(s) of individual well pads and adjacent undisturbed reference areas for comparison. A total of 200 sample basal points were recorded at 0.5 m intervals along the transect(s) and were used to measure basal plant cover (%), density, and vegetative composition. In the Moxa Arch in 2011, 619 well pads and their respective reference sites were monitored using a modified Daubenmire method in accordance with BLM Technical Reference 1734-4 (BLM 1999). This method involved a total of ten 1 m^2 frames being placed along a 50 m transect thought by the observer to be representative of a well pad or adjacent, undisturbed reference area. Inside each frame, basal plant cover (%), frequency, and vegetative composition were estimated. A total of 254 well pads and respective reference sites were monitored between June 7 and June 14 and a total of 365 well pads and respective reference sites were monitored between June 21 and June 28 in the Moxa

Arch during 2011. Although monitoring techniques and timing differed between the Jonah Infill and Moxa Arch in 2011, both are in accordance with BLM Technical Reference 1734-4 (BLM 1999) so we compared quantitative vegetation measurements from well pads and reference sites to binary data (i.e., pass/fail) between fields to evaluate discrepancies between regulatory criteria in place for each field.

In the Jonah Infill, soil surveying has taken place and data tables from Natural Resource Conservation Service's (NRCS) Soil DataMart and Soil Survey Geographic Database (SSURGO) were linked to our database. Soil map units, which were a result of surveying, have played a large part in defining ecological sites and ecological site descriptions (ESDs) (Brown 2010). For this reason, these data are linked to well pad data and through this relationship queries can be conducted to determine the ESD of the specific sites where individual well pads are located. Soil surveying has not been completed in the Moxa Arch, so soil map units and ESDs were not available to us for that gas field.

For the sake of comparing reference areas within a given ESD, we grouped well pad and reference site data in the same soil map units together to determine variation in reference sites in the same unit. In 2009, we selected four soil map units to evaluate, as these map units all contained four or more well pads and reference transects. In accordance with BLM Technical Reference 1734-4 (BLM 1999), a modified Daubenmire method was used to collect data in 2009. This method involves a 1 m^2 frame placed 10 times over a single 50 m transect placed on well pads and undisturbed reference areas adjacent to well pads. In 2009, 113 well pads were monitored and vegetation on each pad was compared to vegetation on a selected reference area. Only one transect was examined on each well pad, which was compared to a single transect from the chosen reference area. While a specific well pad is only compared to one reference area represented by a single transect, a single reference area may sometimes be used in comparison against multiple well pads.

Results

Regulatory Success Standards

Comparison of quantitative vegetation data to binary (i.e., pass/fail) regulatory success criteria exposed discrepancies between, and among, regulatory agencies (Table 2.1). The Jonah Interagency Office (JIO), which regulates BLM land in the Jonah Infill, requires reclaimed sites to meet 11 situational criteria: (1) bare ground cover on the reclaimed site must be equal to or less than the reference site, (2) forb richness on the reclaimed site must be equal to or greater than the reference site, (3) forb frequency or density on the reclaimed site must be 75% or greater than the reference site, (4) shrub richness on the reclaimed site must be equal to or greater than the reference site, (5) shrub frequency or density on the reclaimed site must be 50% or greater than the reference site, (6) no more than 10% of shrub density on the reclaimed site may be rabbit brush, (7) at least 15% of shrub density on the reclaimed site must be the dominant shrub in the reference site, (8) no noxious weeds may be present on reclaimed sites, (9) at least 3 grass species must be present on reclaimed sites, (10) at least 2 grass species must be perennial bunch grasses, and (11) plants must be resilient as determined by well-developed root systems, flowers, and seed heads (BLM 2006, CSR 2013).

The Kemmerer BLM District Field Office, which regulates the Moxa Arch, requires reclaimed sites to meet three situational criteria: (1) total vegetation cover on a reclaimed site must be 80% or greater than the reference site, (2) at least 90% of vegetation occurring on a reclaimed site must contain species from a BLM approved seed mix, that occur on the reference site, or are deemed desirable by the BLM (i.e., no more than 10% of vegetation cover may be weed species), and (3) sites are stabilized immediately by mulching, sterile hybrids are planted if necessary, and diversion and water treatment structures are in place if needed(BLM 2010, CSR 2013).

WYDEQ which has SWPPP regulatory authority in the Jonah Infill and Moxa Arch has two situational criteria for success: (1) total perennial vegetation cover on a reclaimed site must be 70% or greater than the reference site, and (2) vegetative cover on well pads must extend to access roads, unless permanently installed anchor points have been installed to control erosion (obtained from permit information in annual report document).

In 2011, the Jonah Infill had 67 of 102 (65.7%) well pads monitored pass WYDEQ SWPPP criteria and 0 of 102 (0%) well pads pass all of JIO reclamation success criteria. The Moxa Arch had 338 of 619 (54.6%) well pads pass WYDEQ SWPPP criteria and 312 of 619 (50.4%) well pads pass Kemmerer BLM reclamation success criteria. Although monitoring techniques differed between the Jonah Infill and Moxa Arch in 2011, both techniques were in accordance with BLM Technical Reference 1734-4 (BLM 1999). Therefore, quantitative well pad vegetation data were compared to reference site vegetation data in both fields. In a cross-query, we found 63 of 102 (61.8%) of Jonah Infill well pads would have passed Kemmerer BLM reclamation success criteria and 0 of 619 (0%) of Moxa Arch well pads would have passed all of JIO's reclamation success criteria (Figures 2.1 and 2.2). Moxa Arch did not measure forb, shrub or grass richness, but did have measurements of percent ground cover, forb density, shrub density and noxious weed presence. When compared to JIO regulatory success standards, Moxa Arch well pads had 82 of 619 well pads pass the forb density requirement, 82 of 619 well pads pass the percent ground cover (or percent bare ground) requirement, 53 of 619 well pads pass the shrub density requirement, and 205 of 619 sites pass the lack of noxious weed requirement. Of the 82 well pads passing the forb density requirement in Moxa Arch, 43 reference sites had 0 forbs and of the 53 well pads passing the shrub density requirement, 22 reference sites had 0 shrubs. There were no well pads passing all four criteria simultaneously. Although we analyzed only differences amongst JIO, Kemmerer BLM, and WYDEQ criteria, it is important to note other six BLM district field offices throughout the state have varying criteria for reclamation success (Table 2.1).

