Western Coordinating Committee on Revegetation and Stabilization of Deteriorated and Altered Lands

2005
Annual Research Reports

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CALIFORNIA

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INTRODUCTION

This report summarizes restoration research in the Department of Botany and Plant Sciences, the Department of Environmental Sciences, and the Center for Conservation Biology, University of California, Riverside; and the USDA Forest Fire Laboratory, Riverside. The research is/was funded by The National Science Foundation, the Environmental Protection Agency, the National Park Service, the Fish and Wildlife Service, and the University of California Integrated Pest Management Program. Experiments are being carried out primarily in parks and conservation reserves in vegetation types that are threatened by development. This includes coastal sage scrub vegetation, oak savannas, and Mojave Desert. These vegetation types are being lost to urbanization and contain many threatened, endangered, and sensitive plant and animal species, and are the subject of many restoration and mitigation studies.

COMPLETED PROJECT

1. Nitrogen Deposition Impacts on Coastal Sage Scrub and Mixed Coniferous Forest
(T. Meixner, E.B. Allen, UC Riverside; M.E. Fenn, USFS)

Up to 50 kg/ha/yr of N is deposited on the natural vegetation of California, primarily nitrate originating from automobile emissions. The impact of N deposition is different on different vegetation types, depending upon their rate of productivity, rate at which N accumulates or flushes through the system, and amount of N deposition. This study compared the impacts of N deposition on native plants and ecosystem dynamics in two major vegetation types, coastal sage scrub and mixed coniferous forest. A hydrologic approach was employed to determine the potential for N movement out of these systems. We hypothesized that CSS will retain N in the soils longer than forest, even if air pollution regulations were to mandate reduced N emissions. Thus the potential for restoration of N-impacted soils will be diminished in CSS, and this vegetation is currently experiencing high rates of invasion by exotic annual grasses coupled with a decrease in native shrub cover. In addition to changes in vegetation, the soil microorganisms are undergoing change, with losses in diversity and density of mycorrhizal fungi. N movement through soil horizons was slight during the dry 2002 season, but we observed N accumulation at 75 cm deep during 2001. We are currently assessing the impacts of N deposition on the vegetation diversity along a

rural to urban air pollution gradient in CSS. A Ph.D. dissertation was completed in December 2004, one manuscript is in press, and several manuscripts are submitted.

ONGOING PROJECTS

1. Exotic weed control at the Shipley Ranch Reserve (E.B. Allen, M.F. Allen, UC Riverside, and Douglas Deutschman, San Diego State University)

   The Shipley Ranch Reserve is a habitat mitigation reserve that was purchased by the MWD in return for the land being flooded at the Diamond Valley Lake Reservoir. It was historically grazed, but the cattle were removed in about 1990 and the vegetation has been recovering since. However, a large fire in 1993 burned much of the ranch, and native species recovery has been slow. A second fire burned through part of the reserve in November 2003, and has provided an opportunity for observation of restoration success post-fire. Large areas are dominated by exotic annual grasses that were once native shrub- and forbland. Our objectives were to reduce the grass cover to allow native species to recolonize. We used three methods, a grass specific herbicide, sheep grazing, and dethatching of grass litter to promote native species establishment. The sheep grazed 1 ha plots for 48 hours in spring 1999, 2000, and 2001. The herbicide Fusilade was applied to 1-ha plots during the 1999 and 2000 spring seasons. Dethatching was done during October-November 1999 prior to the winter rainy and spring growing season. The dethatching treatment allowed the recolonization of many annual plants, including many exotics. Both grazing and Fusilade/dethatching decreased the abundance of exotic annual grasses as hoped, but grazing also decreased the native forbs. However, during the spring, 2005 field survey we learned that the effects of both grazing and herbicide were persistent 5 years after the last application of the treatment. The post-fire data from the 2004 field season showed a reduction in exotic grass but an increase in exotic forbs.

2. Restoration of Habitat for the Endangered Quino Checkerspot Butterfly (E.B. Allen, UC Riverside)

   Abandoned farmland was purchased as part of the Western Riverside County Habitat Conservation Plan. This Plan includes some 130 sensitive, threatened and endangered species (plants, birds, herptiles, fish, insects). The farmland is destined to become habitat for some of these species, if it can be restored. A project funded by the US Fish and Wildlife Service was initiated in abandoned farmland in fall 2004 to restore habitat for the endangered Quino checkerspot butterfly, *Euphydryas editha quino*. The butterfly larvae feed almost exclusively on one plant species, *Plantago erecta*, while the adults use nectar from several shrubs of coastal sage scrub vegetation. The farmland is surrounded by remnants

of this vegetation, but the soil was treated with sewage sludge, making restoration challenging. The site was burned in July, 2004 to control grasses, but following an unusual October rain, was again covered with exotic annual grasses. The site was disked in November to control grasses again, and several additional weed control methods were applied. These included grass-specific herbicide (Fusilade), mowing, and seed bank solarization using plastic. The plots were seeded in January, 2005. The solarized plots had the lowest density of exotic grasses and forbs and the highest establishment of native species. The Fusilade treatment was second best. The mowing and herbicide treatments will be applied again this growing season, and a new set of solarized plots were initiated and seeded.

NEW PROJECT

1. Restoration of Mojave Desert vegetation invaded by exotic annual grasses and forbs (E.B. Allen, UC Riverside)

   Several species of exotic grasses (*Bromus rubens, Schismus barbatus*) and forbs (*Erodium cicutarium, Brassica tournefortii*) have invaded the Mojave Desert and are especially abundant in areas of high anthropogenic nitrogen deposition. Several treatments were applied to control the exotics and test response of the native vegetation. These include application of the grass-specific herbicide Fusilade, hand weeding of exotic forbs, and application of sugar to immobilize soil N. The latter treatment is done to reduce available soil N that appears to increase exotic species growth to the detriment of native species. Field and greenhouse studies are also underway to test the impacts of N fertilizer on native and exotic plant growth. The first year results (spring 2005) showed that herbicide is very effective in controlling the grasses and allowing native forb growth, and hand weeding of exotic forbs in addition to grass control increases native forbs even more. These plots will be followed for a second year, and include the sugar treatment which was applied this growing season.

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Wood, Y.A., T. Meixner, P.J. Shouse, and E.B. Allen. 2005. Altered ecohydrologic response drives native shrub loss under conditions of elevated N-deposition. Journal of Environmental Quality 35: in press.

DiTomaso, J.M., M. L. Brooks, E. B. Allen, R. Minnich, P. M. Rice, and G. B. Kyser. 2006. Control of invasive weeds with prescribed burning. Weed Technology, in press.

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Publication in press at last report, now published

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COLORADO

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INTRODUCTION

This report summarizes reclamation, restoration and related research projects at Colorado State University during 2003. Research was conducted by the Department of Forest, Rangeland and Watershed Stewardship, the Department of Soil and Crop Sciences, the Department of Biology, the Department of Microbiology, the Department of Horticulture and Landscape Architecture, and the Center for Environmental Management of Military Lands with funding from the Colorado Agricultural Experiment Station, USDA, EPA, U.S. Army, and the Colorado Department of Public Health and Environment.

COMPLETED PROJECTS

1. Shrub Establishment Techniques of Coal Mine Lands in Colorado (Edward Redente and Mark Paschke, Forest, Rangeland and Watershed Stewardship Department)

   This project began in September 2000 and was completed in 2005. The objective was to develop methods for the establishment of woody plants on coal mine disturbances in northwest Colorado. Three mines sites were included in the study and methods included strip seeding, transplanting, testing seed mixtures with relatively low-competitive grasses and forbs, soil depth, soil quality, and fencing to exclude deer and elk.

2. Erosion Control Master Plan for the Combat Maneuver Training Center, Hohenfels, Germany (Steven Warren and Mary Schuette, Center for Environmental Management of Military Lands)

This project began in February 2003 and was completed in June 2005. The project produced a GIS-based erosion control plan for the training area. The user simply clicked on an area of concern and the system displayed a list of all acceptable erosion and sediment control practices. After selecting a practice, the system displayed the most appropriate spatial placement of the practice.

3. Soil Erosion Survey for Lovell Local Training Area, Wyoming (Steve Warren and Tom Ruzycki, Center for Environmental Management of Military Lands)

   This project began in 2004 and was completed in January 2005. It applied a new generation, 3-dimensional erosion and deposition model at the training area to identify lands that were eroding excessively and were in need of remediative action.

ONGOING PROJECTS

1. Reclamation at the Summitville Superfund Site (Edward Redente and Mark Paschke, Forest, Rangeland and Watershed Stewardship Department)

   This project began in the fall of 1995 and involves a greenhouse phase and a field phase.The objective of the project is to test reclamation alternatives for stabilizing acid generating waste rock material at an elevation of 11,000 feet.

2. Metal Toxicity Thresholds for Important Reclamation Species in the Western U.S. (Edward Redente, Mark Paschke, and Ken Barbarick, Department of Forest, Rangeland and Watershed Stewardship and the Department of Soil and Crop Sciences).

   This project began in June 1999. The objective is to establish heavy metal toxicity thresholds for approximately 35 plant species that are commonly used in reclamation work in western North America. The project involves large greenhouse screening studies and will eventually establish toxicity thresholds for a variety of grasses, forbs and shrubs for As, Cd, Cu, Mn, Pb, and Zn.

3. Integrated Control and Assessment of Knapweed and Cheatgrass on Department of Defense Installations (Mark Paschke and Edward Redente, Department of Forest, Rangeland and Watershed Stewardship; Don Klein, Department of Microbiology; Steve Warren, Center for Environmental Management of Military Lands; Northern Plains Agricultural Research Laboratory—USDA-ARS in Sidney, MT; Department of Energy Remote Sensing Laboratory, Las Vegas, NV)

   This project began in April 2000 and will end in 2006. The objective is to develop a strategy for the control, monitoring, and prediction of knapweed and cheatgrass infestations at Fort Carson in Colorado and Yakima Training Center in Washington.

