ABANDONED COAL MINE LAND RESEARCH PROGRAM

NINTH PROJECT REVIEW SEMINAR

UNIVERSITY OF WYOMING
GILLETTE, WYOMING

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The seminar series is sponsored jointly by the University of Wyoming, Office of Research and the Abandoned Mine Lands Program of the Wyoming Department of Environmental Quality.

SPECIFICATION AND RECOMMENDATIONS FOR REPAIR OF RESIDENTIAL STRUCTURES DAMAGED BY GROUND MOVEMENTS RELATED TO MINE SUBSIDENCE

K.D. BASHAM, W.L. JOHNSON

Specifications and Recommendations for Repair of Residential Structures Damaged by Ground Movements Related to Mine Subsidence

October 30, 1997

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Amount: $59,000

Project Summary:

Abandoned mines underlay many areas of Wyoming. As mine cavities collapse they can cause settlement (subsidence) and ground distortions on the surface which may damage or even destroy buildings and affixed utilities. To increase the ability of building officials, contractors, architects, engineers, and homeowners of Wyoming to mitigate subsidence related building damage, the author has reviewed and updated the ***Specifications and Recommendations for Residential Construction Subjected to Ground Movements Related to Mine Subsidence***. Also, a document entitled ***Specifications and Recommendations for Repair of Residential Structures Damaged by Ground Movements Related to Mine Subsidence*** is being developed.

The primary purpose of the first document, developed by the University of Wyoming in 1988 and funded by the Wyoming DEQ/LQD, is to provide construction specifications and recommendations for new structures built in areas with a potential for mine subsidence. This document provides guidelines and recommendations for residential construction that will reduce subsidence related building damage. Revisions include the new subsidence risk categories, construction updates, and additional guidelines developed from mine subsidence insurance claims since 1988. This document also serves as an essential part of the qualifying process to insure new structures through the Wyoming Mine Subsidence Insurance Program. The second document or repair manual will consist of guidelines, recommendations, and repair schemes for repair of residential structures damaged by mine subsidence type ground movements. This repair manual will help architects, engineers, construction professionals, and homeowners of Wyoming to efficiently devise and execute suitable repair schemes. The repair manual will also set a standard for optimizing subsidence related building repair which will help reduce future and repeat subsidence damage and insurance claims.

To help introduce both documents, the investigator plans to develop information pamphlets addressing mine subsidence in Wyoming, related building damage, new construction guidelines, and repair schemes. Information pamphlets will give initial guidance about mine subsidence and related concerns to homeowners and building professionals. In summary, results of this project will enhance the ability of Wyoming communities to minimize the potential residential building damage caused by mine subsidence and to optimize subsidence repairs.

Project Goals:

1) Review and update the DEQ/Land Quality Division's document entitled ***Specifications and Recommendations for Residential Construction Subjected to Ground Movements Related to Mine Subsidence.***

2) Develop and publish a document entitled ***Specifications and Recommendations for Repair of Residential Structures Damaged by Ground Movements Related to Mine Subsidence.***

3) Develop information pamphlets to introduce mine subsidence, related concerns, and subsidence documents to homeowners and building professionals of Wyoming.

Progress:

Phase I — Develop and publish the second edition of ***Specifications and Recommendations for Residential Construction Subjected to Ground Movements Related to Mine Subsidence.***

The document is 100% complete and being published.

Phase II — Develop and publish ***Specifications and Recommendations for Repair of Residential Structures Damaged by Ground Movements Related to Mine Subsidence.***

The document is 60% complete.

Funding: 25% Remaining

DETERMINATION OF CONTRIBUTION TO CUMULATIVE GROUNDWATER IMPACTS FROM COALBED METHANE DEVELOPMENT AND SURFACE COAL MINING

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ABANDONED COAL MINE LANDS RESEARCH PROGRAM

Annual Interim Progress Report
November 9, 1997

Determination of Contribution to Cumulative Groundwater Impacts From Coalbed Methane Development and Surface Coal Mining

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Concerns over the cumulative effects of coalbed methane and surface coal mining on water quantity have increased in recent years. As surface coal mines must satisfy certain constraints imposed by the Surface Mining Control and Reclamation Act (SMCRA), the question of determination of responsibility for aquifer impacts is a critical issue. This project was funded for the purpose of developing methods to make such determinations. The 3 primary objectives for the project are to

- ***Investigate the existence of anisotropy of hydraulic conductivity in the coal aquifer for the purpose of evaluating modeling methods used by Peacock and Kern (1995), and to verify the presence or absence of inter-aquifer communication at these test sites.***

- ***Develop methods to differentiate groundwater changes due to surface coal mining activities from those associated with non-mining related aquifer stresses.***

- ***Acquire and assess all available data from Permit to Mine Applications using all available means for the four active mines nearest the Marquiss CBM development.***

Current Progress:

The majority of work associated with objectives 1 and 3 had been completed in 1996. Since then, a great deal of additional progress has been made. This years work has included,

1) an additional large scale pump test with inner and outer rings of observation wells,
2) finalization of a regional scale geologic model for the coal aquifer in the Powder River Basin based on 1986 well logs,
3) development of a regional conceptual hydro-geologic model for the Powder River Basin between Gillette and Wright Wyoming,

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4) setup and application of MODFLOWP to investigate model sensitivity and calibration in steady state, and
5) publication of new statistical techniques for testing the null hypothesis of isotropy vs anisotropy and methods to estimate confidence intervals for axes of anisotropy.

Aquifer Testing:

In previous years work on this project, 4 aquifer tests were conducted in the Powder River Basin. Three of the tests were conducted at local scale (25 to 150 foot well centers) and one of the tests was conducted at a larger subregional scale (1/4 mile well centers). Two of the local scale testes were located in close proximity to North West trending lineaments. The local scale tests showed axes of anisotropy oriented Northwest with ratios of anisotropy approximately 2:1 while the large scale test resulted in axes oriented approximately Northeast with a ratio of 6:1. To study this seeming inconsistency, an additional test was conducted with a total of 7 wells, with 3 monitoring wells located on 150 foot well spacings and 3 located on 1/4 mile well spacings. This allowed analysis of both large and small scale axes from a single test. Geologically, this test was located on an anticlinal structure. When all wells were analyzed together, the ratio of anisotropy was estimated to be 2.57 with 95% confidence interval ranging from 1.0 to 5.07. The axes of anisotropy were oriented N 54°E. When the near wells were analyzed alone, the ratio of anisotropy was estimated to be 1.28 and there were not sufficient wells to estimate the variance of the estimate. When only the outer wells were analyzed, an elliptical cone of depression did not fit the data as well as a hyperbolic drawdown pattern. This may indicate either that the amount of observed drawdown was insufficient to adequately identify the drawdown pattern or that the flow regime in this area does not follow the assumption of homogeniety of the aquifer. However, the estimates obtained from the short range wells indicates that the Northeast orientation of axes of anisotropy observed in the previous years test is likely due to local influences related to lineaments or faulting. Based on the consistency observed between the two large scale tests it appears that regional models should be conducted with axes of anisotropy oriented approximately East Northeast to Northeast **with a ratio of anisotropy ranging from 2:1 to 6:1.**

Model Parameterization and Inverse Modeling

The combination of conceptualization and numerical discretization define a nonlinear model with a set of parameters (hydraulic conductivity, boundary conditions, vertical leakance, among others which we attempt to estimate through calibration and validation to known data. In general, a largely trial and error procedure is used to incorporate known information with unknown parameters to develop a model "parameterization" which can be adequately calibrated to water level observations.