Table 2.1. Regulatory reclamation success criteria for oil and gas well pads in Wyoming vary among Bureau of Land Management (BLM) field offices, interagency offices and Wyoming Department of Environmental Quality (WYDEQ). Buffalo, Casper, Cody, Rock Springs, and Worland BLM field offices were in the process of changing reclamation success criteria in 2013 and are not included in this table.

Regulatory Body	**Percent Cover Requirements**	**Erosion Control Requirements**	**Weed Requirements**	**Grass Requirements**	**Forb Requirements**	**Shrub Requirements**	**Plant Vigor Requirements**
Jonah Interagency Office	Ground cover percent on reclaimed sites must be equal to or greater than reference site	Site must be stable according to BLM Technical Note 346	No noxious weeds or highly competitive invasive species appear on reclaimed site	At least three total grass species must be present on site, of which at least 2 must be perennial bunch grass species	Forb richness on reclaimed sites must be equal to or greater than reference site, and density or frequency must be >75% of reference site	Shrub richness on reclaimed sites must be equal to or greater than reference site, and density or frequency must be >50% of reference site. No more than 10% of total shrub cover can be rabbit brush	Plants must be resilient as displayed by root system, flowers, and seed heads
Pinedale Anticline Project Office	Plant community must be sufficient to minimize visual impacts, provide habitat and forage, and impede noxious weed invasion	Plant community must stabilize soils	No state or federally listed noxious weeds appear on reclaimed site. Active treatment in place for weedy bromes	At least three total grass species must be present on site, of which at least 2 must be perennial bunch grass species	Forb richness on reclaimed sites must be equal to or greater than reference site, and density or frequency must be >75% or reference site (both within 5 years)	Shrub richness on reclaimed sites must be equal to or greater than reference site, and density or frequency must be >50% of reference site (both within 5 years)	Plants must be resilient as displayed by root system, flowers, and seed heads. Removal of external influences (e.g., irrigation) required for at least 1 year
Kemmerer BLM	Ground cover on reclaimed sites must be equal to or greater than 80% of reference site	Disturbed areas should be immediately stabilized by mulching	Weeds must not account for more than 10% of total vegetation cover on reclaimed sites	N/A	N/A	N/A	N/A
Rawlins BLM	Ground cover on reclaimed sites must be equal to or greater than 80% of reference site	Erosion controls should be equal to or less than the reference sites	No noxious weeds may be present on a reclaimed site	N/A	N/A	N/A	N/A
WYDEQ	Ground cover on reclaimed sites must be equal to or greater than 70% of reference site	Grass must extend to active roadway unless the roadway is permanent	N/A	N/A	N/A	N/A	N/A

Reference Sites

Quantitative vegetation data were collected from well pads and undisturbed reference sites in the Jonah Infill (Curran et al. 2013). We grouped reference sites based on the soil map unit in which they are located. All soil map units for which reference transects were analyzed are characterized with having primary parent material of slope alluvium and receive an average of 7-9 inches of precipitation per year. Map unit 5203 is characterized as having slopes from 1-6%, a top soil horizon with 1 inch of sandy loam, a second horizon of sandy clay loam to 10 inches, and a third horizon of loam to 24 inches. Map unit 2205 is characterized as having slopes from 0-4%, a top soil horizon with 3 inches of sandy loam, a second horizon of sandy clay loam to 25 inches, and a third horizon of gravelly sandy loam to 40 inches. Map unit 5504 is characterized as having slopes from 2-35%, a top soil horizon with 3 inches of coarse sandy loam and a second horizon of sandy clay loam to 15 inches. Map unit 5332 is characterized as having slopes between 1-8%, a top soil horizon with 3 inches of loam, a second horizon of clay loam to 10 inches, and a third horizon of parachannery loam to 43 inches. Reference sites showed high levels of variability within soil map units, especially in bare ground percentage and forb richness measurements (Table 2.2).

Table 2.2. Reference Site Variability in Bare Ground (%) and Forb Richness in Jonah Infill in 2009.

Reference sites from the Jonah Infill were grouped based on the soil map unit in which they exist. Variation occurred across all measured categories, especially percent bare ground and forb richness.

Soil Map Unit	**Reference Transects per Map Unit**	**Mean Bare Ground (%)**	**Bare Ground Range**	**Percent Bare Ground Standard Deviation**	**Mean Forb Richness**	**Forb Richness Range**	**Forb Richness Standard Deviation**
5203	53	59.2 %	35-80 %	12.56	3.35	1-7	2.09
2205	4	63 %	51-73 %	9.32	3	2-5	1.41
5332	18	78.2 %	66-83 %	5.82	4.4	0-8	2.66
5504	5	57.8 %	49-75 %	11.58	6	3-9	2.45

Soil map unit 5203, which had 53 well pads located within it, had a range of 1-7 forbs present in reference transects. Three well pads had reference transects with 7 forbs present. This suggests 50 out of 53 comparative reference transects would fail JIO regulatory success standards if measured against the most diverse forb transect in the map unit. It also suggests certain well pads with greater forb richness than other well pads are consider failures according to JIO's binary (i.e., pass/fail) regulatory success standards.

Discussion

The lack of consistency among regulatory agencies in requirements for reclamation can be problematic, as many practitioners work across lands regulated by various field offices or interagency offices. Not only do inconsistencies complicate the ability to set consistent reclamation goals, but levels of success may vary to a point where sites passing regulatory criteria in some areas are actually less effective at providing ecosystem services compared than sites failing regulatory criteria in other areas. This is especially important since many areas where oil and natural gas are extracted in Wyoming are considered to be critical habitat areas for wildlife species such as greater sage grouse, mule deer, antelope and elk (Sawyer et al. 2006, Doherty et al. 2008, Winslow et al. 2009). To see continued success of these species, revegetation processes must be understood and implemented to provide necessary habitat requirements (Holechek 2006, Winslow et al. 2009). For revegetation efforts to be successfully implemented and for wildlife managers to evaluate health of wildlife habitats, a consistency of reclamation success criteria across agencies would be helpful. The lack of consistency among agencies may prevent meaningful comparisons of reclaimed lands because fields not included in regulatory success standards may not be measured. Additionally, lack of consistency in monitoring methods and techniques in different fields may prevent valid statistical analysis.