4. Turning the tide on invasive exotic weeds: Utilizing the chemical weapons of native plants to combat exotic weeds on abandoned coal mines (M.W. Paschke, E.F. Redente, J.M. Vivanco and L.G. Perry, Department of Forest, Rangeland and Watershed Stewardship and the Department of Horticulture and Landscape Architecture)

   The objective is to determine if native allelopathic plants could be used to displace exotic invasive species. If so, then allelopathic seed mixes could be an effective tool for controlling exotic weeds in western coal mines.

5. Integrated control of spotted knapweed: Utilizing spotted knapweed-resistant native plants to facilitate revegetation (M.W. Paschke, J.M. Vivanco, L.G. Perry and R.M. Callaway, Department of Forest, Rangeland and Watershed Stewardship and the Department of Horticulture and Landscape Architecture at CSU, and Division of Biological Sciences, University of Montana)

   The objectives are to determine if plants that excrete high concentrations of organic acids into the rhizosphere can be used to detoxify spotted knapweed soils and allow for the subsequent establishment of native vegetation and, to identify additional species that produce high concentrations of organic acids.

6. Development of tools to integrate restoration activities in the National Park Service (M.W. Paschke, Department of Forest, Rangeland and Watershed Stewardship)

   The objective of this project is to bring current academic input into the process of land resource management and restoration within the National Park Service. This project facilitates the Natural Resource Program Center of the NPS, and specifically the Restoration Technical Advisory Group, to meet their stated goals to: 1) coordinate and enhance communication on natural resource restoration issues within the NRPC, Regions, and Parks; 2) provide Service wide consistency with respect to restoration; and 3) promote scientifically sound restoration practices within the NPS.

7. Allelochemical control of non-indigenous invasive plant species affecting military testing and training activities (J.M. Vivanco, M.W. Paschke, and R.M. Callaway, Department of Horticulture and Landscape Architecture and the Department of Forest, Rangeland and Watershed Stewardship at CSU, and Division of Biological Sciences, University of Montana)

   The objective of this project is to utilize the chemical properties of allelopathic invasive weeds as an economical and safe way to control other exotic species, and in the process understand the invasive properties of these weeds in order to control their spread on military sites.

8. The effect of long-term composted biosolids and biosolids-alum water treatment residuals reapplications on native rangeland soils and vegetation (J.A. Ippolito, M.W. Paschke and K.A. Barbarick, Department of Forest, Rangeland and Watershed Stewardship and the Department of Soil and Crop Sciences)

   The goal of this project is to understand both the long-lasting environmental effects of a single composted biosolids application, a single biosolids-water treatment residual co-application, and the short-term impacts of a repeated application on soils and plant community dynamics in a rangeland ecosystem.

9. Cheatgrass control and community restoration in Rocky Mountain National Park (C.S. Brown and M.W. Paschke, Department of Bioagricultural Sciences and Pest Management and the Department of Forest, Rangeland and Watershed Stewardship)

   The objective of this project is to test strategies for selecting species for revegetation and restoration of cheatgrass (*Bromus tectorum*) infested sites after chemical control of the weed. In particular, we are investigating whether the facilitation, tolerance, or inhibition model of succession is supported by performance of seeded species mixtures that have been selected based on their roles in natural successional processes.

10. Integrated Management of *Centaurea maculosa* (Spotted Knapweed) in the Western United States while using its chemical weapons as ecologically benign herbicides (J.M. Vivanco, M.W. Paschke and S. Nissen, Department of Horticulture and Landscape Archtecture, Department of Forest, Rangeland and Watershed Stewardship, and the Department of Bioagricultural Sciences and Pest Management)

    The objectives of this project are to identify native plants, suitable for revegetation, that are resistant to residual (-)-catechin present in the soil of reclaimed *C. maculosa* invaded sites and, to explore how various methods used to control *C. maculosa* impact the amount of (-)-catechin released into the soil.

11. Effects of Fire on Biological Soil Crusts and Their Subsequent Recovery (Steven Warren, Center for Environmental Management of Military Lands, CSU; Paul Kugrens, Biology Department, CSU; Larry St.Clair, Brigham Young University)

    This project which began in 2004 year, will examine the effects of a prescribed burn in the pinyon-juniper ecosystem on the biological soil crusts over a period of 2-3 years. We will examine biological soil crust biomass and species composition, nitrogen fixation and soil stability.

12. Use of Radioisotopes to Validate Three Erosion Models at the Combat Maneuver Training Center, Hohenfels, Germany (Steven Warren, Center for Environmental Management of Military Lands)

This project began in 2005. Soil cores have been collected from an uneroded area to develop a reference profile of ^{210}Pb isotopes in the soil. Soil samples from a disturbed area will be compared with the reference profile to determine soil erosion and sediment deposition. These measurements will then be compared with estimates produced by various soil erosion/sediment deposition models to determine which is most appropriate for the area.

13. Cyanobacterial Inoculation for Soil Stabilization at the Yucca Mountain Nuclear Repository (Steven Warren, Center for Environmental Management of Military Lands and Paul Kugrens, Department of Biology)

This project began in 2003. Cyanobacteria were collected at a nearby undisturbed area and propagated in the laboratory. Live cyanobacteria were immobilized in clay pellets and applied to the disturbed area. The hypothesis was that the pellets would be dissolved by incident rainfall and the live, but immobile, cyanobacteria would be transported into the soil pores where they would become established and help stabilize the soil.

PLANNED OR POTENTIAL PROJECTS

1. Long-term Effects of Biosolid Application on a Molybdenum Tailings. The project will examine plant growth, soil chemical characteristics, soil microbial characteristics, plant uptake of heavy metals, and potential impact of forage from the tailings on ruminant digestion.

2. Restoration of Biological Soil Crusts Following Fire. This project will investigate new technologies to restore naturally occurring biological soil crusts following fire in the sagebrush steppe.

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Ippolito, J. A., E. F. Redente, and K.A. Barbarick. 2005. Amendment effects on pH and salt content of bauxite residue. Soil Science 170:832-841.

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Paschke, M.W., K. Topper, R.B. Brobst and E.F. Redente. 2005. Long-term effects of biosolids on revegetation of disturbed sagebrush steppe in Northwestern Colorado. Restoration Ecology 13:545-551.

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IDAHO

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INTRODUCTION

This report summarizes revegetation and restoration research conducted at the USDA-ARS Northwest Watershed Research Center in Boise, Idaho for 2005. The focus of the NWRC revegetation/disturbed land program is to characterize establishment requirements of native grass and shrub species; evaluate impacts of wild and prescribed fire on vegetation, invasive weeds, soil erosion, streamflow and water quality; and to optimize restoration strategies for disturbed rangeland in the Great Basin region of the western United States.

ONGOING PROJECTS

1. Prescribed-Fire Research at the Reynolds Creek Experimental Watershed in Southwestern Idaho (Stuart Hardegree, Fred Pierson, Pat Clark, Gerald Flerchinger, Mark Seyfried)

   The Northwest Watershed Research Center initiated a landscape-scale, prescribed-fire research program in 2001 at the Reynolds Creek Experimental Watershed (RCEW) in southwestern Idaho. This program is a cooperative effort with the private-land owners at RCEW, the Bureau of Land Management, Lower Snake River District and Owyhee Field Office, Idaho Department of Lands, and other ARS research locations in the sagebrush-steppe vegetation type. The objectives of this research program are to assess prescribed-fire impacts on vegetation, soil, and water resources, post-fire grazing management, weed response, and the efficacy of fire treatments for fuels management and juniper control. The second prescribed fire in this program was conducted in September 2004 at the Whiskey Hill research site in RCEW. NWRC continues to monitor vegetation recovery, hydrologic impacts and grazing animal behavior at both Whiskey Hill and the Breaks sites (burned in 2002). The Upper Sheep research site at RCEW will be burned in 2007 and will include more detailed pre and post-fire analysis of hydrology and runoff as it is a discrete watershed.

2. Hydrologic Impacts of Western Juniper (Stuart Hardegree, Fred Pierson, Pat Clark, Gerald Flerchinger, Mark Seyfried, Danny Marks, Tony Svejcar, Jon Bates)

Wildfire played an important role in the control of western juniper in the western United States prior to European settlement. NWRC continues to cooperate with the Eastern Oregon Agricultural Research Center in Burns, Oregon, and the Bureau of Land Management, Lower Snake District, to establish a series of 8 watershed-research locations in southern Idaho and eastern Oregon to study the hydrologic impacts of juniper. In 2005, NWRC completed the construction of two weir structures and three complete meteorological stations in the South Mountain area of Owyhee County, Idaho. NWRC expects to complete instrumentation two additional watersheds by September, 2006. The basic experimental design will be to monitor meteorological inputs, runoff and water quality in each watershed (~150 acres). These watersheds will be monitored for vegetation attributes, infiltration, erosion, streamflow, snow distribution, grazing animal behavior and forage utilization for an initial calibration period of 5-8 years. After a period of watershed calibration, half of the watersheds will undergo mechanical eradication of juniper. All watersheds will be monitored for an additional 8-10 year period, at which time, juniper eradication will take place on the second set of field sites. Subsequent control of juniper on these watersheds will be maintained by use of prescribed fire. NWRC welcomes collaboration with other research programs and projects that could benefit from our long-term infrastructure at these sites.

3. Risk Assessment of Fuel Management Practices on Hillslope Erosion (Fred Pierson, Pete Robichaud, Ken Spaeth, Corey Moffet)

NWRC continues to cooperate with the Forest Service, Rocky Mountain Research Station in Moscow, Idaho to develop a web-based erosion risk management tool (ERMiT) for natural resource managers to use following wildfires, prescribed fires and areas treated with different fuel management practices. In 2005, rainfall simulation and rill erosion studies were conducted in wild and prescribed fire sites in Idaho and Montana. Field experiments were conducted in Montana and Colorado to test the efficiency of post-fire mitigation practices such as contour-felled logs, straw wattles, hand trenches, straw mulch, contour raking, and wood mulch for controlling soil erosion.