We used a nonlinear optimization procedure implemented in MODFLOWP to attempt to estimate model parameters including heads along boundaries, hydraulic conductivity in the coal aquifer, hydraulic conductivity in transition zones between the coal aquifer and mapped clinker pods along the coal crop line, and even the number of transition zones. This procedure known as inverse modeling involves attempting to minimize an objective function by iteratively searching for optimal combinations of parameter estimates. The objective function we considered was the root mean squared error between predicted heads and

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observed heads in premining steady state conditions. The primary difference between the inverse modeling technique and more common trial and error methods is that parameter estimates are investigated simultaneously allowing assessment of model sensitivity to individual parameters but perhaps as importantly, assessment of the extent to which 2 parameters effectively have the same effect on modeled predictions. The primary tools are measures of sensitivity of the model to parameters and the correlation between individual parameters in the model. If two parameters are highly correlated, this is an indication that either parameter could be dropped without undue reduction in the quality of model calibration.

Inputs to the conceptual model which are fairly well developed include the geology along the crop line, aquifer tests in the vicinity of coal mines, the axes of anisotropy as a result of these investigations and water levels in the vicinity of coal mines. Information which is largely unknown includes boundary conditions along the western edge of the modeling grid, hydraulic conductivity in the coal and Wasatch aquifers at locations distant from the eastern crop line, the extent that clinker is in contact with coal and the amount of recharge to be expected, the location of major faults and lineaments particularly in the Northern half of the modeled domain, and the degree of interconnection between the coal aquifer and the overlying Wasatch.

The primary work conducted this year has been investigations of these unknowns in terms of model sensitivity and the ability of the existing data to discriminate between various parameterizations of the model. It was found that many of the properties described above where highly inter-correlated. This indicates that the data are capable of supporting only a small number of parameters when regional scale models are of interest. To investigate the appropriate level of model parameterization we started with a very simple model including a homogeneous aquifer with constant head boundaries. In this setting it was found that the hydraulic conductivity in the coal and the gradient of the piezometric surface as controlled by the boundary conditions were perfectly correlated, (i.e. the optimal RMSE could be obtained by setting the gradient at any reasonable value and solving for conductivity). Therefore, further investigations of hydraulic conductivity in the coal can only be conducted conditional on chose n boundary conditions. Therefore a combination of boundary conditions and hydraulic conductivity were selected which resulted in conductivities in the coal consistent with aquifer test data and boundary conditions which resulted in a fully saturated coal aquifer and a Wasatch aquifer which was wet. The next parameters investigated were those associated with description of the crop line. In particular, a single transition zone was defined to allow conductivities adjacent to the cropline to differ from those in the coal. Increased conductivities along the cropline resulted in somewhat improved calibration. The next level of complexity included a set of distinct transition zones along the cropline allowing for differential flows from clinker pods in contrast to flows associated with non clinker material along the cropline. In this case some transition pods resulted in increased conductivities while others resulted in greatly decreased conductivities. Additional investigations involved vertical leakance parameters and investigations of heterogeneity in the coal and Wasatch aquifers. It was found that in order to reduce RMSE errors below 20 feet, the coal aquifer must be parameterized as a heterogeneous medium. Further investigations of heterogeneity included the use of conditional simulation to input artificial high conductivity areas and low conductivity areas into the conductivity array. This investigation showed that calibration could be further improved through introduction of additional "facsimile" aquifer tests in appropriate areas. However, it is not known how this introduction of additional aquifer tests affects the results of predictive modeling in areas spatially distant from existing monitoring wells. This issue will be further evaluated in the remaining part of the project.

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METHODOLOGY FOR THE DESIGN AND DEVELOPMENT OF A GIS-BASED SPATIAL DECISION SUPPORT SYSTEM FOR ASSESSING THE HYDROLOGIC IMPACTS OF COAL MINING AND MINE LAND RECLAMATION IN WYOMING

J.D. HAMERLINCK, K.T. PEACOCK, G.E. JONES

Wyoming Abandoned Coal Mine Lands Research Program
Interim Project Review
November 1997

Methodology for the Design and Development of a GIS-Based Spatial Decision Support System for Assessing the Hydrologic Impacts of Coal Mining and Mine Land Reclamation in Wyoming

August 1, 1996 - December 31, 1998

Principal Investigators:
Jeffrey D. Hamerlinck, University of Wyoming; Kenneth T. Peacock, U.S. Bureau of Land Management; and Greg E. Jones, Powder River Coal Company

PROJECT OVERVIEW

This interim progress report provides a brief project background and summary of work undertaken over the 12-month period from November 1, 1996-October 31, 1997.

Problem Statement. The coal permitting process places heavy demands on both permit applicants and regulatory authorities relative to the management and analysis of hydrologic data. To meet these challenges, a need exists for the development of computer application tools capable of: 1) managing large quantities of spatial and non-spatial digital hydrologic data; and 2) providing an efficient means for utilizing such information in an integrated hydrologic impact analysis/modeling environment.

Objective. The primary objective of this research is to develop an integrated, modular spatial decision support system (SDSS) for assessing the hydrologic impacts of coal mining activities in the Powder River Basin of northeastern Wyoming. Components of the system will include existing surface and groundwater models (HEC-1; MODFLOW), integrated with a pair of professional and desktop geographic information systems (ARC/INFO and ArcView). Upon completion, the project will deliver a GIS-based spatial decision support system "software application toolbox" for use by regulatory agencies and industry alike.

STATEMENT OF WORK

Seven primary tasks were originally identified for completion under the scope of this work:

TASK 1: STUDY AREA DATABASE DEVELOPMENT. Development of required base data layers for inputs to selected models for the Antelope Creek Watershed Study Area.

TASK 2: HEC-1/GIS INTERFACE DEVELOPMENT. Essentially an ArcView interface and "applications toolbox" for HEC-1; will require two major tasks:

2a. Develop graphical user interface for model input parameter generation, including creation of necessary derived GIS coverages, hydrologic response unit delineations, and parameter estimation;

2b. Provide GIS output capabilities of modeling results for calibration and validation purposes.

TASK 3: MODFLOW/GIS INTERFACE DEVELOPMENT. Interface for GIS-based MODFLOW parameter input, analysis, and output generation; three major subtasks have been identified:

3a. Develop graphical user interfaces for creating necessary derived GIS coverage model inputs; grid generation and grid parameter population;

3b. Create functionality to directly convert data layers into readable MODFLOW arrays;

3c. Provide GIS output capabilities for portrayal of modeling results for calibration and validation purposes.

TASK 4: CHIA MODELING SUPPORT AND BETA TESTING. This task will involve providing support and training to modelers associated with the Wyoming CHIA development effort, focusing on impact analysis in the Antelope Creek watershed study area (CIA 1).

TASK 5: PHC MODELING SUPPORT AND BETA TESTING. Working in cooperation with Powder River Coal Company, the SDSS will be beta tested for PHC-type applications in an active coal mining area of the Antelope Creek watershed study area.

TASK 6: USER GUIDE DEVELOPMENT. Development of a user guide for the completed SDSS, including an overview of component module functionality.

TASK 7: REPORT GENERATION. Includes two interim review reports, a Final Executive Summary Report and the Final Technical Report (based on user guide developed in Task 6).

Over the last year, several developments have lead to significant modifications to portions of this work plan. These changes may be attributed primarily to recent decisions regarding the *Wyoming Initiative Cumulative Hydrologic Impact Assessment* (CHIA) modeling effort. Originally, one of the major components of this project's purpose was to provide GIS-based support to the Wyoming Initiative effort. However, following completion this spring of the pilot CHIA for the Little Thunder Creek watershed, a decision was made to not move forward with plans to apply the model in the Powder River Basin's other four Cumulative Impact Areas (CIAs), including the Antelope Creek watershed identified in Task 1. The results of this action on our project involve only Tasks 1, 4, and 5; final deliverables of the project will remain essentially the same.