The Society for Ecological Restoration International (SER) Primer (2004) suggests nine ecosystem attributes should be used in measuring reclamation success: (1) similar diversity and community structure in comparison with reference sites; (2) presence of indigenous species, (3) presence of functional groups necessary for long-term stability; (4) capacity of the physical environment to sustain reproducing populations; (5) normal functioning; (6) integration with the landscape; (7) elimination of potential threats; (8) resilience to natural disasters; and (9) self-sustainability (Ruiz-Jaen and Aide 2005, SER Primer 2004). Current regulations for oil and gas pad reclamation on Wyoming's BLM lands fail to incorporate measures for normal functioning, resilience to natural disasters, and self-sustainability and vary in how the other six ecosystem attributes are measured.

While the use of reference sites as comparative measures for reclamation success has been argued, it is clear they can help determine practical goals for reclamation efforts (SER Primer 2004, White and Walker 1997). However, using only one transect to characterize a reference site to base reclamation goals and success criteria on is problematic for several reasons. First, reference sites may experience seasonal and interannual variation leading to an inconsistent target for restoration success (White and Walker 1997). Second, limited comparisons to a reference transect may fail to capture dynamics of a reclaimed site and are not solid measures for determining resiliency and self-sustainability (Parker 1997, Herrick et al. 2006b, Hobbs and Harris 2001). Lastly, the shrubland ecosystems where most oil and gas development in Wyoming occur are known to be heterogeneous and patchy across space, so selecting only one reference transect may result in bias and fail to capture variation existing in a natural community (Davies et al. 2007, Finn and Knick 2011, Gasch et al. in preparation, Havstad et al. 2007, Herrick et al. 2006b, Ruiz-Jaen and Aide 2005). Instead of using a single transect to define a reference site, a reference site should be large enough to include a range of ecological variation and be characterized using vegetation sampling from multiple undisturbed areas in proximity to a given reclaimed site (Gasch et al. 2014, White and Walker 1997).

If resiliency and self-sustainability are to be incorporated into regulatory success standards, long-term monitoring of reclaimed sites to measure trends and account for ecosystem dynamics should be combined with efforts to compare reclaimed sites to reference sites (Hobbs and Harris 2001). In order for long-term monitoring to successfully indicate these traits, there should be consistency in monitoring methodology and timing across years (see chapter 3). Long-term monitoring of reclaimed sites has potential to not only measure resiliency and self-sustainability, but may also increase our understanding of how reclamation practices (e.g., seeding, soil amendment application, etc.) affect the trajectory of reclaimed sites in different geographic locations.

Continued studies should be conducted to improve our ability to successfully select a reference site (e.g., How large should a reference site be? How intensively sampled should reference sites and well pads be?) and to attempt to improve monitoring of reclaimed sites so that all ecosystem attributes suggested by the SER Primer (2004) can be incorporated in regulatory reclamation requirements. Improved knowledge in these areas will help regulatory agencies to use best available science to guide policy. A goal of advancing our studies in oil and gas pad reclamation should be to aim for a more consistent set of regulatory success standards across a region, which in turn will improve our ability to successfully implement reclamation plans and allow us to use regulatory requirements as more definitive indicators of reclamation success and improve our ability to assess the ecological state of disturbed and reclaimed lands. Due to the variability in climate, topography, soil types, and other factors, there should be some flexibility between regulatory success standards in different areas. However, consistency in monitoring methods and techniques should be standard across fields to allow for statistical comparison and certain regulatory success standards (e.g., bare ground cover, lack of noxious weeds, etc.) should be uniform across fields as key indicators of reclamation success.

In summary, regulatory success standards for reclamation are the targets practitioners must aim at when remediating land disturbance. Our findings show inconsistencies among regulatory agencies involved in reclamation in Wyoming. These inconsistencies are problematic because many practitioners work on lands spanning multiple regulatory boundaries and, without consistency, reclamation plans are difficult to implement and reclamation success is difficult to measure. We recommend continued use of reference sites for comparative purposes to evaluate reclamation success. However, reference site selection needs to be examined more carefully and should be improved and standardized between and amongst regulatory agencies. Additionally, monitoring should be consistent and occur for multiple years to measure functionality, resilience and site-stability of reclaimed well pads, which are not accounted for when conducting a one-time vegetative comparison of a reclaimed site to a reference area.

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CHAPTER 3: Monitoring Reclamation Sites in Wyoming Gas Fields: Suggestions for Improving Data Quality

Introduction

Restoration Ecology provides a unique opportunity to share knowledge between the scientific community, practitioners and regulatory agencies (Dickens and Suding 2013, Halle 2007, Hobbs and Harris 2001, Suding 2011). Although many isolated studies have been conducted by the scientific community, the field of restoration ecology is comprised of more practitioners than scientists and our knowledge of large-scale restoration efforts is limited (Aronson et al. 1995, Hild et al. 2009). There have been multiple calls to establish conceptual bases, frameworks, intents, or definitions for restoration ecology, but few have incorporated comprehensive assessments to account for large-scale work of practitioners (Allen et al. 1997, Clewell 2009, Ehrenfeld 2000, Hild et al. 2009, SER Primer 2004, Wyant et al. 1995). A lack of centralized data and comprehensive assessments may limit scientific knowledge by excluding past failures and successes of restoration efforts (Hallett et al. 2013, Suding 2011). The Wyoming Reclamation and Restoration Center (WRRC) at University of Wyoming has worked closely with BP America Production Company (BP) and Conservation, Seeding and Restoration, Inc. (CSR) to develop a database to track large-scale reclamation efforts associated with oil and gas development in Wyoming (Curran et al. 2013).