4. Cooperative Model Development and Enhancements at NWRC: Rangeland Hydrology and Erosion Model (RHEM) (Fred Pierson, Ken Spaeth, Corey Moffet)

The enhancement of the SPUR/WEPP (Simulation, Production, and Utilization of Rangeland and Water Erosion Prediction Project) model has been a cooperative project between ARS and NRCS since 1995. The objective of this effort has been to take advantage of the complementary strengths of both SPUR and WEPP by integrating the two models into a more functional rangeland ecosystem model responsive to the needs of resource managers. In 2005, a broader cooperative effort was initiated between the NWRC and ARS, Tucson, NRCS Grazinglands

Team, Forest Service, Rocky Mountain Research Station and the Bureau of Land Management to develop a Rangeland Hydrology and Erosion Model (RHEM) based on SPUR and WEPP technologies. Potential applications of RHEM include: evaluating the impacts of land management practices (grazing, fire, range improvements practices); developing hydrologic information for Ecological Site Descriptions; assisting in conservation planning, and evaluating the outcome and benefits of conservation practices.

5. Thermal-germination model development for predicting germination response to temperature (Stuart Hardegree)

The Northwest Watershed Research Center has previously reported on development of predictive models for estimating cumulative seed germination response to temperature and water stress. Typically, these models are used to generate coefficients that are used to screen germplasm or rank relative potential performance of seedlots. NWRC uses these models to predict field performance and is, therefore, more interested in predicting germination time rather than just germination rate. In 2005, NWRC tested 8 thermal germination models to evaluate relative performance in predicting germination time under field-variable temperature tests. The 8 models were a 4 cardinal temperature models with different shape assumptions regarding base temperature and the distribution of thermal time across subpopulations; 2- and 3-dimensional regression estimation of germination rate, and 2 geostatistical methods that do not have any inherent shape assumptions regarding model shape. In general, all models fit relatively well in predicting germination response to constant temperature, except for the cardinal temperature models which exhibited relatively large predictive errors at low temperatures. The geostatistical model did not yield model coefficients that were useful for comparing seedlots, however, it produced the most accurate estimates of germination time and was the most efficient to implement. NWRC uses these predictive models to assess relative seedlot performance under alternative field regimes, thus producing data for ecological comparisons of germination syndrome. The cardinal-temperature models yielded coefficients that could be linked to physiological processes, but did not perform as well in predicting germination time under all thermal conditions.

6. Influence of rangeland vegetation on soil water movement to deep drainage. (Mark Seyfried)

The NWRC is exploring how different rangeland vegetation impact the amount and timing of water movement through the soil profile resulting in deep drainage (downward movement of water through the bottom of the root zone). The amount and spatial distribution of deep drainage and groundwater recharge affect water supply and quality in the rapidly growing, semiarid USA. We synthesized research from the fields of ecology and hydrology to address the issue of deep drainage in semiarid regions. We started with a recently developed hydrological model that accurately simulates soil-water potential and geochemical profiles

measured in thick (>50 m), unconsolidated vadose zones. Model results indicated that, since the climate change that marked the onset of the Holocene period 10 to 15,000 years ago, there has been no deep drainage and that continuous, relatively low (< -1 MPa) soil-water potentials have been maintained at depths of 2–3 m. The scenario derived from these results proposes that the native, xeric shrub dominated plant communities that gained dominance during the Holocene, generated and maintained these conditions. We presented three lines of ecological evidence that support the scenario. First, that xeric shrubs have sufficiently deep rooting systems with low extraction limits to generate the modeled conditions. Second, the characteristic deep-rooted soil-plant systems store sufficient water to be effectively buffered against climatic fluctuations. And third, adaptations resulting in deep, low extraction limit rooting systems confer significant advantages to xeric shrubs in semiarid environments. We then considered conditions in semiarid regions in which the model scenario may not apply, leading to the expectation that portions of many semiarid watersheds supply some deep drainage. Further ecohydrologic research is required to elucidate critical climatic and edaphic thresholds, evaluate the role of important physiological processes (such as hydraulic redistribution), and evaluate the role of deep roots in terms of carbon costs and whole plant development.

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IDAHO

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INTRODUCTION

This report summarizes revegetation and restoration research conducted by members of the USDA Forest Service, Rocky Mountain Research Station, Shrubland Biology and Restoration Research Work Unit stationed in Boise, Idaho and their cooperators during calendar year 2005. Most research is encompassed within the collaborative Great Basin Native Plant Selection and Increase Project (GBNPSIP). This effort emphasizes development of native plant materials for the Great Basin and the technology required for their use. Additional research examined the ecology and fire response of rush skeletonweed (*Chondrilla juncea*) on the lower Snake River Plain. Research was partially funded by the USDI-BLM Great Basin Restoration Initiative (GBRI) and Native Plant Initiative, the National Fire Plan, and the Joint Fire Sciences Program.

COMPLETED PROJECTS

1. Revegetation Equipment Catalog (Harold Wiedemann, Texas A&M [retired], College Station, TX; Nancy Shaw, USDA-FS-RMRS, Boise, ID; Mike Pellant, USDI-BLM-GBRI, Boise, ID; and Stephen B. Monsen, USDA-FS-RMRS [retired], Provo, UT)

   A catalog (www.reveg-catalog.tamu.edu) listing equipment designed or adapted for range and wildlife habitat improvement and disturbed land rehabilitation in the western United States was compiled with support from the GBNPSIP and the GBRI. The catalog contains 15 chapters describing major categories of revegetation equipment, uses and features of individual equipment items, photos, and contact information for vendors, including websites. Texas A&M University is maintaining the website; H. Wiedemann is updating and checking the catalog quarterly. Users include researchers, practitioners, and students. The website received 41,000 visitors (average visit about 6 minutes) in 2005; 82% of these were from the United States and Canada.

2. Factors affecting rush skeletonweed (*Chondrilla juncea*) expansion on the Snake River Plain (Lynn Kinter, University of Wyoming/USDA FS RMRS, Boise, ID;

Nancy L. Shaw, USDA FS RMRS, Boise, ID; and Ann L. Hild, University of Wyoming, Laramie, WY)

Publications reporting post-fire spread from seed and effects of origin, harvest date and incubation temperature on seed germination have been drafted. An additional paper on post-fire demographics and a summary General Technical Report on all research including a survey of community invasibility by rush skeletonweed will be completed in 2006.

Seed germination: Seeds were harvested at three sites on Idaho's Snake River Plain. At constant incubation temperatures from 6 to 30°C, germination ranged from 50 to 59% of filled seeds, and at 34°C germination declined to 42%. Germination rate was greatest for seeds incubated at 18 to 26°C, with 50% germination occurring in less than 1.3 days. Over the fruiting period of July to October 2003, germination was greatest in late September, while germination rate was greatest on both the early and late September collection dates. Total germination exhibited a strong positive correlation with seed weight ($p < 0.0001$; $R^2 = 0.71$). Seed weight was negatively correlated with mean daily temperature for the 2-week period preceding seed collection ($p < 0.0001$; $R2 = 0.65$), and not correlated to total precipitation for the 1 to 4 weeks preceding seed collection. Among the three seed collection sites, large differences were found in germination, but not in germination rate. Seeds from all sites germinated readily following dry afterripening period and displayed no secondary dormancy.

Post-fire seed ecology: We examined the effects of wildfires and environmental conditions on the ability of rush skeletonweed, a perennial Eurasian composite, to invade degraded sagebrush steppe communities, largely dominated by cheatgrass (*Bromus tectorum*). Recruitment of rush skeletonweed from seed and root buds was investigated on 11 burned and unburned plot pairs established following summer 2003 wildfires. Laboratory emergence from fall 2003 seed banks (55.6 m^{-2}) was lower than emergence from fall 2004 seed banks (140.1 m^{-2}) ($p = 0.0012$); emergence did not differ between burned and unburned plots in either year ($p = 0.3711$). In 2003, laboratory emergence of viable sown seed was greater from burned than from unburned field soils ($p = 0.0543$). This effect was lost by 2004 ($p = 0.6296$). Laboratory emergence of sown seed was nearly tripled when planted in sterilized (25%) compared to unsterilized (9%) soils in 2004 ($p < 0.0001$), indicating seed loss to soil biota. Seeds from bags buried in the field in late October 2003 reached peak germination of about 31% by mid-January 2004, and remained only 1% germinable by August 2004. Of 2,800 seeds field sown in late October 2003, only four seedlings emerged by August 2004. Between fall 2003 and spring 2005 we excavated 1,627 rosettes in the field; most (93.2%) developed from root buds and the remainder (6.8%) from seed. Nearly all of the seedlings (108 of 112) germinated in spring 2005; about two-thirds of these emerged on burned plots. Results indicate that seedling establishment of rush skeletonweed on the Snake River Plain may be episodic, but provides for long-distance dispersal. Stand development may result primarily from root sprouting.

ONGOING PROJECTS

1. Great Basin Native Plant Selection and Increase Project (Nancy Shaw, USDA FS RMRS [Team Leader] and Mike Pellant, USDI BLM Great Basin Restoration Initiative Coordinator, Boise, ID)

   The use of native plants for rehabilitation after wildfires and restoration of disturbed wildlands is encouraged by various BLM programs, initiatives, and policies. The Great Basin Native Plant Selection and Increase Project, funded by the BLM through the FS Rocky Mountain Research Station covers selection of native plant materials, culture, seed increase, and use on degraded rangelands. Priorities are: 1) increase of native plant materials available for restoration; 2) management of shrub seed sources in wildland stands and technology to improve the diversity of introduced grass monocultures; 3) technology transfer; and 4) genetic research.