First, while Task 1—the development of required GIS base data layers for inputs to selected models for the Antelope Creek watershed study area--had essentially been

completed, the watershed will not be utilized in Task 4—CHIA modeling support and beta testing, due to the unavailability of required ancillary data inputs originally identified for development under the CHIA modeling effort. Rather, Task 4 will be appropriately scaled-back to involve a duplication of modeling methodologies for the Little Thunder Creek watershed using new GIS-based decision support tools for model input and output. Related to this change is a corresponding increased emphasis on Task 5--PHC modeling support and beta testing. Given the uncertain future of GIS-based CHIA modeling needs, the project has and will continue to focus increased attention on developing tools for assisting mines in determining probable hydrologic consequences associated with mine permitting requirements. As outlined above, this effort will continue to involve work with Powder River Coal Company, utilizing PRC's active coal mining areas in the Antelope Creek watershed as a test bed for tool development.

In regard to project team personnel, several actions have taken place in the last 12 months. In January 1997, Josh Johnson, a graduate student in UW's Department of Geography and Recreation was assigned to the project as a graduate research assistant. Josh's work on the project will focus on GIS/groundwater model integration, providing the basis for thesis research under his Master's program in Geography/Water Resources, anticipated for completion in correspondence with the overall project in December 1998. More recently, two WWRC co-principal investigators have left the project—Tony Anderson, following completion of his work on the CHIA surface water modeling effort, and Jim Oakleaf, GIS support, now with the Idaho Division of Water Resources. Results of these departures have had minimum impact on the project's overall progress, primarily slowing recent activities in completion of Task 2. This personnel need has been addressed however, and it is anticipated that Mr. Mike Anderson, a University of Wyoming student graduating this fall in Geology, will be joining the project team on January 1, 1998 to assume responsibility for completion of the GIS/surface water model integration portion of the project. Mike will bring a wealth of valuable experience to the project, having previously worked on the CHIA surface water modeling effort as a technician and in the Powder River Basin for his graduate research on infiltration in reclaimed stream channels.

RECENT ACCOMPLISHMENTS

To date, work has focused on Tasks 1, 2, and 3. Task 1 was completed prior to the work plan modifications described above. However, the spatial data developed should prove very useful for a wide range of non-project management and research applications in the future. A preliminary assessment of the potential for utilizing GIS in assessing hydrologic impacts was presented at two conferences this spring; Wyoming Water '97 in Casper, WY, and the Annual Meeting of the American Society for Surface Mining and Reclamation in Austin, TX.

Task 2—HEC-1/GIS interface development—continues, with input parameter utilities well underway. The November 18th presentation accompanying this report will demonstrate current functionality using data provided by co-principal investigator Greg Jones of Powder River Coal Company.

As described above, Task 3—MODFLOW/GIS interface development—has been the primary focus of Josh Johnson's thesis research. Johnson is currently evaluating available GIS interface tools for use with MODFLOW and Visual MODFLOW, and recently attended a training course sponsored by the University of Memphis's Groundwater Institute, entitled "GIS-Based Ground Water Flow Modeling Using ArcView." Johnson's thesis proposal, "The integration of GIS and MODFLOW as a tool for assessing groundwater hydrology impacts of surface coal mining in the Powder River Basin, Wyoming," is currently under development.

Finally, the project team is currently considering formation of a 'technical advisory committee' composed of a small group of representatives from both industry and government, which would provide feedback on design and utility of the various modules of the SDSS as they are finalized over the next 14 months.

PUBLICATIONS TO DATE

Hamerlinck, J.D. and J.R. Oakleaf. 1997. **Utilizing Geographic Information Systems Technology in the Wyoming Cumulative Hydrologic Impact Assessment Modeling Process**, in Proceedings, Vision 2000, 14th Annual Meeting of the American Society for Surface Mining and Reclamation, May 10-15, 1997, Austin, TX. p. 667-676.

Oakleaf, J.R. and J.D. Hamerlinck. 1997. **Integrating Geographic Information Systems Technology into Groundwater- and Surface-Water Modeling Associated with Wyoming's Cumulative Hydrologic Impact Assessment**, in Proceedings, Wyoming Water '97: What's New in the Toolbox-Applied Research for Management of Wyoming's Water Resources, April 21-23, 1997, Casper, WY. p. 25-33.

INTERACTIONS INFLUENCING SELENIUM TOXICITY IN AQUATIC SPECIES ON RECLAIMED MINELANDS

M.F. RAISBECK, E.L. BELDEN

Interactions Influencing Selenium Toxicity in Aquatic Species on Reclaimed Minelands

Interim Report to the ACMLRP
11/18/97

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Problem Summary

The possibility of Se mobilization as a result of surface mining and the resulting increased bioavailability to livestock, wildlife and waterfowl is a serious potential problem in mine reclamation. Artificial wetlands and impoundments have been proposed for reclamation of many mine sites in the Powder River Basin of Wyoming. Such wetlands will attract migratory waterfowl, which are among the species most sensitive to the environmental impacts of selenium (Se). The geochemical similarities of Se and sulfur (S) in the semi-arid western Great Plains make it likely that environmental disturbances which mobilize Se will also mobilize S. Indeed, much of the surface water in the Powder River Basin contains high concentrations of S in the form of various sulfate salts. Although theoretical models suggest that S will modify Se toxicity, at present it isn't known how the main surface water contaminant of the region will influence the toxicity of Se. The purpose of this project is to determine whether sulfate concentrations typical of surface waters int he Powder River Basin potentiate the reproductive toxic effects of Se. Such knowledge is critical to determining acceptable regulatory thresholds for these elements in wetlands were both elements are present.

Methods

Model: Game farm mallards were chosen as the experimental model because: 1) they are genetically similar to one of the species most at risk of selenosis in Powder River Basin wetlands; 2) they are well characterized pathophysiologically and there is thus a considerable knowledge base to draw upon; and 3) we have considerable experience with the species, which has been used extensively in selenosis research elsewhere. Embryonic deformities (terata) and reproductive failure are reported to be the most sensitive indicators of Se toxicity in waterfowl (Heinz et al., 1989) and represent the toxic endpoint of greatest environmental concern. Therefore, this experiment focused on reproductive effects as the major endpoint to evaluate the toxic effects of Se with or without supplemental sulfate. Other endpoints

included feed consumption, body weight, pathology, blood, egg and hepatic Se concentrations.

Exposure: Selenomethionine (Semet) in aquatic plants and invertebrates was the main culprit in spontaneously episodes of waterfowl selenosis (Ohlendorf 1986; Fairbrother and Fowles 1990; Heinz et al., 1989). To mimic this exposure, we prepared experimental diets by absorbing an aqueous solution of Semet (Calbiochem Bulk Chemicals, La Jolla, CA) into duck chow (Mazuri 20% Layer Pellets), then air drying the diet. Control diets were treated similarly with untreated water. The purity of purchased Semet was confirmed by elemental analysis, thin layer chromatography and hydride-ICP.

Sulfur exposure under natural conditions will be as S-amino acids in feedstuffs, and as sulfate ion in drinking water. We believe the latter to be most important (ie. of greatest magnitude), thus S was supplied as an equimolar mixture of Ca, Na, K, and Mg salts at 1000, 2000, and 3000 ppm sulfate ion in drinking water. By using a mixture of salts we kept the concentration of individual cations below toxic thresholds.