Since the inception of the database, the US Fish and Wildlife Service (USFWS) has expressed interest in considering reclamation efforts under the Policy for Evaluation of Conservation Efforts When Making Listing Decisions (PECE) clause of the Endangered Species Act when deciding whether or not to list the greater sage grouse as an endangered species. Well aware of inconsistencies of reclamation success standards amongst regulatory agencies (see chapter 2), USFWS will take other measurements, such as stability and vegetative trends of reclaimed sites, into account when making their listing decision. Measuring stability and self-sustainability of reclamation efforts requires long-term monitoring (Zedler 2007). Inconsistencies in monitoring which make evaluation of site stability, self-sustainability, and vegetation trends were revealed when monitoring data from the Wyoming Reclamation Database (Curran et al. 2013). The purpose of this paper is to elucidate monitoring inconsistencies revealed by a six-year dataset in the Jonah Infill natural gas field of Wyoming and to highlight areas where improvements can be made.

Methods

A reclamation database was populated using data gathered from practitioners and regulatory agencies across two Wyoming natural gas fields in the Greater Green River Basin: Jonah Infill and Moxa Arch (Curran et al. 2013). The database houses quantitative vegetation monitoring data, reclamation practice data, binary data showing the pass/fail status of various regulatory success criteria, climate data which was obtained from Oak Ridge National Laboratory's DAYMET database, and geographic data from multiple other sources. The effort to create this database was spearheaded by BP America Production Company (BP), Conservation, Seeding, and Restoration, Inc. (CSR) and Wyoming Reclamation and Restoration Center (WRRC).

Although complete descriptions of monitoring methods and techniques are not housed in the database, annual reports describing monitoring methods and techniques were made available to us. This paper focuses on the Jonah Infill, and descriptions of the monitoring methods used each year are described below. It is important to note several field technicians collected data across the field each year. The majority of well pads are measured only once per year with a ‘divide and conquer’ method by individual field technicians, and field technicians are not consistent between years.

For monitoring sites in 2006 and 2007, CSR randomly placed five 1 m^2 frames constructed of PVC pipe on well pads and adjacent reference areas to estimate percent ground cover undergoing reclamation activity. Within each frame, 7 categories of ground cover were recorded (grass, forb, shrub, weed, litter, rock, and bare ground). The average for each category was recorded to describe the state of reclamation for individual well pads. A total of 87 well pads were monitored, four of which were monitored on August 30, 2006 with the rest being monitored between June 5 and June 8, 2006. A total of 77 well pads were monitored, all between July 11 and July 17, 2007. There is no evidence frames were placed in the same locations between years.

A change occurred in 2008 and 2009, when CSR used a modified Daubenmire method in accordance with BLM Technical reference 1734-4 (BLM 1999) to measure percent ground cover based on 8 categories (shrub, forb, grass, weeds, litter, rock, biological soil crust, and bare ground). A 1 m^2 frame was placed 10 times over a 50 m transect placed on a representative area of well pads undergoing reclamation activity and on reference sites. The average for each category was recorded to describe the state of reclamation for individual well pads. A total of 87 well pads were monitored, two of which were on September 1, 2008 and the rest were between June 11 and June 14, 2008. A total of 113 well pads were monitored in 2009, five on October 11, 2009, eight on June 26, 2009, and the rest between July 13 and July 17, 2009. There is no evidence of transects being placed in the same location between years.

Another change occurred in 2010 and 2011, when percent basal cover, density, and percent vegetative composition were measured by CSR using a step-point method in accordance to BLM Technical reference 1734-4 (BLM 1999). Either one 100 m transect or two 50 m transects were placed on representative area(s) of each individual well pad. A total of 200 sample basal points were recorded at 0.5 m intervals along the transect(s). Ten 1 m^2 square frames were also randomly placed on sites to measure density and richness of shrubs and forbs. A total of 114 well pads were monitored between June 1 and June 7, 2010. A total of 102 well pads were monitored between July 6 and July 10, 2011. There is no evidence that transect or frame placement in 2011 mimicked that of 2010.

Daily temperature and precipitation data were downloaded for a central point in the Jonah Infill from Oak Ridge National Laboratory's DAYMET database. Daily temperature was plotted from January 1 until the mean collection date of monitoring occurred for 2009, 2010, and 2011. Daily precipitation data was plotted from October 1 of the previous year until mean collection date of monitoring in 2009, 2010, and 2011 since October 1 is used by the U.S. Geological Survey to denote the beginning of a water year.

Results

Although the method by which grass species richness was measured was not explicitly described in any annual report, there are records on all datasheets and monitoring files we obtained across all years entered into our Jonah database. Grass species richness is the only required quantitative measure of reclamation success not based on comparison to a reference site (chapter 2). For this reason, we plotted the number of sites passing grass species richness requirements from 2007-2011 (Figure 3.1). While the number of sites passing the total grass species richness requirement seemingly increase linearly over time, the low number of sites passing the bunch grass species richness requirement in 2010 is peculiar.