   Collaborators include the USDI Bureau of Land Management, Great Basin Restoration Initiative, Boise, ID; USDA Forest Service, Shrub Sciences Laboratory, Provo, UT and Boise, ID; Utah Division of Wildlife Resources, Great Basin Research Center, Ephraim, UT; USDA Agricultural Research Service, Forage and Range Research Laboratory, Logan, UT;
   USDA Agricultural Research Service, Bee Biology and Systematics Laboratory, Logan, UT; Utah Crop Improvement Association, Logan, UT; Association of Official Seed Certifying Agencies, Moline, IL; USDA Natural Resources Conservation Service, Idaho, Utah, Nevada and the Aberdeen Plant Materials Center, Aberdeen, ID; Brigham Young University, Provo, UT; USDA Forest Service, National Seed Laboratory, Dry Branch, GA; Colorado State University Cooperative Extension, Tri-River Area, Grand Junction, CO; USDA Agricultural Research Service, Western Regional Plant Introduction Station, Pullman, WA; Oregon State University, Malheur Experiment Station, Ontario, OR

2. Germination ecology of Great Basin *Penstemon* species (Nancy Shaw and Ann DeBolt, USDA FS RMRS, Boise, ID)

   We are examining intraspecific variability and developing seed production practices and seeding technology for three penstemons of the northern Great Basin. Sand penstemon (*Penstemon acuminatus*), hotrock penstemon (*P. deustus*), and sagebrush penstemon (*P. speciosus*) occupy different habitats and may be valuable for use in postfire seedings, mixed plantings, roadway revegetation, and low water use landscaping. In 2005 data (morphology, phenology, seed production and growth) were collected from three irrigated and two dryland common gardens of these species.

3. Seed Sources and Cultural practices for *Lomatium grayi*, *L. dissectum*, and *L. triternatum* (Nancy Shaw and Ann Debolt, USDA FS RMRS, Boise, ID)

Seed supplies of *Lomatium* species are currently not available for use on Great Basin rangelands. Production of seed fields will require development of appropriate cultural practices including seeding techniques, irrigation requirements, and control of weeds, diseases, and seed predators. Irrigated seed fields were established in 2004; plant growth, survival and seed production data collection will continue through 2007. Two nonirrigated common gardens of *L. dissectum* are being established in 2006 for examination of intraspecific variability. Morphological and phenological data will be collected through 2008.

4. Seed germination of *Lomatium dissectum* (Melissa Scholten, USDA FS RMRS, Boise, ID; Marcelo Serpe, Boise State University, Boise, ID; Nancy Shaw, USDA FS RMRS, Boise, ID)

Lomatium dissectum (fernleaf biscuit root) is a perennial, herbaceous plant found in semiarid habitats of the Western United States. This species produces seeds that are initially dormant. We have investigated the anatomical characteristics of the dormant seeds and the effect of various environmental conditions on breaking dormancy. Dormant seeds have underdeveloped embryos that are completely surrounded by the endosperm. In an attempt to promote embryo growth and break dormancy, we exposed the seeds to dry-after ripening, warm-moist conditions, and cold stratification. Warm moist conditions or a combination of dry after-ripening followed by warm-moist conditions did not induce embryo growth. In contrast, cold stratification promoted embryo growth. During 12 weeks of cold stratification the embryo grew from 1 to 7 mm; approximately the full size of the embryo. Most embryo growth occurred during the first 6 weeks of stratification. Cold stratification also promoted germination. However, after 12 weeks of cold stratification germination was only 20%. We are currently investigating the effect of longer stratification periods on breaking dormancy. Taken together, the presence of underdeveloped embryos in dormant seeds and the requirement for cold stratification indicates that *L. dissectum* seeds have morphophysiological dormancy. Furthermore, the release from dormancy appears to require long periods of stratification. This characteristic may lead to the formation of a persistent seed bank.

5. Cooperative Native Seed Increase Program **(**Ann DeBolt, USDA FS RMRS, Boise, ID; Chet Borup, Association of Official Seed Certifying Agencies, Moline, IL; Stanford Young, Utah Crop Improvement Association; and Foundation Seed Programs in Washington, Oregon, Nevada, Idaho, and Utah)

This Program was established as a cooperative, multi-state approach for increasing seed supplies of a greater variety of native forb species for Great Basin restoration. It will also contribute to a database of cultural practices, problems, and research needs in the areas of seed or seeding technology and seed production practices for individual species. Personnel from the USDI BLM and the USDA FS Rocky Mountain Research Station, Shrubland Biology and Restoration Project collaborate in identifying forb species and populations required for imminent

restoration projects. Harvested seed (Source-Identified and tested for germination and purity) is provided to participating private seed growers through State Foundation Seed Projects. First-year harvest is purchased by the State Foundation Seed Projects for distribution to additional growers. Growing records that identify successful cultural practices and problems are also forwarded to the Foundation Seed Project and to the Rocky Mountain Research Station contact. As of February 21, 2006, sixteen seed lots had been distributed representing 12 different species (11 forbs, 1 grass). No seed has yet been purchased, though at least two lots could be produced this season. Several additional non-dormant seed lots will be distributed in spring 2006. Key research species will be added to the program in fall 2006.

Six forb species have had some seed harvested through the Utah Crop Improvement Association (UCIA) program. Three grasses in the UCIA program (two bluebunch wheatgrass accessions and one Sandberg bluegrass accession) have had seed harvested for use in restoration projects and are currently planted in seed increase fields. Sand Hollow bottlebrush squirreltail grass and a Thurber needlegrass accession from Mountain Home, Idaho are currently planted in seed increase fields, with some harvest expected in summer 2006.

6. Development of Seed Sources of Sulfur-flower Buckwheat (*Eriogonum umbellatum*) for the Great Basin (Nancy Shaw and Ann DeBolt, USDA FS RMRS, Boise, ID)

Sulfur-flower buckwheat is a widespread forb of the Great Basin with considerable potential for use in restoration. Thirty-eight collections have been made from the Great Basin in 2003 through 2005. Common garden studies will be established at the USDA FS Lucky Peak Nursery and Orchard Research site in spring 2006 for examination of intraspecific variability. Data (plant survival and growth, morphological characteristics, and phonological data) will be collected through 2008.

PLANNED OR POTENTIAL PROJECTS

1. Competitive Dynamics Among Crested Wheatgrass and Native Grasses and Forbs (Marshall Haferkamp and Jennifer Muscha, USDA ARS Fort Keogh LARRL, Miles City, MT and Nancy Shaw, USDA FS RMRS, Boise, ID)

A greenhouse study is being conducted to examine the competitive interactions among mature plants of crested wheatgrass (*Agropyron cristatum*), bottlebrush squirreltail (*Elymus elymoides* var. *elymoides*), western yarrow (*Achillea millefolium*), and sagebrush penstemon (*Penstemon speciosus*) at selected densities.

2. A Comparison of Techniques for Seeding Mixtures of Native Species (Mike Pellant, USDI BLM Great Basin Restoration Initiative, Boise, ID, Nancy Shaw, USDA FS RMRS, Boise, ID and cooperators)

Reestablishing native communities requires equipment capable of handling seeds with differing sizes, shapes, and microsite requirements for germination and establishment. Recent modifications of the rangeland drill have increased its flexibility. Newer drills such as the Truax were designed to address these issues and handle the challenges of rangeland terrain. To date, studies comparing the relative merits of the standard rangeland drill and newer seeding equipment have not been conducted. Our research will be conducted on recent burns in the northern Great Basin. The seeding mix will include large and small seeded native forbs and grasses, similar to the mix being used for crested wheatgrass diversification studies being conducted by our cooperators.

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INTRODUCTION

This report summarizes revegetation and restoration research conducted in 2005 by the Reclamation Research Unit at Montana State University.

COMPLETED PROJECTS

1. Bond Release Vegetation Criteria (Dennis Neuman and Pam Blicker, Reclamation Research Unit, Montana State University and Ken Aho and Tad Weaver, Department of Ecology, Montana State University).

   Since the passage of the Surface Mining Control and Reclamation Act (SMCRA) in 1977, vegetation data have been collected by mine operators to describe pre-mining vegetation and establish baseline data from which vegetation reference areas can be derived. These vegetation reference areas are intended to serve as a standard for comparisons to revegetated areas on reclaimed coal mines to evaluate the success of reclamation for bond release. To date, the reference area data and pre-mine data have not been synthesized in a manner to facilitate statistical equivalency, derivation of revegetation standards, or facilitate appropriate categorization of reference areas and data in relation to some revegetation and postmine land use requirements. Data quality objectives and a quality assurance/quality control system were designed to screen data for inclusion in the database. A relational database has been designed and tested with representative data sets. Multivariate statistics were used to classify vegetation communities at three mine sites and these plant communities were characterized. A final operational database and user manual were written.

2. Characterization of the Floodplains of Sections of Warm Springs Creek, Anaconda Superfund Site (Dennis Neuman, Stuart Jennings, John Goering, and Pam Blicker, Reclamation Research Unit, Montana State University)

   As part of remedial design for a severely contaminated floodplain, the chemical characteristics and stability of the streambanks were assessed. Field and laboratory data were generated and a Final Design Report was prepared and

submitted to US EPA.

3. Assessment of Effects of Amendments on Vegetation Performance at a Bentonite Minesite (Dennis Neuman, John Goering, and Pam Blicker, Reclamation Research Unit, Montana State University).