Preliminary results

Last year we fed 15 ppm Se as the experimental diet. With the exception of a slight, non-significant decrease in blood Se concentrations, there were no apparent toxic interactions between Se and S. This dose, however, was significantly more embryotoxic than we anticipated on the basis of the research literature. We therefore elected to use 8 ppm Se as the primary toxic diet in the 1997 experiment.

In 1996, 15 ppm Se caused measurable feed refusal and a decrease in feed consumption. This year, there was no difference in feed consumption between the Se-diet and control groups. All birds gained weight while on experimental diets. There was no significant difference between dietary group mean weight gains although the 8 ppm Se/3000 ppm SO_4 group gained more near the end of the feeding period. Again in contrast to last year's 15 ppm birds, there we no apparent differences in plumage or general body condition between dietary groups.

Hens in the 8 ppm Se/3000 ppm SO_4 laid more eggs than did controls, but fewer of these eggs were viable. Terata (deformities) in eggs from Se-treated hens were similar to those we reported last year, ie. beak deformities, missing limbs, fused digits, edema and hydrocephaly. Complete statistical analysis is still pending, but our initial impression is that there were more deformed embryos from this year's 8 ppm hens than from last year's 15 ppm hens. This is probably due to higher early embryonic mortality in last year's eggs, ie. 15 ppm embryos were more likely to die before visible malformations occurred.

A smaller than expected percentage of eggs hatched this year in all treatment groups. Embryos developed normally until approximately 2 days prior to hatching. We are still trying to ascertain the cause, but, as this problem occurred with all treatment groups, it does not seem likely to be related to Se or SO_4 treatments.

A high percentage of last year's 0 Se/high SO_4 ducklings exhibited various neurologic signs such as convulsions and incoordination shortly after hatching. This effect was not seen in this year's birds.

Selenium analysis of tissues, blood and eggs is pending equipment repairs. We anticipate spending the remainder of academic 97-98 will be devoted to chemical analysis, data checking and statistical analysis.

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Fairbrother A, Fowles J (1990): Subchronic effects of sodium selenite and selenomethionine on several functions in mallards. *Arch Environ Contam Toxicol* 19:836-844.

Heinz GH, Hoffman DJ, Gold LG (1989): Impaired reproduction of mallards fed an organic form of selenium. *J Wildl Mangae* 53:418-428.

Ohlendorf HM, Hoffman DJ, Saiki MK, Aldrich TW (1986): Embryonic mortality and abnormalities of aquatic birds: Apparent impacts of selenium from irrigation drainwater. *Sci Total Environ* 52:49-63.

STRATEGIES FOR ESTABLISHMENT OF BIG SAGEBRUSH (Artemisia tridentata spp. wyomingensis) ON WYOMING MINED LANDS

G.E. SCHUMAN, D.T. BOOTH

EXECUTIVE SUMMARY

STRATEGIES FOR ESTABLISHMENT OF BIG SAGEBRUSH (ARTEMISIA TRIDENTATA SSP. WYOMINGENSIS) ON WYOMING MINDED LANDS

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ABANDONED COAL MINE LAND RESEARCH PROGRAM

OCTOBER 22, 1997

Wyoming big sagebrush (Artemisia tridentata ssp. wyomingensis) is one of the most widely distributed and adapted shrub species in Wyoming and the region. However, its reestablishment on mined lands has generally proven difficult. This research was designed to integrate several shrub establishment approaches in a manner to define effective strategies for establishment of big sagebrush. Specific objectives included: determine the efficacy of direct-applied topsoil for enhanced sagebrush establishment, determine the value of an annual-grain stubble mulch and a surficially applied straw mulch for increasing sagebrush establishment through enhanced moisture conservation and microsite modification, determine the effect of competition from concurrently seeded grasses on establishment of big sagebrush, determine the effect of seeding fourwing saltbush as a pioneer species for enhancing establishment of sagebrush, determine the effect of arbuscular mycorrhizae (AM) on moisture stress tolerance of big sagebrush seedlings, and evaluate the reclamation methods and resulting shrub densities of pre-1985 reclamation.

This research was composed of three field studies and one laboratory/greenhouse study. The field studies were identified as the "Establishment Study", the "Pioneer Plant Study", and the "Survey Study". The Establishment and Pioneer Plant studies were implemented simultaneously at the North Antelope Coal mine about 100 km north of Douglas, Wyoming. The Survey study involved evaluating fourteen pre-1985 reclamation sites representing 7 surface coal mines and 1 open-pit uranium mine in Wyoming. The greenhouse study was study was conducted at the Plant, Soil, and Insect Sciences Department at the University of Wyoming and was initiated to compliment the Establishment study and enable greater evaluation of the role of AM in sagebrush establishment.

Establishment Study

This study was designed to evaluate three sets of main treatment variables: (1) topsoil management procedures (direct-applied or stockpiled), mulch methods (stubble, straw, stubble + straw, and no mulch), and level of grass competition (no grass and two levels of a concurrently seeded native grass mixture. Sagebrush seedling densities measured in the study exhibited an interaction between topsoil management, mulch type, and grass competition. Sagebrush seedling densities exhibited a different response in the spring 1992, fall 1992 and spring 1993 compared to the fall 1993 and fall 1994. The large increase in sagebrush seedling densities exhibited between the spring 1993 and fall 1993 was attributed to the wet and cool spring and summer of 1993. Even though 1993 climatic conditions greatly increased sagebrush seedling densities, the density measured in the 1992 and spring of 1993 on the direct-placed topsoil-no competition, mulched treatments exceeded the recently established shrub standard (1 shrub/m2) for Wyoming. This emphasizes the importance of good cultural practices especially since these sagebrush densities were achieved during a below average (87%) precipitation year. Direct-placed topsoil resulted in 40% more sagebrush seedlings in the spring of 1993. The 1992 soil moisture content of the surface 7.5 cm was always higher on the direct-hauled compared to the stockpiled topsoil. This greater soil moisture aided in the improved sagebrush establishment on the direct-placed treatment. No sagebrush seedlings could be attributed to soil seedbank because control plots in an adjacent study did not have any sagebrush seedlings present. There was no difference in sagebrush seedling densities due to grass competition between 16 and 32 kg PLS/ha for either of the two topsoil management treatments. However, grass competition reduced sagebrush seedling

densities throughout the duration of the study on the direct-placed topsoil treatment where mulch was applied.

Arbuscular mycorrhizae spore numbers were significantly higher on the direct-placed topsoil compared to the stockpiled topsoil. However, mycorrhizal infection of 396 sagebrush seedlings removed from the competition-mulch-soil management treatment plots in June 1993 showed no differences in spite of the difference in AM spore levels observed initially.

The presence of mulch greatly affected sagebrush seedling establishment in 1992. No seedlings were evident in the first year where mulch was not applied. Mulch has been shown to affect seedling microclimate through reduced diurnal temperature fluctuations and increased soil moisture.

Arbuscular Mycorrhizae Study

A greenhouse study was conducted to further examine the influence of AM and seedling age on soil moisture stress tolerance of big sagebrush. A fresh source of topsoil was collected at the North Antelope Coal Company mine. Arbuscular mycorrhizae was eliminated from a portion of the soil using a pasteurization process to represent a non-mycorrhizal topsoil. One hundred and eight 15-cm pots were filled with either fresh topsoil (mycorrhizal) or non-mycorrhizal soil and seeded with sagebrush. At 30, 45, 60, 90, 120, and 150 days of growth, no additional water was applied to eighteen pots of each treatment. Pots were allowed to dry until the sagebrush seedling died and they were removed from the soil and examined for root mycorrhizal infection. Soil water content of the potting soil was determined and compared to a moisture retention curve established for this soil to determine soil water potential.