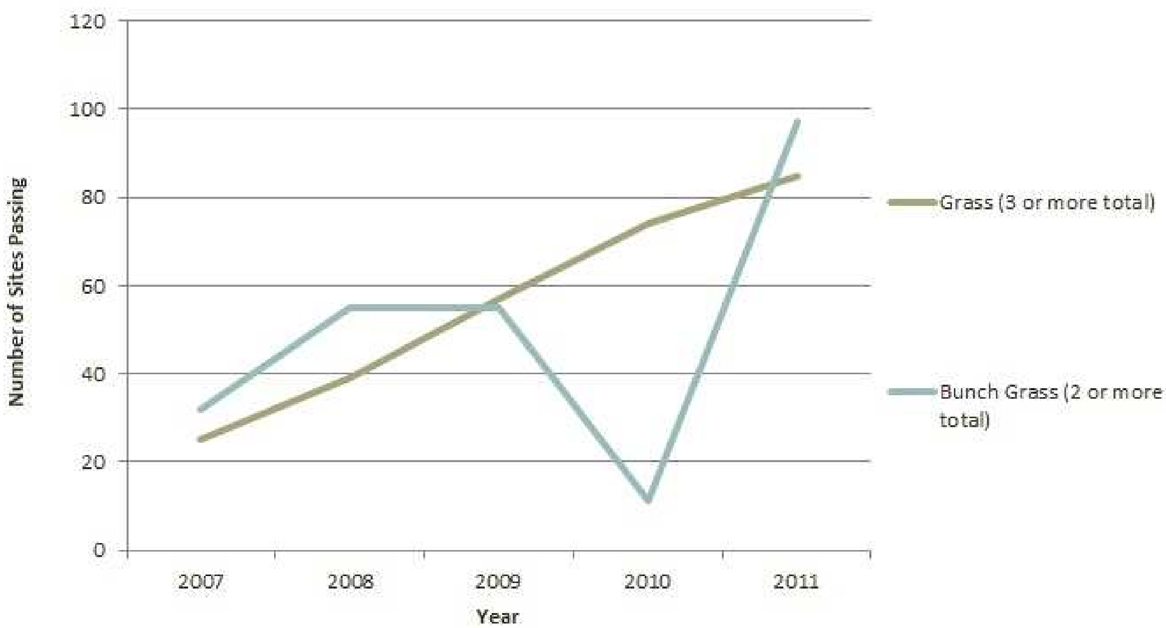

Figure 3.1. Number of sites passing grass richness (3 total grass species, and at least 2 perennial bunch grass species) were plotted from 2007-2011 in the Jonah Infill development area of Wyoming. In 2009, 55 sites passed both grass and bunch grass richness criteria. In 2010, only 11 sites passed bunch grass criteria while 74 passed the total grass criteria. In 2011, 97 sites passed bunch grass requirements and 85 sites passed total grass criteria.

Another quantitative measurement related to reclamation success throughout all years was bare ground (%). Although observers, monitoring timing and monitoring methods varied across years, bare ground (%) was plotted for each individual well pad monitored between 2006-2011 (Figure 3.2). In general, there was an initial decrease in bare ground percentage over time, with a general increase in bare ground percentage in 2010 followed by a general decrease in bare ground percentage in 2011. Several factors, including observer bias, monitoring time, and monitoring technique may be responsible for the lack of trend in this figure.

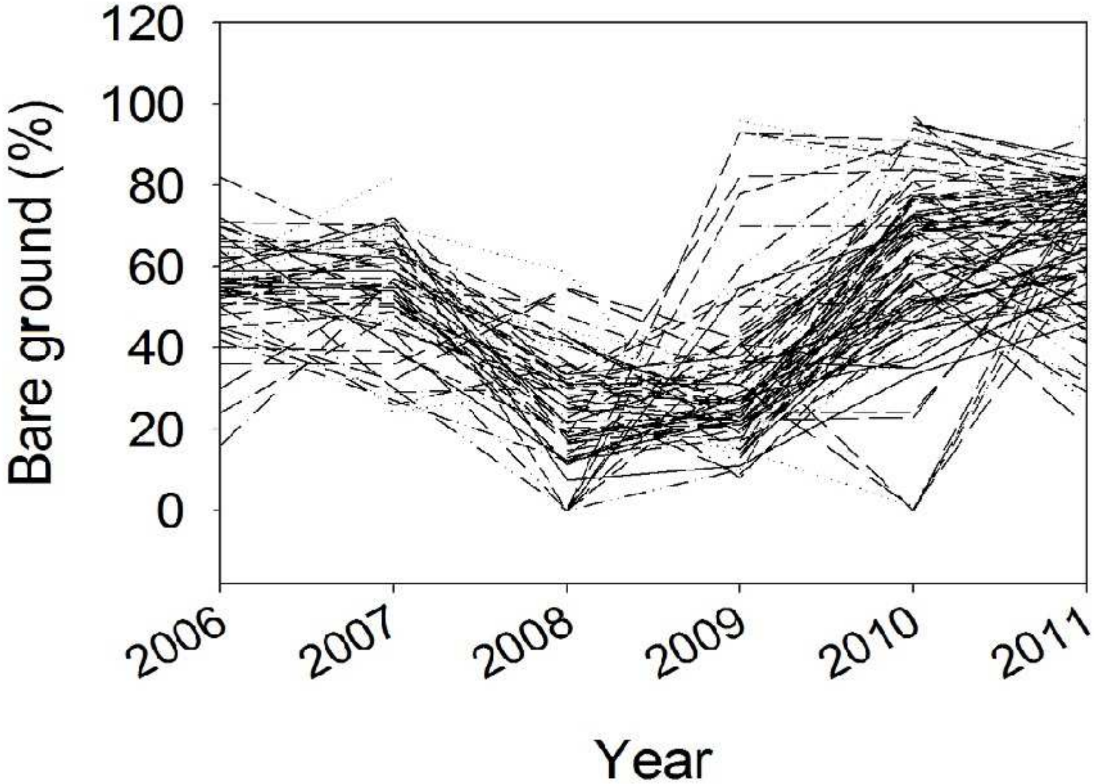

Figure 3.2. Bare ground (%) for individual well pads was plotted from 2006-2011 in the Jonah Infill development area of Wyoming. Each line represents an individual well pad.

Daily climate data from a central point of the Jonah Infill were downloaded and minimum daily temperature and daily precipitation were plotted from January 1 through the mean collection date of monitoring data (July 16, 2009, June 4, 2010, and July 7, 2011) (Figures 3.3-3.6). Since 0^{o}C is commonly used to represent the temperature below which development stops for cool season cover crop species (Miller et al. 2001), we put an indicator line at 0^{o}C in Figures 3.3, 3.4, and 3.5. In 2009, there were over 50 consecutive days where the minimum temperature was above freezing prior to monitoring. In 2010, there were only 4 consecutive days where minimum temperature was above freezing prior to monitoring. In 2011, there were 19 consecutive days where minimum temperature was above freezing prior to monitoring.