A total of 135 experimental plots [15 treatments with 3 fertilized rates nested within each treatment and replicated three times] were implemented on bentonite spoils in the 1980s by staff of the Reclamation Research Unit at Montana State University. Treatments varied from physical manipulations to additions of chemical and biological amendments. The plots were seeded with mixes of plant species. Effects of these amendments and treatments on spoil chemistry and vegetation were documented in several early RRU reports. In April, 2005, a reconnaissance team from the Reclamation Research Unit conducted a qualitative assessment of the vegetation status of the experimental reclamation plots. The purpose of this assessment was to determine which of the treatments support the "best" vegetation. Based on this assessment, soils and vegetation from these "best" plots were then evaluated in July. These treatments were as follows: 1) Treatment #7 – Manure at 112 Mg/ha + H_2SO_4 at 20 Mg/ha: 2) Treatment #9 – Gypsum at 6.7 Mg/ha + $CaCl_2$ at 17.2 Mg/ha; and 3) $MgCl_2$ Brine. Quantitative evaluation of the vegetation growing on these experimental plots in 2005 revealed the following:

1. The mean vegetation cover values for each treatment, across all replications, were not significantly different among the three chosen treatments. Mean canopy cover values were 21.1% for spoils treated with gypsum and $CaCl_2$, 24.4% for spoils treated with H_2SO_4 and manure, and 27.3% for spoils amended with a brine of $MgCl_2$. These cover values were markedly lower than those measured in previous years. In 1987 and 1989, the mean percent canopy cover of vegetation growing on the $MgCl_2$ brine treated plots was 39.3% and 46.0%, respectively (Dollhopf et al. 1990). These cover values are greater than the mean value of 27.3% found in 2005. In 1986, mean vegetation cover values measured on the spoils treated with gypsum/$CaCl_2$ and those treated with H_2SO_4 and manure were 54.0 and 77.6%,
2. Community composition did vary significantly ($P < 0.05$) among the treatments. Perennial grasses, specifically Alkali sacaton (*Sporobolus airoides),* dominated the vegetation community growing on the spoils treated with $MgCl_2$ brine (Image 2). Perennial forbs, chiefly Prostrate summercypress *(Kochia prostrata)* accounted for the majority of the vegetation growing on the materials initially treated with H_2SO_4 and manure.
3. Few of the seeded species were found growing on the experimental plots. Many other species have colonized the plots, but they contributed little to vegetation cover or biomass.

4. Mean Aboveground biomass varied from 494 g/m^2 for plant of the acid/manure plots to 968 g/m^2 for vegetation on the plots treated with $CaCl_2$ and gypsum. Like vegetation cover, the composition of plants contributing to aboveground biomass varied among the three treatments.
5. Level of soil pH across all treatment and depths were very similar with a range of 6.78 to 8.04.
6. The electrical conductivity (EC) of spoil (top 20 cm) treated with H_2SO_4 and manure was markedly reduced compared to either the control samples or the soils collected from the other treated plots. Correspondingly, the soluble concentrations of calcium, magnesium, and sodium as well as the sodium absorption ratios of the top 20 cm of the acid/manure treated spoils are less than all other samples.
7. The EC and SAR values for the $MgCl_2$ brine-treated spoils have not changed since they were last measured in 1989 (Dollhopf et al. 1990).
8. In 1980, the SAR levels of spoils treated with $CaCl_2$ and gypsum ranged from 16.8 to 47.7 (Dollhopf et al. 1988). Slightly lower SAR levels were found in 2005.
9. The manure incorporated into this treatment (H_2SO_4 and manure) was clearly visible in the soils profile. However, much of the manure had not decomposed since it was added to the spoils 25 years ago. Roots were abundant to a depth of 45 cm.
10. The depth of the amended zone (gypsum and $CaCl_{2)}$ was clearly defined at 45 cm, and copious roots were found in the soil profile to this depth. The amended zone was visible to a depth of approximately 56 cm. Roots were abundant to 20 cm with fewer observed below this depth in the profile.

ONGOING PROJECTS

1. East Helena Smelter Superfund Site (Dennis Neuman, Reclamation Research Unit, Montana State University).

   Reclamation Research Unit scientists continue to advise the U.S. Environmental Protection Agency on issues dealing with land reclamation, agricultural land use, ecological risks, and urbanization at this Montana Superfund Site. A summer field tour of impacted lands surrounding the smelter is conducted. The RRU scientists have conducted research and acted as reclamation policy advisors to the EPA for nearly twenty years. Preparations fro completing EPA's Proposed Plan for remediation of this Superfund Site were initiated in 2005.

2. Ash Disposal Pond Revegetation (Frank Munshower and John Goering, Reclamation Research Unit, Montana State University)

   This is a long-term investigation of the potential to revegetate the surface of the coal ash disposal ponds near Colstrip, MT. Permanent reclamation of the ponds is the ultimate goal of this study. Initial objectives were to determine 1) how much

soil is necessary over the ash to permit establishment of a permanent vegetation cover; 2) if a diffusion barrier is necessary to seal the ash from the soil and prevent movement of salts into the soil; 3) if topsoil is necessary over the soil layer to provide an adequate plant growth medium; and 4) to determine what plant species should be seeded on the site to insure survival of a permanent plant cover that can be grazed by wildlife and/or livestock. Replicated field plots were constructed of varying materials and depths, with and without barriers, with and without topsoil, and species selection trials were integrated into the experimental design. The hydrologic and vegetation response to the different treatments have been monitored throughout a thirteen-year period.

3. Long-term Water Quality Monitoring, Colstrip, Montana (Stuart Jennings and John Goering, Reclamation Research Unit, Montana State University)

   Mining of near surface coal deposits in Montana and Wyoming is a significant commercial industry. The Rosebud Coal member of the Paleocene age Fort Union formation is mined at Colstrip Montana. A large portion of the coal mined is burned on-site for power generation. The large ecological disturbance caused by mining and power generation is a concern to nearby residents, particularly the ranching community downgradient from the mine disturbance. This research project provides twice yearly sample collection of ground, surface and spring water quality to ensure the non-degradation of water quality in ranch lands adjacent to the mine. Research is performed in conjunction with Battelle Pacific Northwest Labs from Richland, Washington.

4. Phytostabilization Studies at the Keating Tailings Site (Dennis Neuman, John Goering, and Pam Blicker, Reclamation Research Unit, Montana State University)

   The objective of conducting a phytostabilization study at the Keating Tailings Site is to provide BLM managers and decisions makers with site specific information and data relating to the implementation, costs, and effectiveness of this technology so that it may be applied to other similar acid metalliferous mine tailing sites administered by BLM. During the 2005 field season, seeding density, and cover were measured, and plant were collected for determine metal concentrations in their tissue. Additional monitoring is scheduled for 2006.

5. Anaconda Smelter Superfund Site (Dennis Neuman, Stuart Jennings, John Goering and Pam Blicker, Montana State University)

   Members of the Reclamation Research Unit are assisting the U.S. Environmental Protection Agency in evaluation remedial designs and assessing remedial actions being implemented at this large (> 300 square miles) Superfund Site. Land reclamation was selected by the US EPA as the main remedy for large tailings ponds (> 4000 acres), and landscapes contaminated by aerial emissions. Both land restoration research and matters of land management are integrated with EPA

policy so that appropriate risk-based cleanup is achieved.

6. Evaluation of Organic Matter Addition and Incorporation on Steep Cut Slopes (Stuart Jennings and John Goering, Reclamation Research Unit, Montana State University)

Fundamental to successful revegetation of highway corridors following disturbance is the creation of a growth environment conducive to the establishment and early survival of the seeded plants. Steep cut slopes present a unique problem. The steepness of cut slopes prevents practical replacement of salvaged topsoil with conventional equipment. The current remedy is simply to broadcast seed and hydromulch the bare slope. These techniques all too often result in marginal plant establishment since germination and initial seedling survival is limited by nutrient poor, rocky substrates characteristic of cut slopes. The resulting poor vegetation establishment leads to increased erosion and sedimentation, occasional slope failure, increased noxious weed growth, and low aesthetic quality. All of these factors except the latter can be expected to substantially increase maintenance costs in the affected areas. The overall research objectives for the project are to: 1]. reduce sediment yield and erosion from steep highway cut slopes through amendment with compost; 2]. enhance vegetation establishment on steep highway cut slopes through amendment with compost; 3]. develop amendment rates, application protocols and techniques for compost addition and incorporation on steep highway cut slopes; 4]. implement, monitor and evaluate test plots on steep highway cut slopes; and 5]. communicate, report and provide technology transfer of the research findings. Several components have been completed including conducting a review of relevant scientific literature with respect to organic matter amendment addition to enhance plant growth media, and an assessment of their applicability to conditions in Montana, and investigation of methods for organic matter application and incorporation to steep slope areas (greater than 33 percent) through literature review and correspondence with equipment manufactures and contractors. During the 2003 field season test plots were construct on steep highway cut slopes with erosive and/or poorly vegetated parent material, and an evaluation of the equipment and protocols for application and incorporation of compost on steep cut slopes were conducted. Future plans include monitoring of vegetation response on and off the plots.

7. Optimization of Construction BMP Performance in the Northern Rockies for Enhanced Stormwater Control (Stuart Jennings, Reclamation Research Unit, Montana State University)

The overall purpose of this project is to evaluate the effectiveness of installed stormwater BMPs under several geological and climatological regimes characteristic of the Northern Rocky Mountains. Data and observations from this investigation will be synthesized and modeled to formulate improved guidelines for BMP construction. Dynamic technology transfer will be employed to

disseminate these guidelines and associated documents through interactive, computer-based products including both website and CD media. This project is progressing through five related parts described below:

1. Literature review of existing stormwater BMP guidelines from Montana, Idaho, and Wyoming;
2. Inventory of BMPs utilized in Stormwater Pollution Prevention Plans (SWPPPs) filed with State regulatory offices in Montana, Idaho, and Wyoming;
3. Assessment and evaluation of the apparent effectiveness of these BMPs as installed in the field;
4. Data interpretation, computer modeling and synthesis of the assembled information;
5. Technology transfer utilizing several media formats with emphasis placed on delivering design guidelines to permittees.

8. Vegetation and Soils Monitoring of Reclaimed Abandoned Mine Sites Administered by Bureau of Land Management (Dennis Neuman, Reclamation Research Unit, Montana State University)

   This project involves development of a monitoring program to determine the effectiveness of past reclamation practices applied to abandoned mine land sites administered by the Bureau of Land Management in Southwestern Montana. As part of the monitoring program, baseline data are to be gathered to determine changes in vegetation and soils. These data and supporting information will then be used by the Bureau of Land Management to schedule maintenance of these areas as necessary to provide continued integrity of the reclamation.