Sagebrush seedlings from the mycorrhizal treatment exhibited infection on 65-86% of the root segments examined while only 1-2% of the root segments from the non-mycorrhizal treatment exhibited infection. All seedling age groups that were mycorrhizal were able to tolerate greater soil moisture tensions before dying compared to the non-mycorrhizal seedlings. No non-mycorrhizal seedlings survived when water potentials were below -3.3 MPa; however, many mycorrhizal seedlings survived in soils as dry as -3.7 MPa. Sagebrush seedling age and mycorrhizal treatment exhibited an interaction, indicating that as sagebrush seedlings aged the beneficial effects of AM on soil moisture stress tolerance increased. The research clearly indicate that those seedling > 120 days of age that are non-mycorrhizal are much less tolerant of soil moisture stress than younger non-mycorrhizal seedlings within the soil moisture ranges experienced in the study.

Pioneer Study

This phase of the research was initiated to evaluate the role of fourwing saltbush as a pioneer plant to enhance the later establishment of big sagebrush and to evaluate the role of this plant in excluding big sagebrush when planted at rates in excess of 2.2 kg PLS/ha. Direct-placed and stockpiled topsoil treatments were assessed and no grass competition was imposed in this study. A small-grain stubble mulch was established on the entire plot area. Sagebrush seeding treatments included: (1) sagebrush seeded in 1992 and 1993, (2) 1992 fallow and sagebrush

seeded in 1993, (3) fourwing saltbush seeded in winter 1991 and sagebrush overseeded in 1993, and (4) control. Seedling densities were measured annually and color pictures were taken of each 1 m2 quadrat where seedlings were enumerated. Sagebrush seedling heights were also measured.

Total shrub (saltbush and sagebrush) seedling densities was greater on stockpiled topsoil than on direct-placed topsoil. However, there was a significant difference between replications, which confounds the interpretation. The lack of a significant benefit for direct-placed topsoil contrasts with the benefits noted in the Establishment Study and by other research evaluating seedling establishment, nutrient availability, microbial population and water infiltration reported over the past two decades. Whatever the reason, long-term sagebrush seedling survival was greater on the stockpiled topsoil for all seeding treatments. The plots seeded to sagebrush two consecutive years, after five growing seasons and averaged across the stockpiled and direct-placed topsoil treatments, had greater sagebrush seedling densities than those treatments that were fallowed and then seeded to sagebrush a year later. However, the differences observed were quite small considering that the two consecutive seedings resulted in over twice as much sagebrush seed being sown. Sagebrush seedling density was less when seeded after saltbush establishment than when seeded during the first year or after fallowing for one year. Sagebrush seedling height was also less for this seeding treatment; however, the differences observed were no statistically significant. Total shrub density was greater where both the saltbush and sagebrush were seeded. On the surface the data implies that the saltbush reduced sagebrush seedling establishment but when evaluating the seed establishment efficiency and seedling heights within the saltbush-sagebrush treatment it appears that the use of saltbush as a pioneer species neither improved or reduced the establishment of sagebrush. The photographic data provide clear evidence of sagebrush establishment for three and four growing seasons after the last seeding. This is consistent with the data observed in the Establishment Study.

Survey Study

Fourteen, pre-1985 reclaimed mine sites, representing eight mines in Wyoming were selected. The post-mining shrub component of the vegetation of these sites was dominated by fourwing saltbush (5 sites) or by fourwing saltbush-sagebrush (9 sites), although the seed mixtures that produced the post-mining communities varied but fourwing saltbush and sagebrush dominated the shrub species. Transects were systematically located across each site and were oriented perpendicular to the length of the site. Shrub density by species was determined. Shrub seedlings, standing-dead shrubs, and shrub height were measured. Degree of browsing was also noted. Total shrub densities, canopy cover, and shrub density by species was calculated. Diversity indices were also calculated using the shrub density data. Antelope and sage grouse habitat requirements were used to assess wildlife habitat quality of the shrub communities evaluated.

Total shrub densities were nearly 3 times greater on the saltbush-sagebrush sites compared the fourwing saltbush sites. When extrapolating the newly established shrub density requirement of 1 shrub/m2 on 20% of the land area to 100% of the land area, the shrub density can be assumed to be 0.2 shrubs/m2 . On this basis, only one of the five saltbush communities and seven of the nine saltbush-sagebrush communities had shrub densities greater than the 0.2 shrubs/m2. While

this extrapolation provides a means of comparing the pre-1985 reclamation plantings to the new standard, we recognize its limitations. It ignores the current requirement of shrub patch spatial diversity. If you evaluate the survey sites as a patch of mature shrubs and use the standard density then none of the site would meet the new shrub standard.

Shrub densities on saltbush-sagebrush sites was closely correlated to total shrub seeding rates. No correlation was found between seeding rates and shrub density among the saltbush sites. Grass seeding rates on all sites ranged from 15 to 29 kg PLS/ha and this level of competition did not effect on shrub density. This finding agrees with that observed in the Establishment Study where the only difference in sagebrush establishment occurred between no grass competition and when grass was seeded. Natural immigration of shrubs was also limited and only occurred in areas adjacent to established shrub communities. Therefore, significant natural immigration will likely require several decades unless overseeded with shrub species to speed up the process.

Evaluation of the survey study data in terms of wildlife habitat resulted in several interesting and important findings. When comparing published shrub cover requirements for antelope to those measured on the reclaimed sites, only two of the saltbush sites and four of the saltbush-sagebrush sites provided marginal to adequate cover. Cover needs for sage grouse were only met at one saltbush site and at four saltbush-sagebrush sites. The present shrub reclamation guidelines in Wyoming focus solely on shrub density, rather than on cover, to assess reclamation success. These findings indicate that cover is equally important to shrub density when evaluating reclaimed lands for wildlife habitat. When evaluating sagebrush height, five of the nine saltbush-sagebrush sites and only one of the saltbush sites had heights great enough to fall within requirements established for antelope. Sage grouse sagebrush height requirements for nesting habitat were met a one saltbush site and at seven of the nine saltbush-sagebrush sites.

Diversity indices were three times higher on saltbush-sagebrush sites compared to the saltbush sites.

The data indicate that the more shrub species included in the original seed mixture the greater the overall shrub density and diversity. Several of the saltbush-sagebrush sites displayed encouraging signs of increased shrub densities by the presence of age stratified populations. Sites with more shrub species in the initial seed mixture more closely resemble the diversity of the pre-mine community and are more likely to have the highly desired characteristics necessary for optimum wildlife habitat.

Summary

Establishment of Wyoming big sagebrush on mined lands in Wyoming can be enhanced by the improved understanding of seedbed ecology and environmental factors that were evaluated by this research. Mulch, removing herbaceous competition, and direct-placed topsoil (Establishment Study) improved sagebrush seedling establishment and survival. The densities of sagebrush seedlings established met the density requirements of the new Wyoming shrub standard, which indicates that the standard is achievable under the conditions encountered during the study period. The research has also clearly shown that sagebrush seed will remain viable for at least 3 years after seeding, which enables seed germination to occur over a period of several

years and varying climatic conditions. The use of fourwing saltbush as a pioneer species to improve sagebrush recruitment did not show any increase in sagebrush establishment nor did it result in any reduction in sagebrush establishment. However, it did result in increased total shrub density and cover, further supporting the importance of including multiple shrub species in the seed mixture.

Our survey of fourteen pre-1985 reclamation sites in Wyoming showed that greater shrub establishment was achieved when the initial seed mixture included saltbush and sagebrush compared to when only saltbush was in the mixture. The fourteen sites did not produce shrub densities that would meet the new Wyoming shrub standard. However, the findings point out the importance of shrub cover in assessing wildlife habitat rather than using only shrub density as a criteria of reclamation success.