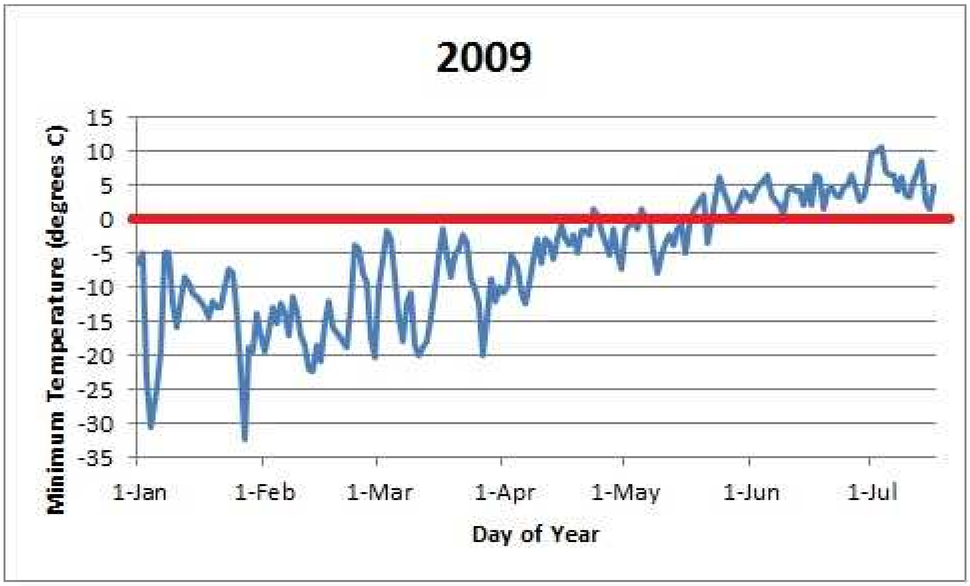

Figure 3.3. Minimum daily temperature from January 1, 2009 through July 16, 2009 in the Jonah Infill development area of Wyoming.

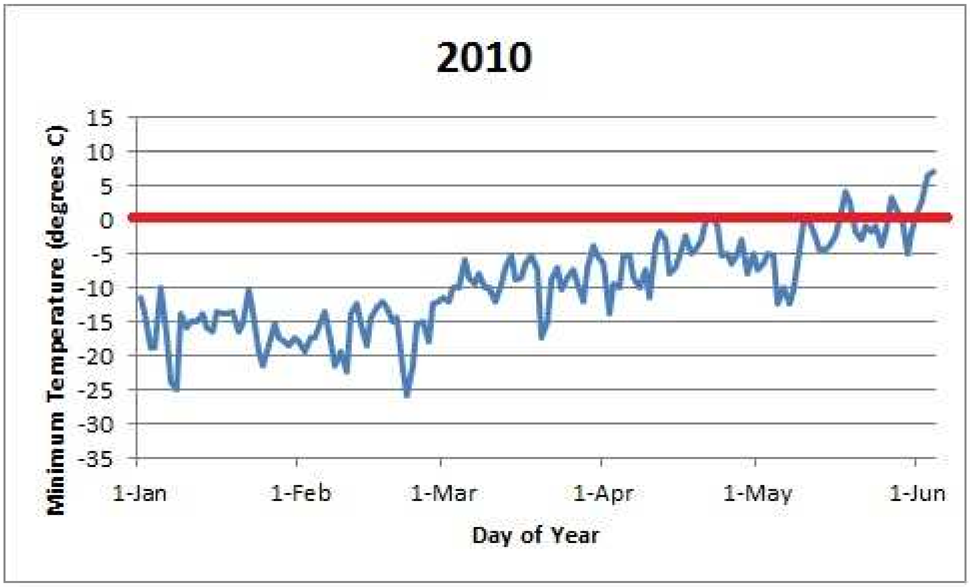

Figure 3.4. Minimum daily temperature from January 1, 2010 through June 4, 2010 in the Jonah Infill development area of Wyoming.

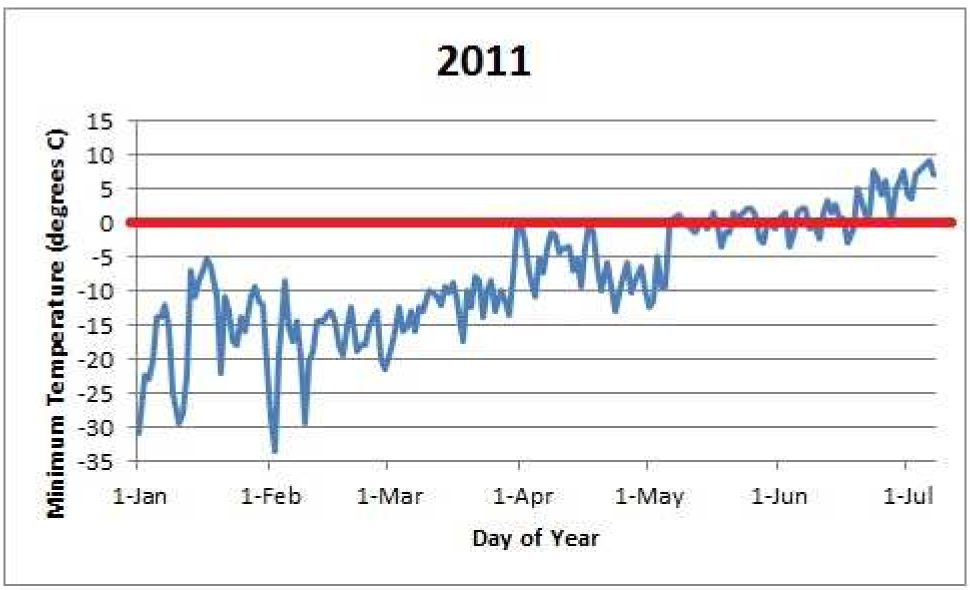

Figure 3.5. Minimum daily temperature from January 1, 2011 until July 7, 2011 in the Jonah Infill Development area of Wyoming.

Precipitation received varied from year to year on days leading up to when vegetation monitoring data were gathered. Between October 1, 2008 and July 16, 2009, the Jonah Infill natural gas field received approximately 282 mm of precipitation (Figure 3.6). Between October 1, 2009 and June 4, 2010, the Jonah Infill natural gas field received approximately 193 mm of precipitation (Figure 3.7). Between October 1, 2010 and July 7, 2011, the Jonah Infill natural gas field received approximately 297 mm of precipitation (Figure 3.8).