PLANNED OR POTENTIAL PROJECTS

1. Compost application for optimized vegetation response.

2. Steep slope revegetation by compost addition.

3. Compost addition for enhanced vegetation condition and stormwater treatment.

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INTRODUCTION

This report summarizes revegetation and restoration research conducted in 2005 by the Department of Land Resources and Environmental Sciences at Montana State University.

COMPLETED PROJECTS

1. An assessment of mycorrhizal infectivity potential of customized mycorrhizal inoculum source for Glacier National Park (Catherine Zabinski, Land Resources and Environmental Sciences, Montana State University and Joyce Lapp, Restoration Biologist, Glacier National Park)

   There is general interest in adding mycorrhizal inoculum to severely disturbed soils and to cover soils that have not recently had plants growing in them. While commercial mycorrhizal inoculum has become widely available, some National Parks are concerned about introducing non-native soil biota. Glacier National Park has developed a mycorrhizal inoculum bed outside their native plant nursery to generate inoculum for restoration projects within the park. Soils from the area to be restored are used to fill the bed, and native plants are grown in those soils. Root fragments and soils from the bed are used as a mycorrhizal inoculum source. We have worked with the park to determine which native species serve as the best host species and the density of mycorrhizal propagules in the inoculum bed.

ONGOING PROJECTS

1. The Ecology of Plant-Fungal Symbioses in Extreme Environments (Catherine Zabinski and Ylva Lekberg, Land Resources and Environmental Sciences, Montana State University)

   The study of plant growth and the mycorrhizal symbiosis in extreme environments is relevant to understanding the potential for vegetation establishment on industrially-impacted sites. This research focuses on arbuscular mycorrhizae (AM) and plant growth on thermal soils Yellowstone National Park.

These soils are characterized by acidic to basic chemistry, elevated rooting zone temperatures (up to 57^{o}C), low phosphorous levels, and potentially toxic concentrations of multiple elements. These sites are very old, and therefore the potential exists for plant and fungal adaptations to extreme environmental conditions. We are collaborating with Dirk Redecker, University of Basel, to apply molecular tools to identify fungal species that are active in the roots of plants growing on thermal soils. We are using t-RLP's to compare AM fungal community composition in extreme environments relative to non-extreme environments. While this work is not directly applied restoration, it builds our understanding of the mycorrhizal symbiosis in extreme conditions, which could directly inform our understanding of symbioses in disturbed and reclaimed sites.

2. Recreation Impacts on High Elevation Soil Biota and Soil Processes (Brian Eckenrod and Catherine Zabinski, Land Resources and Environmental Sciences, Montana State University)

Mountainous regions are some of the most heavily utilized recreation areas, and this increased pressure from human use has resulted in major ecological changes, ranging from soil compaction and decreased water infiltration to loss of habitat and vegetation loss. Soil animals and soil microbial communities facilitate the decomposition of organic matter, making nutrients available for subsequent plant and microbe uptake and are essential to the productivity, successful establishment and sustainability of restored systems. Our research has three main objectives: 1) to compare soil biota structure and function in disturbed, adjacent undisturbed and restored high elevation sites; 2) to compare rates of decomposition and nitrogen mineralization on undisturbed, disturbed, and restored campsites; and 3) to characterize soil chemical and physical properties across both site types and locations. We are sampling sites in the Gallatin and Bitterroot Mountains in western Montana, and North Cascades and Mount Rainier National Parks in Washington. We have measured mycorrhizal infectivity potential, decomposition of standardized substrates over a 24-month period, N mineralization across the growing season, soil enzyme activity, substrate-induced respiration rates, and soil chemical and physical properties. We hope to determine whether there are general patterns of response to disturbance that can be incorporated into restoration plans for these sites.

3. Belowground Ecology of an Invasive Forb and Native Grasses (Catherine Zabinski, Karla Sartor, Land Resources and Environmental Sciences, Montana State University, Bret Olson, Animal, Range and Natural Resources, Montana State University)

Restoration of degraded rangelands includes revegetating areas with invasive species. We have an ongoing research project to identify the role of arbuscular mycorrhizae in increasing competitive interactions between the invasive forb, *Centaurea maculosa*, and two native grass species. This past year our work has focused on determining the mechanisms of competition between invasive and

native species, specifically related to root and mycorrhizal fungus function. With this work we have shown that the invasive forb receives more benefit from the symbiosis than the native grasses.

4. Revegetation Post-Disturbance in Cheat grass-Invaded Great Basin Shrublands (Nancy Shaw, USDA FS Rocky Mountain Research Station, Hilary Parksinson and Catherine Zabinski, Land Resources and Environmental Sciences, Montana State University)

   As a spin-off from the USDA-RMRS initiative to develop forb plant materials for revegetation, we are investigating species combinations that will result in increased plant community diversity and reduced cheat grass invasion in revegetated areas post fire disturbance. We are just in the planning stages for both greenhouse and field experiments to measure forb growth with and without cheat grass. This work is focused on Great Basin plant communities.

5. Native Species Selection for Optimizing Constructed Wetland Function (Paul Hook, Intermountain Aquatics, Otto Stein, Department of Civil Engineering, Montana State University Carrie Taylor, and Catherine Zabinski, Land Resources and Environmental Sciences, Montana State University)

   Constructed wetlands are an important source of waste water treatment, but in colder environments there utility maybe be seasonally-limited. Previous work done by Drs. Hook and Stein and associated graduate students, documented more efficient wastewater treatment in cold temperatures with certain plant species in constructed wetlands. This research project is a follow up designed to screen 19 wetland species across a gradient of wetland function for their ability to deliver oxygen to the rooting zone, and hence increase wetland treatment processes that are oxygen-dependent during winter months.

6. Using Reinforced Native Grass Sod for Biostrips, Bioswales, and Sediment Control (DC01) (Xiamming Shi, Western Transportation Institute, Montana State University, Doug Dollhopf, Reclamation Research Unit and Land Resources and Environmental Sciences, Montana State University, Tracy Dougher, Plant Sciences, Montana State University, and Lisa Rew, Land Resources and Environmental Sciences, Montana State University)

   This study was funded by California Department of Transportation, with the main objective to develop native grass sod for six ecoregions of California to aid highway site stabilization. Control of storm water runoff and sediment loss from disturbed land adjacent to highways is a cause of concern in many areas, and the California highway system is no different. Efforts to establish native grass from seed on slopes and water conveyance features requires long establishment periods

before a degree of effectiveness is attained. It is anticipated that the use of reinforced native grass sod will facilitate quick vegetation establishment and soil reinforcement, reduce the risk of non-native weeds and fire hazards, and thus reduce the use of herbicides. In addition, the native grass sod is expected to minimize the amount of maintenance and water treatment needed for the vegetation management. We have selected seven grass species native to each eco-region and are growing them in 5 and 7 species mixes in climate controlled mini-greenhouses.

PLANNED OR POTENTIAL PROJECTS

1. Restoration and revegetation of tamarisk-invaded riparian areas.

2. Extension of work on disturbance effects on soil biota function, to address the question of how restoration ecologists should plan soil amendments to increase revegetation success.

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NEVADA

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INTRODUCTION

This report summarizes reclamation/restoration projects in progress during 2005 by the Ecology and Restoration of Great Basin Watersheds Research Work Unit and the Great Basin Ecosystem Management Project for Maintaining and Restoring Riparian Ecosystem Integrity, two USDA Forest Service, Rocky Mountain Research Station projects, located in Reno, Nevada. Cooperators in these research projects include the Humboldt-Toiyabe National Forest; Bureau of Land Management; Joint Fire Sciences Program; Agricultural Research Service, Reno, NV; Environmental Protection Agency, Ada, OK; University of Nevada, Reno, Reno, NV; Western Carolina University, Cullowhee, NC; Lafayette University, Easton, PA; and University of Tennessee.

COMPLETED PROJECTS

1. Changing Fire Regimes, Increased Fuel Loads, and Invasive Species: Effects on Sagebrush Steppe and Pinyon-Juniper Ecosystems (Jeanne C. Chambers, E. Durant McArthur, Robin J. Tausch, Stephen Monsen, Nancy L. Shaw, Susan E. Meyer, USDA Forest Service, Rocky Mountain Research Station; Richard R. Miller, Oregon State University; Robert Blank, USDA Agricultural Research Service; Stephen C. Bunting, University of Idaho; Bruce Roundy, Brigham Young University; Scott C. Walker, Utah Division of Wildlife Resources; Mike Pellant, USDI Bureau of Land Management)

   Pinyon-juniper woodlands and Wyoming big sagebrush ecosystems have undergone major changes in vegetation structure and composition since settlement by European Americans. These changes are resulting in dramatic shifts in fire frequency, size and severity. This integrated, multiple investigator project was largely funded by the Joint Fire Sciences Program. It was conducted in Oregon, Idaho, Nevada, and Utah and examined: (1) presettlement fire regimes and the spatial and temporal changes that have occurred in Intermountain Region woodlands and sagebrush steppe ecosystems, (2) changing fuel loads and the consequences for the ecosystem types and conditions that currently exist on the landscape, and (3) the environmental and ecological factors that influence

community susceptibility to invasive species. This research is providing both regional and local information on characteristics of woodlands and shrublands at greatest risk of catastrophic fire, most susceptible to cheatgrass invasion, as well as most suitable for prescribed fire. It also is providing information on the effects of resource availability, community condition, and fire on community susceptibility to cheatgrass and secondary weed invasion. The project is resulting in several technical reports and peer reviewed manuscripts.