Many of the findings reiterate some important and well known facts; however, many of these findings are still not fully accepted by reclamationist and regulatory personnel when developing reclamation plans. Recommendations from this research will result in improved sagebrush establishment on Wyoming mined lands.

Acknowledgment: We would like to acknowledge and thank Mr. Scott E .Belden, Environmental Coordinator, North Antelope Coal Company, Gillette, Wyoming for his personal and company assistance in this research.

THE INFLUENCE OF POST-HARVEST AND PRE-PLANTING SEED TREATMENT ON SAGEBRUSH SEEDLING VIGOR

D.T. BOOTH, Y. BAI, and E.E. ROOS

SAGEBRUSH SEED PRODUCTION
an extension of
THE INFLUENCE OF POST-HARVEST AND PRE-PLANTING SEED TREATMENT ON SAGEBRUSH SEEDLING VIGOR

D.T. Booth, Y. Bai, and E.E. Roos

Introduction

Since Wyoming big sagebrush is commonly recommended for revegetation of mined lands, and since there is a need to improve sagebrush seeding success, a project titled, 'Influence of Post-harvest and Pre-planting Seed Treatment on Sagebrush Seedling Vigor' was initiated in the fall of 1993 to measure factors affecting sagebrush seed quality. The results of those studies suggested to us that a comparison of sagebrush seed production and quality on and off mine sites, and an evaluation sagebrush management to increase seed dry weight were needed. We therefore proposed a redirection and extension of the field work. These were granted and the progress of the study is reported here. The ongoing research is a cooperative effort by scientists of the High Plains Grasslands Research Station, Cheyenne, WY (ARS) and the National Seed Storage Laboratory, Fort Collins, CO (ARS) with the Dave Johnston Coal Mine, Glenrock, WY.

Methods

The study was installed at the Dave Johnston Coal Mine in July of 1995. Five study sites were selected at the mine where stands of sagebrush occupied areas of mined land adjacent to undisturbed rangeland. Within each study site single sagebrush plants were given the following cultural treatments: (1) a 1 m^2-piece of fabric mulch was installed around the base of the plant to reduce competition from herbaceous plants, (2) a windbreak was erected on the north and west side of the plant, (3) both mulch and a windbreak were installed, and (4) no treatment. Plants selected for these treatments were surrounded by a 1-meter^2 fence, then paired with an unfenced adjacent plant from which data are also being collected. Plants were fenced to keep the seedheads from being eaten by wildlife. Data being collected from the plots include soil moisture; number of seed stalks and seeds produced per plant; and seed weight, moisture, viability, germinability, and vigor.

Results

Given the unusually high spring precipitation received in Wyoming in 1995, we were not expecting differences due to treatments for the 1995 harvest and there were none. In 1996, there were differences in the weight of seed materials harvested among sites, and between reclaimed versus native stands. The native stands yielded a mean of 63 g per plant and the reclaimed yielded 117 grams per plant. There were also differences among the 5 study sites for average number of stems per plant and in the time to 50% germination of the seed. These differences simply underscore the need to have multiple study sites because of site-to-site variability. Seed germination ranged from 0 to 80%, with most lots germinating between 50 and 60% and with no differences by subplot (reclaimed vs native) or cultural treatment. Time to 50% germination ranged from 1 to 3.3 days with most lots averaging about 2.3 days.

Observations made September 1998 indicate that sagebrush seeds are not ripening as soon as in previous years. The 1998 harvest is now planned for November.

Other Significant Information

The monies we received from this grant provided the greatest portion of support for Dr. Y. Bai's position. That position contributed to our obtaining additional funds from the Saskatchewan Agricultural Development Fund and Ducks Unlimited of Canada to conduct cooperative work with the University of Saskatchewan on winterfat seedbed ecology. Since winterfat is a shrub commonly used in revegetation of Wyoming coal mined lands, we have listed publications from that project with those from the sagebrush work.

Publications

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EVALUATION OF PREVIOUSLY COLLECTED COAL MINE RELATED WILDLIFE DATA

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Evaluation of Previously Collected Coal Mine Related Wildlife Data: 1997 Annual Progress Report

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Objectives

The objectives of Phase I of our study are to (1) evaluate the quality and quantity of wildlife data from five Wyoming coal mines (both in permit applications and in annual monitoring reports) and determine the appropriate methods for analysis of the data; (2) analyze data from the five mines in relation to objectives for the wildlife monitoring program (assumed to be estimating the response of wildlife resources potentially affected by each mine); (3) recommend objectives and a completion option for Phase 2 of the project, and (4) recommend future wildlife monitoring procedures and reporting formats. A secondary objective of Phase 1 is to convert existing data for the five mines from hard copy format into readily accessible electronic format. Phase 2 of the project, if completed, will repeat Phase 1 on all or a subset of all remaining coal mines in the state.

Methods

Data Collection

Wildlife data reported in mine permit applications and subsequent annual reports are in the process of being entered in a Microsoft Access (version 7) database. Only data available in applications and annual reports housed in the Cheyenne office of the Department of Environmental Quality, Land Quality Division are being considered.

The five mines chosen for Phase 1 of the project were Jacobs Ranch, Black Thunder, North Rochelle, Rochelle, and North Antelope. These mines were chosen in part because of their relative close proximity and because a cumulative hydrologic impact assessment (CHIA) is being conducted in this part of the Powder River basin. Coordination between this and other projects in the area is important because wildlife parameters measured in this study may be related to both mining activities and non-mining variables contained in other data bases such as topography, soil types, and precipitation.

The five mines under study collected five types of wildlife data during permit application and subsequent monitoring. These types are: (1) aerial surveys for large ungulates (primarily pronghorn, deer, and elk); (2) ground and aerial surveys for raptor nests; (3) ground surveys for large ungulates, (4) ground surveys for upland game birds (primarily sage grouse), and (5) ground surveys for lagomophs. Microsoft Access databases designed to hold the large ungulate aerial surveys, the raptor nest surveys, and the large undulate ground surveys have been completed. Databases designed to house the upland game bird data and lagomorph data are simple in nature and are currently being constructed. Approximately 200 hours ($\approx$1.25 months) of time has been spent on data entry. To date, all aerial surveys for large ungulates from the five mines have been entered. Approximately 30% of the raptor nest surveys and 1% of the ground surveys for large ungulates have been entered. We estimate that between 45%-50% of the total data entry task has been completed and that all data entry will be completed by the end of January 1998. Data quality assurance checks are being completed on all entered data.

Statistical Methods

We anticipate at least two basic types of statistical analyzes for most of the various survey data, the BACI analysis and trend analysis. BACI analyzes compare the number of animals seen in an "impacted" area with a "control" area both before and after mining permit approval or mining activity. Our use of this method will depend on the availability of a suitable control. Trend analyzes generally attempt to assess the statistical significance of upward or downward trends in time series of data. Many of the responses in the trend analyzes may need to be adjusted for other variables (or covariates) in our database. Relationships between covariates and the response of interest will be a useful by product of trend analyzes. Examples of this type of relationship include adjusting raptor nest production to account for differences in prey (i.e., lagomorph) abundance and adjusting certain large ungulates counts to account for differences in habitat type. In general, analyzes will be conducted for each mine separately and data will be pooled across mines when necessary or when similar patterns exist across mines. Hypothetical examples of these two general types of analyzes are presented next.