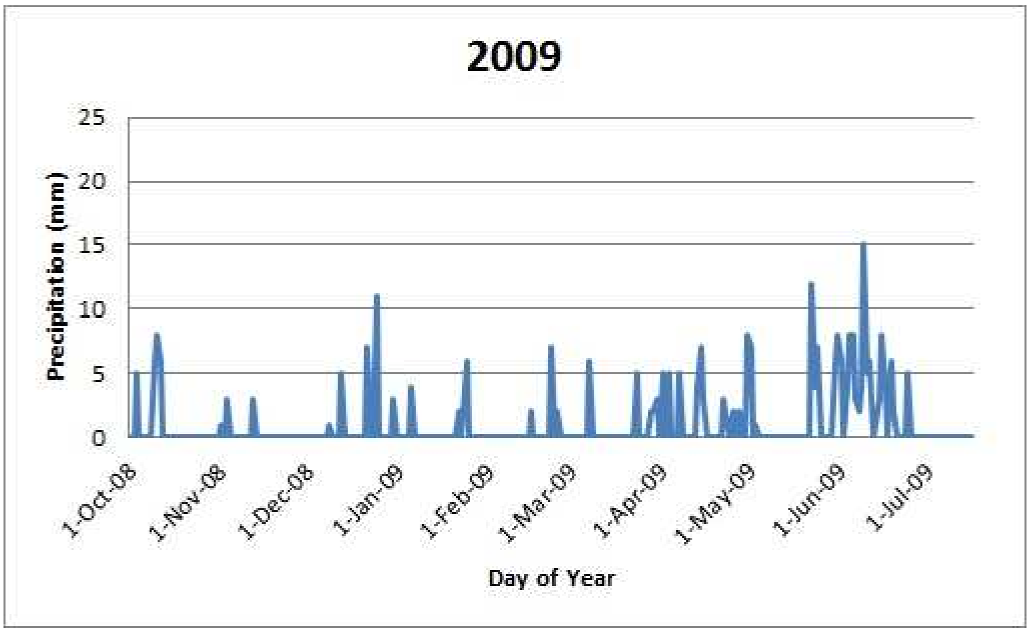

Figure 3.6. Daily precipitation data from October 1, 2008 through July 16, 2009 showed a total of 282 mm precipitation was received in the Jonah Infill prior to monitoring.

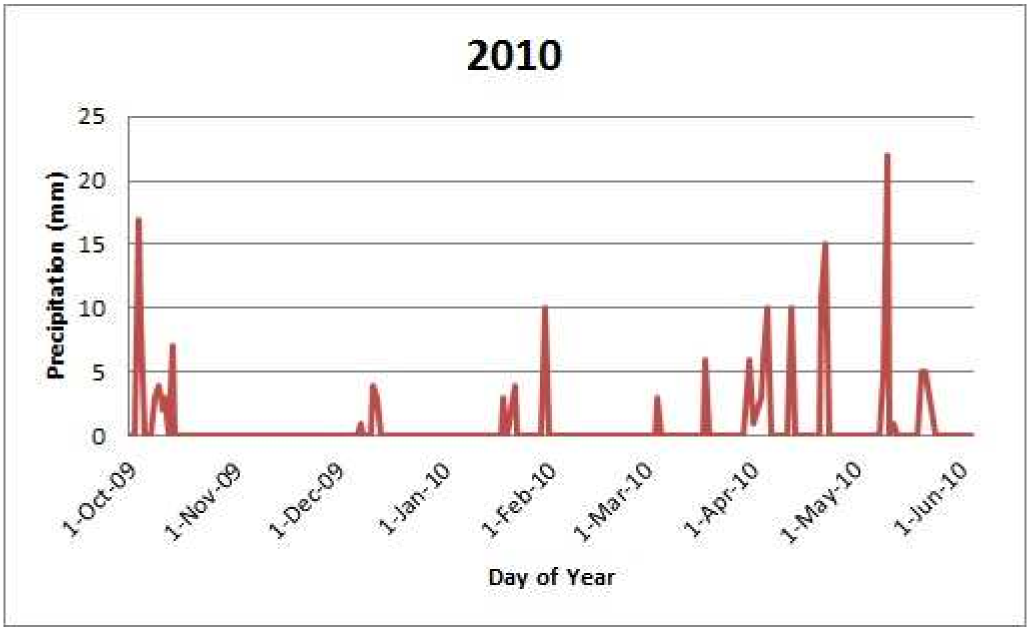

Figure 3.7. Daily precipitation data from October 1, 2009 through June 4, 2010 showed a total of 193 mm precipitation was received in the Jonah Infill prior to monitoring.

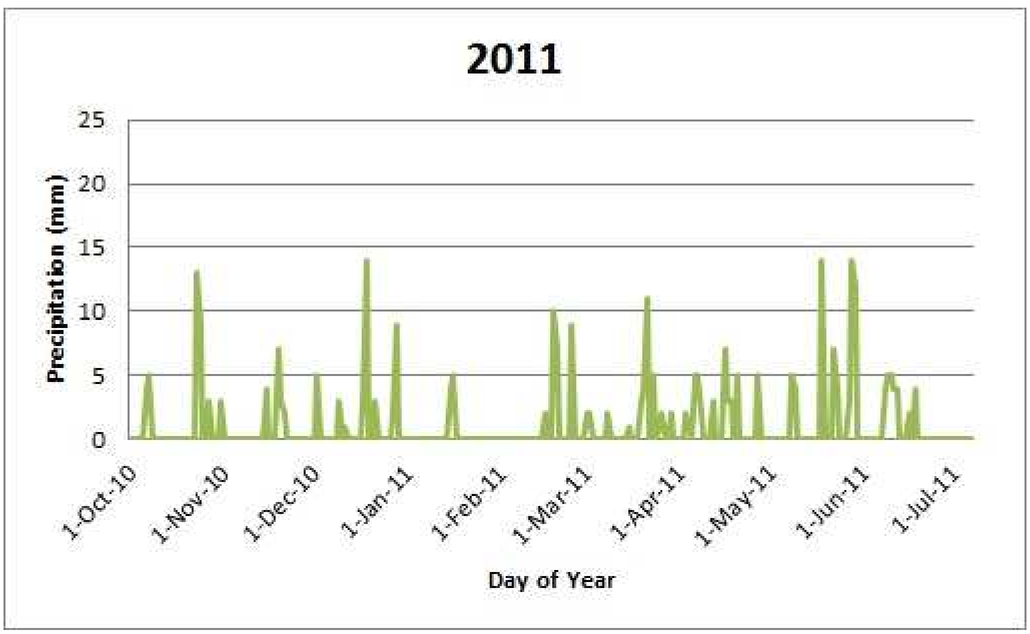

Figure 3.8. Daily precipitation data from October 1, 2010 through July 7, 2011 showed a total of 297 mm precipitation was received in the Jonah Infill prior to monitoring.