ONGOING PROJECTS

1. Determining the Environmental and Ecological Factors that Make Great Basin Watersheds Susceptible to Invasive Plant Species (Jeanne C. Chambers and Robin Tausch, USDA Forest Service, RMRS, NV; Bob Blank, ARS, Reno, NV; Bruce Roundy, BYU, Provo, UT; Susan Meyer, USDA Forest Service, RMRS, NV)

   This research is examining key factors influencing community susceptibility to the invasion and spread of invasive species in the Great Basin, beginning with the fire-adapted, exotic annual grass, cheatgrass (*Bromus tectorum*). It is addressing the hypothesis that most communities become more susceptible to exotic species invasion as a result of an increase in resource availability, such as occurs following fire or degradation by previous disturbance or land use activities. Specifically, it is evaluating the effects of resource availability (i.e., nutrients, water) as influenced by environmental gradients, fire, and community condition or health on invasive species establishment, reproduction, and expansion. It is evaluating the problem on both a local and regional basis, and including an examination of functional or "healthy" communities, communities at risk of conversion to invasive species, and revegetated communities. This research is highly integrated with our ongoing Joint Fire Science Program studies. The project has been funded from 2001 through 2006 through R&D proposals submitted in support of the National Fire Plan. It has resulted in a review manuscript and several draft manuscripts.

2. A Demonstration Area on Ecosystem Response to Prescribed Burns in the Great Basin Pinyon-Juniper Woodlands (Jeanne C. Chambers, Robin J. Tausch, and Michael C. Amacher, USDA Forest Service, RMRS; Dru Germanoski, Dept. Geology and Environmental Geosciences, Lafayette College; Erica Fleishman and Karen Seto, Center for Conservation Biology, Stanford University; Desederio Zamudio, Ecology Team, Humboldt-Toiyabe National Forest; David Dobkin, High Desert Ecological Research Institute; Barry Noon, Colorado State University)

   This project has established a demonstration watershed for illustrating both the feasibility and ecological effects of prescribed fire on pinyon-juniper dominated ecosystems to managers, researchers, and the public. It is a collaborative effort between the USDA Forest Service, Rocky Mountain Research Station, Humboldt-

Toiyabe National Forest and the Bureau of Land Management, Battle Mountain Field Office. Objectives include: (1) Determine the recovery thresholds and successional trajectories of vegetation communities with different stand densities of pinyon and juniper; (2) Determine the changes in fuel loads that occur with increasing stand densities of pinyon and juniper; (3) Examine the influence of stand density and topographic position on soil properties and carbon:nitrogen balance; (4) Evaluate the effects of prescribed burn projects on stream channels, sedimentation and water quality; and (5) Examine the effects of the burn on the species richness and occurrence of taxa shown to exhibit quantifiable responses to similar disturbances, i.e., birds, butterflies, and ants. Information from the demonstration area is being used to develop guidelines for evaluating the effects of stand density and fuel loads on vegetation community and soil response to prescribed burns, and to determine when revegetation is required. Also, much needed information on the effects of watershed-scale burns on important taxa (butterflies, ants and birds) in semi-arid ecosystems is being obtained. The research plots were burned in May 2002 and a larger watershed scale burn was conducted in May 2004. Initial project duration was from October 1, 2000 to September 30, 2005. Two additional projects have been funded to support this research including "Effects of Fire and Rehabilitation Seeding on Sage Grouse Habitat in the Pinyon-Juniper Zone" (2002 to 2006) and "Response of Birds, Butterflies, and their Habitats to Management of Wildland Fuels and Fire Regimes." (2005 to 2008). Products to date include both Masters theses and manuscripts.

3. The Great Basin Ecosystem Management Project for Restoring and Maintaining Watersheds and Riparian Ecosystems (Jeanne C. Chambers, Robin J. Tausch, and Michael C. Amacher, USDA Forest Service, RMRS; Dave Jewett, EPA, Ada, OK; Jerry Miller, Mark Lork, Western Carolina University; Dru Germanoski, Dept. Geology and Environmental Geosciences, Lafayette College; Erica Fleishman, Center for Conservation Biology, Stanford University; Greg Baker, State University of New York, Buffalo; Sudeep Chandra, Tom Dudley, Wendy Trowbridge, University of Nevada, Reno; Jim Bergman, Humboldt-Toiyabe National Forest)

   Streams and riparian areas in the Great Basin provide critical ecosystem services including an adequate supply of high quality water, habitat for a diverse array of aquatic and terrestrial organisms, forage and browse for native herbivores and livestock, and recreational opportunities. Many of the stream systems are incised (downcut) and the riparian areas are often severely degraded compromising their capacity to supply these services. In 1993, an ecosystem management project was initiated by the USDA Forest Service, Rocky Mountain Research Station to increase understanding of the structure and functioning of Great Basin watersheds and riparian areas and to develop methods for maintaining or restoring ecosystem sustainability. The emphasis is on integrated studies of the abiotic and biotic components of the systems conducted at multiple spatial scales, including the watershed, riparian corridor, valley segment, and stream reach. The project is unique in that time scales include the mid-late Holocene (last 8000 years), post-

settlement period (1860 to present), and present (up to ten-years ago). The interdisciplinary research team is addressing several objectives: (1) Reconstruct the vegetation and geomorphic history of Great Basin watersheds; (2) Determine the underlying geomorphic and hydrologic processes that characterize the watersheds and riparian areas, and evaluate the effects of both past and present climate change and anthropogenic disturbance on these processes; (3) Evaluate the sensitivity of the study watersheds to both natural and anthropogenic disturbance, and develop a model of watershed sensitivity for managing riparian ecosystems; (4) Examine the effects of watershed geologic characteristics and natural and anthropogenic disturbance on flow regimes and water quality; (5) Determine relationships among riparian vegetation, hydrogeomorphic processes, and basin sensitivity to disturbance; and (6) Use our understanding of past and present ecosystem processes to develop guidelines and techniques for restoring and maintaining sustainable riparian areas. The results of the initial 10-years of the project were published in 2004 by Island Press as a Society for Ecological Restoration publication: Chambers, J. C. and J. R. Miller. 2004. Great Basin Riparian Ecosystems: Ecology, Management, and Restoration. Island Press, Covelo, CA. 303 pages. The process-based information linking climate history, geology, hydrology, and ecology has broad-scale implications for the management of these ecosystems. The specific information obtained on central Great Basin riparian ecosystems is being used to prioritize stream and riparian area restoration efforts, and to test methods for both stream stabilization and riparian ecosystem restoration.

4. Geomorphic, Hydrologic and Vegetation Interactions Related to Alluvial Fans and Meadow Complexes (Dave Jewett, EPA, Ada, OK; Jeanne C. Chambers, USDA Forest Service, RMRS; Jerry Miller, Mark Lord, Western Carolina University; Dru Germanoski, Dept. Geology and Environmental Geosciences, Lafayette College; Greg Baker, State University of New York, Buffalo; Sudeep Chandra, Tom Dudley, Wendy Trowbridge, University of Nevada, Reno; Jim Bergman, Humboldt-Toiyabe National Forest)

The degradation and loss of meadow complexes in the central Great Basin is resulting in the conversion of highly productive, grass and sedge dominated riparian ecosystems to more xeric upland vegetation and, consequently, in a net decrease in the aerial extent of the riparian corridor. This has the potential to affect water retention and storage and thus water supply to downstream users, to decrease the forage base for livestock and native herbivores, and to threaten the biodiversity of the region. This interdisciplinary research project is providing a holistic understanding of the causes of meadow incision, and of incision effects on the geomorphology and hydrology of meadow complexes and, thus, riparian vegetation over a range of spatial and temporal scales. Specific objectives include: (1) Determine the factors controlling meadow distribution; (2) Examine the geomorphic and vegetation evolution of riparian meadows; (3) Quantify the spatial and temporal variations in meadow hydrology; (4) Evaluate the processes

related to meadow dissection and headcut migration and their effects on riparian meadows; (5) Develop a system for evaluating the restoration potential of degraded meadows. The project duration is from April 2003 through December 2006 and funding is from the EPA and RMRS.

NEW PROJECTS

1. A Regional Experiment to Evaluate Effects of Fire and Fire Surrogate Treatments in the Sagebrush Biome (J.D. McIver, H. Barrett, M. Brunson, S. Bunting, J. Chambers, C. D'Antonio, P. Doescher, S. Karl, S. Knick, R. Miller, M. Pellant, F. Pierson, D. Pyke, K. Rollins, B. Roundy, G. Schupp, R. Tausch, D. Turner, M. Wisdom)

This new regional project will implement a comprehensive experiment to evaluate the effects of fire and fire surrogate treatments that are designed to restore sagebrush communities of the Great Basin. The experiment will: 1) provide managers with information to restore ecological communities that is relevant across the 100+ million acres of the sagebrush biome; 2) be matched to the temporal and spatial scales at which managers operate; and 3) reduce management risk and uncertainty of catastrophic wildfire to the greatest degree possible. The need for such an experiment is evidenced by the profound changes in fire regime experienced in the Great Basin in the past 150 years, coupled with the lack of information available to managers on the consequences of methods they might use to reduce fire risk or to restore more desirable plant communities and fire regimes. The objectives reflect a research program that is aimed at defining critical ecological thresholds, through the application of alternative treatments over a wide array of conditions:

(1) Identify the abiotic and biotic thresholds that determine sustainability of big sagebrush plant communities in sagebrush-steppe and sagebrush semi-desert environments, specifically related to threats posed by cheatgrass and pinyon-juniper invasion.
(2) Assess the ecological effects of fire and fire surrogates on big sagebrush communities at risk of crossing a threshold of conversion to cheatgrass or pinyon-juniper, beyond which restoration may be difficult or logistically infeasible.
(3) Evaluate the effectiveness of supplemental restoration treatments (revegetation) needed to prevent big sagebrush communities from crossing the threshold, and to ultimately restore these communities to sustainable states.
(4) Document how fuel loads change across vegetation treatments and ecological sites in relation to the objectives above.
(5) Portray the ecological, social, and economic trade-offs and treatment effects of no action, applying only fire and fire surrogate treatments, and restoration treatments in these sagebrush communities.

(6) Provide insight and guidance regarding use of our results for effective multi-species and multi-scale planning as part of ecosystem management of sagebrush communities in the Great Basin.

This new 5-year project was funded in spring 2005 by the JFSP.