We offer the following as an example of a BACI analysis. We note that two areas are defined at each mine. One area consists of the acreage covered by the mine permit (the *permit* area) and the second area consists of a two mile buffer surrounding the permit area (the *boundary* area). A statistical test to assess the probability that observed differences between the areas before and after mining could have occurred by chance could be conducted. This statistical test compares differences between counts on the permit and boundary area by preforming a one-sided Wilcoxon two sample rank sum test (Hollander and Wolfe, 1973) on the differences. Samples are defined by whether or not the corresponding surveys were conducted pre- or post- mining activity. Time periods which are pre- and post-mining activity may or may not be the same as time periods pre- and post-mine permit approval. For this reason, we will attempt to determine the beginning date and evolution of mining activity for each mine for the final analysis. For our example, which is presented in Figure 1 and Figure 2, four aerial surveys with counts on both the boundary and permit areas are available before mining activity and ten surveys are available after mining activity. Our example is constructed for pronghorn and deer numbers. Figure 1 represents a situation where antelope numbers appear to be impacted by mining activity. Figure 2 represents a situation where deer numbers appear not to be impacted by mining activity.

As an example of a trend analysis, consider the time series of total number of pronghorn counted during aerial surveys at a mine. Trend analyzes may be useful in evaluating pronghorn counts over the life of the mine to date. In this analysis, a test for overall linear trend in total count is computed by fitting a linear component in the regression of total count on time. Deviations from the linear trend (i.e., the detrended time series) are investigated for residual auto-correlation by plotting auto-correlations at various time lags with 95% confidence intervals. If significant auto-correlations are found, statistical p-values for the trend are adjusted by modeling the variance as a function of time and refitting the trend model using weighted least squares techniques. Figure 3 presents a situation where pronghorn numbers appear to be increasing over the current life of the mine. Figure 4 presents the auto-correlations calculated from the detrended time series. No

adjustment of statistical p-values would be necessary in this case because no significant auto-correlations exist. Reasonable covariates which might explain the apparent increase in pronghorn numbers will be considered in the final analysis.

Issues Potentially Affecting Future Recommendations

One objective of our study is to make recommendations for future wildlife monitoring and reporting practices. The following issues encountered in the data entered thus far may effect our recommendations:

1. In some permit applications and annual reports, counts of wildlife seen during aerial surveys were not reported separately for the permit and boundary areas.
2. Occasionally, two mines in close proximity reported a single wildlife count for the combined mine area. Certain analyzes will need to treat this combined area as a single mine.
3. Estimation of animal density or an index to density (like number seen per flight hour) will be important for cross mine comparisons. Flight times and areas surveyed are sometimes difficult to pick out from past permit applications and annual reports.
4. Certain interesting statistical analyzes require physical locations of the animals or animal groups. When present, animal locations in permit applications and annual reports are plotted on hard-copy maps. Submission of electronic map files with wildlife reports would facilitate analysis of animal location and spatial distribution.

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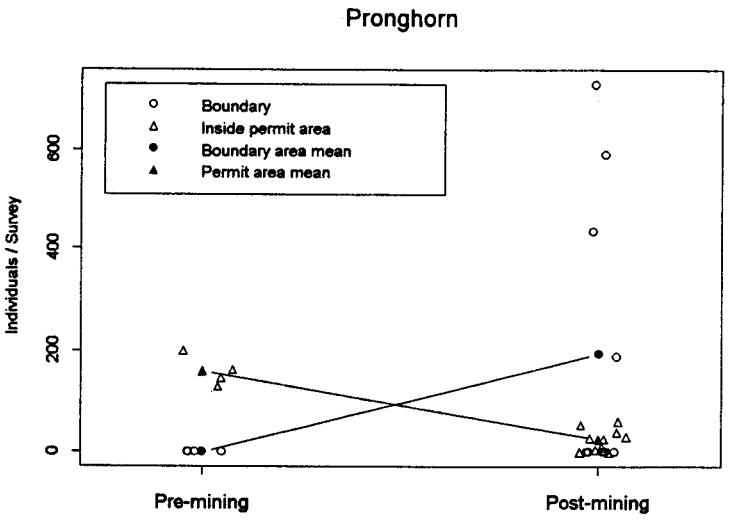

Figure 1: Example BAIC analysis of pronghorn numbers showing an apparent impact pre- and post-mining. Observed data are "jittered" to show overlapping values.

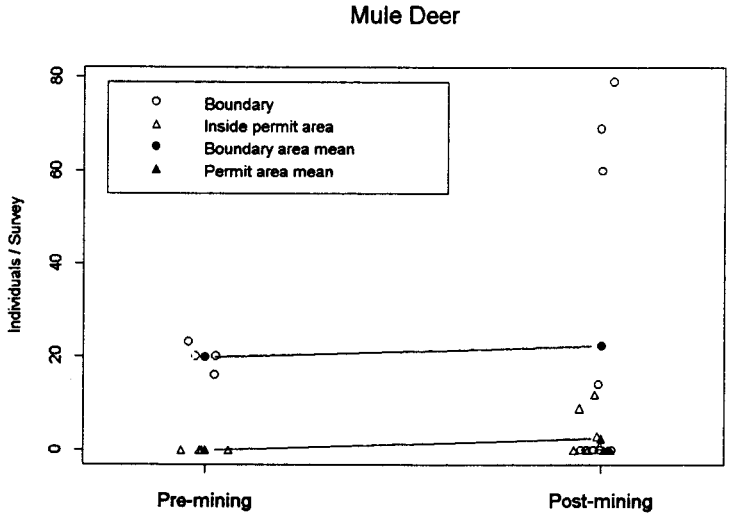

Figure 2: Example BAIC analysis of mule deer numbers showing no apparent impact pre- and post-mining. Observed data are "jittered" to show overlapping values.

CLIMATIC CONTROL OF SAGEBRUSH SURVIVAL FOR MINED LAND RECLAMATION

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University of Wyoming
Abandoned Coal Mine Land Research Program
Project Review Seminar
November 18, 1997 Gillette, WY

Climatic control of sagebrush survival for mined-land reclamation

Initial Progress Report

Principle Investigators:

B.L. Perryman, R.A. Olson, Ann L. Hild, and A.M. Maier

Introduction

Xerophytic shrubs such as big sagebrush (*Artemisia tridentata),* are a major component of rangelands throughout the western United States. Wyoming rangelands are no exception. Several species of shrubs are widely distributed across the state, and are often the dominant members of rangeland plant communities. Because of the almost ubiquitous presence of xerophytic shrubs and their importance to landuse strategies on Wyoming rangelands, regulatory agencies have legally mandated that shrubs be included in the reclaimed plant communities of disturbed mined-lands (Department of Environmental Quality, Land Quality Division: W.S. 35-11-112, Chapter IV, Appendix A, amended and approved by the Office of Surface Mining, August 1996). In most cases the dominant shrub species present in baseline plant communities is big sagebrush. For this reason, big sagebrush is often the primary shrub involved in reclamation efforts.

Although big sagebrush is well adapted to the region when mature, establishment from seed has proven difficult. Problems with establishment include: poor seed quality, low seedling vigor, failure to establish vesicular-arbuscular mycorrhizal (VAM) associations after disturbance, inability of cultural practices to meet microsite requirements, and the inability to compete with associated herbaceous vegetation. Even though establishment from seed has proven at best difficult, the fact remains that native, mature stands of big sagebrush occur on millions of hectares of surrounding undisturbed rangelands. Several researchers have indicated that the age class structure of big sagebrush stands is characterized by the existence of cohorts, and that there may be many years in between establishment of successful cohorts. That is to say cohorts are established in pulses. Since cohort establishment is episodic, there must be a control mechanism which is responsible for establishment and persistence success. A literature search suggests that climate, (specifically amount and timing of precipitation, and temperature range) is the major controlling factor.