Discussion

To evaluate vegetation trends, site stability and self-sustainability, long-term monitoring plans should be incorporated into overall reclamation plans (Zedler 2007). A sound monitoring plan must be unbiased, statistically reliable, repeatable, and economical (BLM 1999, Cagney et al. 2011, ITT 1996). Due to the increasing demand for vegetation monitoring, sampling techniques should strive to become more cost efficient and information rich than in the past (Cagney et al. 2011, Stohlgren et al. 1998). While there are pros and cons to different vegetation sampling techniques, many studies have shown significant differences in results when multiple methods are used (e.g., Cagney et al. 2011, Carlson et al. 2005, Schladweiler and Adams 2010, Stohlgren et al. 1998, Vittoz and Guisan 2007). In semi-natural grasslands, Carlsson et al. (2005) demonstrated subplot frequency analysis found more species in a given area than visual estimate analysis. Therefore, a long-term monitoring plan should incorporate standard techniques and permanent sampling areas to identify trends and evaluate stability and self-sustainability. Additional studies have shown significant differences in results between observers, suggesting monitoring different sites with different individual observers is not an ideal scenario for gathering accurate data at a large scale with multiple observers (e.g., Archaux et al. 2006, Cagney et al. 2011, Vittoz and Guisan 2007). In subalpine meadows, Vittoz and Guisan (2007) demonstrated individual observers tended to overlook individual plant species regardless of expertise level when conducting measurements alone, whereas multiple observers increased accuracy in recording species. In addition to monitoring techniques and observers changing between years, several years of data collection were recorded with observers choosing locations to monitor which they thought represented a well pad or reference area. Representative sampling should be avoided if possible, because it is subject to observer bias (Scheaffer et al. 2012).

In addition to differences in monitoring techniques, inconsistencies in monitoring timing with relation to annual weather conditions, climate and plant phenology may be problematic. Precipitation affects net ecosystem productivity, composition, and diversity of plant communities (Bates et al. 2006, Parton et al. 2012). Although mainly studied in agriculture and horticulture settings, temperature also affects plant growth. For example, cool season crops in Montana are thought to have a lower developmental threshold of $0^{o}C$, meaning plant development cannot occur at temperatures below that level (Miller et al. 2009). It is highly likely vegetation monitoring timing may affect monitoring results. As shown in our results, both precipitation and temperature prior to monitoring were very different between years. Coupled with the facts monitoring techniques and individual observers varied between years, it is difficult, if not impossible, to determine vegetation trends when analyzing monitoring data obtained from reclamation practitioners and regulatory agencies in the Greater Green River Basin.

Although these inconsistencies do not lend themselves to sound data analysis, their existence brings opportunity for scientists to work with practitioners and regulatory agencies to improve the situation. If regulatory agencies hope to see trends in vegetation and site stability and self-sustainability on reclaimed well pads, practitioners must collect data in an unbiased, repeatable and statistically reliable way. Since oil and gas fields are vast and contain many disturbances, methods for improving time efficiency and cost efficiency will be required as the need for vegetation monitoring increases (Cagney et al. 2011, Stohlgren et al. 1998). As scientists, if we are to improve our broad-scale understanding of ecosystem restoration and land reclamation, being knowledgeable of large scale efforts of on-the-ground practitioners is critical. Realizing areas where science can benefit practitioners and offering practical, economically feasible, and statistically sound solutions will be crucial to advancing the field of

Restoration/Reclamation Ecology and informing regulatory agencies in natural resource management (Gibbons et al. 2008). A logical next-step for researchers will be to increase our understanding of how climatic conditions affect reestablishing vegetation communities and to continue to work towards developing monitoring techniques which can be effectively implemented by practitioners.

Several studies have pointed out the need to reduce subjectivity and observer bias in vegetation monitoring (e.g., Booth et al. 2006, Luscier et al. 2006, Cagney et al. 2011). Cagney et al. (2011) demonstrated image-based monitoring can reduce observer bias if separate images are analyzed by the same observer. Additionally, image-based monitoring has been shown to be more time efficient (and therefore, potentially more cost efficient) than traditional transect-based monitoring methods (Cagney et al. 2011) and is beneficial because it provides a permanent record which can be reanalyzed multiple times (Cagney et al. 2011, Crimmins and Crimmins 2008). The use of geo-tagged imagery can also aid our ability to accurately place vegetation monitoring data in space and increase accountability of field technicians and observers (i.e., a geo-tagged photo guarantees a technician's presence on a given site). Finally, repeat imagery can be analyzed and compared to measure changes in plant phenology over time (Crimmins and Crimmins 2008). The use of repeat imagery, coupled with precipitation, temperature and soil data may allow for development of a compound index to build growing degree day models for many species native to rangelands to improve our ability to monitor at proper times to record presence of critical plant species. For these reasons, we suggest image-based monitoring may improve our ability to analyze data by allowing for time efficient, cost efficient, unbiased, repeatable, and statistically valid monitoring while helping to inform decisions regarding selecting a time to monitor. While this chapter elucidates the complications faced in analyzing vegetation monitoring data in a single gas field, we were confounded with problems comparing two gas fields (see chapter 2) because of differences in monitoring techniques in the same year. Ultimately, if we are to improve our understanding of best management practices in reclamation, there must be consistent monitoring methods and techniques implemented across a wide spatial scale to allow for statistically reliable analysis of vegetation reestablishment.

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