Implications

Firstly, if a specific set of climatic conditions controlling cohort success can be elucidated, reclamation efforts such a cultural practices and the design of mirosites can be concentrated in areas that offer a greater chance for success. Acreage scheduled for shrub stands can be identified and targeted to mimic the required climatic

conditions, optimizing the use of resources by allowing reclamation specialists to focus their establishment efforts in a specific direction. Reclamation specialists will have a known, understood, and measurable target set of threshold climatic/microsite conditions.

Secondly, the project will demonstrate the frequency with which these precise climatic conditions occur. It is highly possible that optimum or threshold conditions may only occur a few times a century on any given site. If threshold conditions are infrequent, planting big sagebrush each year on large acreages may not be an efficient use of resources. Identification of the threshold climatic conditions may eventually lead to a method of predicting success based on extended weather forecasts.

Study Objective

The objective of the project is to quantitatively evaluate the relationship of native big sagebrush cohort success, and monthly precipitation and temperature variables. The project will be conducted over a two year period and include all three subspecies of big sagebrush (*Artemisia tridentata wyomingensis, A. tridentata vaseyana,* and *A. tridentata tridentata*). The results will be applicable throughout the coal mining regions of Wyoming.

Statement of Work

The major parts of the research are:

Task 1) Collect shrub stem sections for three subspecies of big sagebrush from a network of sites containing native sagebrush stands

Task 2) Determine cohort establishment years and age class frequencies utilizing dendrochronology techniques

Task 3) Collect climatic data from weather stations and convert to orthogonal predictor variables utilizing principal component analysis

Task 4) Relate cohort origin years to climatic data with the logistic regression model

Principle component analysis will provide orthogonal predictor variables that are combinations of monthly precipitation and temperature variables. These predictor variables (independent) will then be used in a logistic regression analysis utilizing categorical dependent variables such as "many seedling origin year" or "no seedling origin year". Several logistic regression models of different spatial scales will be generated for each subspecies. Principle component analysis will be performed on several combinations of precipitation and temperature variables including, monthly precipitation and mean monthly temperature, monthly precipitation and mean monthly high/low temperatures.

Work Completed to Date

Acceptable sample sites were identified during June 1997. Selection was based on location near (or triangulated between) National Weather Service climate recording stations (Figure 1), and on the presence of at least four different cohorts. The assessment of cohort presence was based on size class of sagebrush plants within a particular stand. A stratified-random sampling design using a baseline was employed to select individual plants for sampling. Approximately 80 stem sections were taken from nine stands of each subspecies during the summer and fall of 1997 (2,160 total stem sections). Stem sections were removed by cutting each plant below ground level to ensure that the first year growth ring was included in the sample. Field sampling is now complete unless growth-ring analyses indicate that follow-up sampling is necessary. Annual growth-ring counts have been initiated for Stand 1, ssp. *wyomingensis*. The age of approximately 40 individual plants has been determined.

Collection of climatic data has been completed (20 weather stations) and is held in both hard copy and electronic forms. This data has been appropriated from both the Wyoming Water Resources Center WRDS data base and the National Weather Service offices in Riverton and Cheyenne, WY. Many of the climatic series begin in the 1940s while several stations contain records back into the early 1900s. All of the selected stations contain monthly precipitation and monthly high/low temperature records. Table 1 displays the selected climatic stations.

Supplemental data including topography, aspect, shrub density, and soil texture were also collected for each stand.

Table 1. Climate Recording Stations

Subspecies: *tridentata*

1. Name/#: La Barge. #5252-3, Period of record 1958-present.
   Location/County: T26N, R112W, Sec. 6, Lincoln County, residence 543 S. Pine St within & 0.3 mi Sw of PO.

2. Name/#: Rairden 2WSW. #7473-4, Period of record 1951-present.
   Location/County: T49N, R92W, Sec. 32, Big Horn County, residence outside & 12 mi N of Worland PO.

3. Name/#: Tensleep 16 SSE. #8858-4, Period of record 1955-present.
   Location/County: T44N, R88W, Sec. 1, Washakie County, ranch outside & 16 mi SSE of PO at Tensleep.

4. Name/#: Worland. #9770-4, Period of record 1915-present.
   Location/County: T47N, R93W, Sec. 25, Washakie County, sugar plant 0.6 mi SW of Worland PO.

5. Name/#: Tensleep 4 NE. #8852-4, Period of record 1964-present.
   Location/County: T47N, R88W, Sec. 3, Washakie County, fish rearing station outside & 4 mi NE of Tensleep PO.

6. Name/#: Pinedale. #7260-3, Period of record 1906-present.
   Location/County: T34N, R109W, Sec.33, Sublette County, residence within and 0.2 mi NE of PO at Pinedale.

Subspecies: *vayseyana*

7. Name/#: Billy Creek. #0740-5, Period of record 1962-present.
   Location/County: T48N, R82W, Sec.17, Johnson County, Billy Cr. Gas Plant 15 mi S of Buffalo PO.

8. Name/#: Buffalo. #1165-5, Period of record 1943-present.
   Location/County: T51N, R82W, Sec. 35, Johnson County, Rays Liquor Store 0.1 mi N of Buffalo PO.

9. Name/#: Merna. #6165-3, Period of record 1963-present.
   Location/County: T35N, R113W, Sec. 32, Sublette County, ranch 16.4 mi WNW of Daniel PO.

10. Name/#: Pinedale. #7260-3, Period of record 1906-present.
    Location/County: T34N, R109W, Sec.33, Sublette County, residence within and 0.2 mi NE of PO at Pinedale.

11. Name/#: Kaycee. #5055-5, Period of record 1943-present.
    Location/County: T43N, R82W, Sec. 12, Johnson County, Wyo Hgwy. Dept. 0.3 mi NNE of Kaycee PO.

12. Name/#: Medicine Bow. #6120-10, Period of record 1881-present.
    Location/County: T22N, R78W, Sec. 8, Carbon County, Medicine Bow Police Station.

13. Name/#: Elk Mountain. #2995-10, Period of record 1948-present.
    Location/County: T20N, R80W, Sec. 20, Carbon County, behind Elk Mtn. Trading post at PO.

14. Name/#: Elk Mountain 9W. #2998-10, Period of record 1948-present.
    Location/County: T20N, R82W, Sec. 22, Carbon County, ranch 9 mi W of Elk Mountain PO.

Subspecies: *wyomingensis*

15. Name/#: Dull Center 1SE, #2725-7, Period of record 1948-present.
    Location/County: T40N, R67W, Sec.30, Converse County, at residence 30 mi NE of PO at Bill.

16. Name/#: Gillette 6SE, #3855-6, Period of record 1925-present.
    Location/County: T49N, R71W, Sec.17, Campbell County, outside residence 6 mi SE of PO at Gillette.

17. Name/#: Rochelle 3E, #7810-7, Period of record 1941-present.
    Location/County: T42N,R67W, Sec.21, Weston County, residence outside and 40 mi north of PO at Newcastle.

18. Name/#: Powder River 2 SW, #7376-5, Period of record 1964-present.
    Location/County: T35N, R85W, Sec .14, Natrona County, Boone Dome gas plant outside & 2 mi SW of Powder River PO.

19. Name/#: Casper WSO AP, #1570-8, Period of record 1901-present.
    Location/County: T34N, R80W, Sec.20, Natrona County, FSS/WSO Bldg at Casper airport outside and 8 mi WNW of Casper.

20. Name/#: Pinedale. #7260-3, Period of record 1906-present.
    Location/County: T34N, R109W, Sec.33, Sublette County, residence within and 0.2 mi NE of PO at Pinedale.

Figure 1. Climatic Stations and Sagebrush Stand Locations