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NEW MEXICO

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INTRODUCTION

This report summarizes the revegetation and native plant propagation research associated with the revegetation research program at the New Mexico State University – Mora Research conducted in 2005. The majority of the revegetation research projects described in this report are associated with research on the direct establishment of container stock onto overburden piles at the Molycorp Inc., molybdenum mine located in Questa, New Mexico. A second area of emphasis has involved developing forest inventory tools for practicing forests and landowners on summarizing forest inventory information. Forest restoration activities are presently dominating forest management in the southwestern United States.

ONGOING PROJECTS

1. Three to 20 Year Transplant Height Growth of *Pinus Ponderosa* (Laws.) Planted on Non-Amended Mine Overburden (John T. Harrington [NMSU] and Mark Loveall [NMSU])

   The purpose of this study is to examine the growth rate of *Pinus Ponderosa* (Laws.) planted directly into mine overburden. Height growth data is being collected on a series of transplant sites associated with a molybdenum mine in north central New Mexico and several reforestation sites in the region. Preliminary analysis indicates a prolonged, five to seven year versus one to three year, period of limited shoot growth following transplanting for seedlings planted directly into mine overburden. However, after 16 years, annual shoot growth appears to be greater on seedlings growing in the overburden than on seedlings transplanted in forested sites. Further analysis of soil/overburden properties and subsequent growth is currently being conducted.

2. Influence of neutral overburden as a cover soil on the root development of *Populus angustifolia* seedlings (John T. Harrington [NMSU] and Ron Weaver [NMSU])

The purpose of this research is to examine the influence of using neutral overburden as a cover soil over more acidic overburden on new root development. Specifically, the first experiments are examining the influence of cover soil thickness in greenhouse trials. Container grown *Populus angustifolia* seedlings were transplanted into containers with various thicknesses of neutral cover soils overlying acidic overburden. Root growth and overburden chemistry data are currently being analyzed. A second set of experiments using, porous root bags which will allow in situ evaluation of root development are being prepared. These later experiments will have root analysis intervals ranging from one growing season through four years.

3. Software development for forest inventory and restoration activities in the southwestern United States

The purpose of this effort is provide researchers and practicing foresters a simple to use set software programs to summarize and present forest inventory data in the southwest. Presently, forest restoration is the predominate forest management activity in both public and private forests in the southwest. A challenge to researchers and foresters has been how to convey forest stocking conditions to land non-technical, managers and land owners. The software is based on the most widely used forest inventory technique, variable radius plot inventory. The software that has already been developed provides a mechanism to present forest inventory data both graphically and numerically. The software allows the user's to compile multiple plot data and convert data from basal area data to stems per acre data. All work thus far has been based on the widely used Microsoft Excel Program. The software presently being developed is alternative scenario software. This software is intended to allow the user to graphically examine the effects of alternative treatments on forest stand structure and stocking. While these software programs will be of limited use to researchers, they are intended to provide a mechanism to assist in technology transfer and decision making.

PLANNED PROJECTS

1. Post-establishment Fertility Responses of Woody Plants Growing on Hard Rock Overburden (John T. Harrington, David R. Dreesen, and Mark Loveall)

2. Influence of Cover Soil Thickness on Woody Plant Establishment on Hard Rock Overburden (See above) (John T. Harrington and David R. Dreesen)

3. Influence of Sequential Versus Simultaneous Establishment of Woody Plants and Grass Cover on Hard Rock Overburden (John T. Harrington and David R. Dreesen)

4. Post-establishment Plant and Landscape Scale Water Relations of Woody Plants on Hardrock Overburden (John T. Harrington)

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OREGON / WASHINGTON / IDAHO

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INTRODUCTION

This report summarizes the revegetation and restoration research being conducted or contracted by the USGS, Forest & Rangeland Ecosystem Science Center (FRESC) for the period of January 1, 2004 to December 31, 2004. Research reported in this document was funded by USGS, the Bureau of Land Management, or by funds obtained through external granting agencies.

ONGOING PROJECTS

1. VegSpec (Phil Smith, Natural Resources Conservation Service, Information Technology Center, Fort Collins, CO; John Patterson, NRCS, Lincoln, NE; James Henson, NRCS, Baton Rouge, LA; Steven Warren, Cntr. for Ecol. Mgmt. of Military Lands, Colo. State Univ., Ft. Collins, CO; David Pyke, USGS, Forest and Rangeland Ecosystem Science Center, Corvallis, OR)

   Current developments include a DVD/Quicktime movie that will provide a demonstration on how to use VegSpec.

2. Interactions of Cattle Grazing and Climate Change on Semi-arid Ecosystem Function (David Clausnitzer, David A. Pyke, Jayne Belnap, Tim Graham, USGS, Forest & Rangeland Ecosystem Science Center, and Robert Sanford, Denver University)

   Analysis of this project is still ongoing. We are using concentrating our efforts in using a structural equation modeling. The initial analyses are showing changes in physical soil parameters associated with livestock grazing intensity as measured

by distance from water. We began testing the Century model using our data from the Great Basin and Colorado Plateau shrub grasslands. Modifications to the model are being conducted to allow it to operate correctly in these ecosystems.

3. Coordinated Intermountain Restoration Project (David A. Pyke and Cindy Salo, USGS, Forest & Rangeland Ecosystem Science Center, and Mike Pellant, Bureau of Land Management, Idaho State Office, Boise ID)

   We have two new projects under this program that began this year. One study is examining the dose responses of cheatgrass and medusahead yield to a range of sucrose applications to the soil in a site in Oregon and one in Idaho. The second study is using a greenhouse study to examine the response of cheatgrass yields to applications of hydroseeding tackifiers (syllium, plantago extracts and polyacrylimide) with and without sucrose. These techniques should result in reduced growth of cheatgrass.

4. Integrated Restoration Strategies towards Weed Control on Western Rangelands (Robert Nowak, Department of Environmental and Resource Science, University of Nevada – Reno and 11 other investigators including David A. Pyke, USGS, Forest & Rangeland Ecosystem Science Center)

   Two study sites were located in each of the four states and the appropriate Environmental Assessments for conducting studies. In Autumn 2004, we repeated studies begun in 2003 where 21 accessions of native grasses were seeded with and without cheatgrass to determine establishment and survival success throughout the Great Basin. In addition, a set of competition and nutrient studies were also repeated to examine the impact of nutrient reductions, native plant mixtures and competition with cheatgrass. We are also investigating soil microbes and nitrogen fluxes with carbohydrates (sucrose) are added to soils.

5. Standardized Federal Emergency Stabilization and Rehabilitation Monitoring Protocols (David A. Pyke and Troy A. Wirth, USGS, Forest & Rangeland Ecosystem Science Center)

   Land management agencies with the USDA and USDI recognize the need for a common monitoring protocol within and among agencies. This specifically addresses the issue raised by a GAO report that the agencies cannot evaluate the effectiveness of Emergency Stabilization and Rehabilitation (ESR) treatments at meeting ESR program goals. We are testing a series of common monitoring procedures for their effectiveness in providing quantitative monitoring data using a standard procedure across the western US. We are also creating a standard database for data entry, retrieval and reporting.

6. Fire and Fire Surrogate Treatments for Restoration of Wyoming Big Sagebrush Communities (Cindy Salo, USGS, Forest & Rangeland Ecosystem Science Center, and Kelly Hogan, FWS, Hart Mt. National Antelope Refuge, Plush, OR)

   We are testing the prediction that fire surrogate treatments have the potential to decrease Wyoming big sagebrush densities and to allow native understory grasses and forbs to increase with lower risk of invasion by cheatgrass than with prescribed fire or wildfire. We collected pretreatment data in 2004 and 2005, then applied chemical (Tebuthiron) treatments in fall, 2005. We will apply mechanical treatments as soon as field conditions (mud) permit and will collect post treatment data in 2006 and 2007.

7. Fuels Management Treatments and Habitat for Greater Sage-Grouse (David A. Pyke and Cindy Salo, USGS, Forest & Rangeland Ecosystem Science Center)

   We are evaluating changes in vegetation after Dept. of the Interior fuels management treatments carried out at sites in Idaho, Nevada, Oregon, and Wyoming between 1997 and 2004, and comparing these changes with habitat needs of Greater Sage-Grouse. We collected field data in 2005 for evaluating changes in vegetation structure and cover and in abundance and diversity of food sources for sage-grouse (sagebrush, forbs, and ground-dwelling insects) at two spatial scales: fine-scale quantitative data to characterize patches (1 ha) and medium-scale qualitative data to determine the extent of different patch types across each fuels management treatment site and untreated comparison area. We will collect an additional year's data in 2006.

8. The Human Footprint in the West: A Large-Scale Analysis of Human Impacts (Matthias Leu, Steve Hanser, and Steven Knick, USGS, Forest & Rangeland Ecosystem Science Center)

   We have produced a fact sheet describing the effects of land use and development, and have mapped the human footprint in the western United States. This publication describes the effects of humans on: 1) predators, 2) species of conservation concern, 3) population dynamics of wildlife, 4) regional migratory bird populations, and 5) spread of invasive plants.

9. Fire and fire surrogate treatments on sagebrush ecosystems (J. McIver, USFS PNW Res. Stn. and multiple investigators including USGS)

   This project will investigate the impacts of fire and fire surrogate treatments on ecosystem processes in mountain big sagebrush and Wyoming big sagebrush communities in the Great Basin. We have selected two site on Hart Mountain National Antelope Refuge. On each site we will collect baseline vegetation and soils data this year prior to applying a prescribed fire, herbicide (SPIKE 20P) and mechanical mowing of sagebrush to reduce fuels.

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UTAH

BRIGHAM YOUNG UNIVERSITY and U. S. FOREST SERVICE SHRUB SCIENCES LABORATORY

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INTRODUCTION

This report summarizes revegetation and restoration-related research conducted by faculty and scientists of Brigham Young University, the U.S. Forest Service Shrub Sciences Laboratory, and their cooperators for the year of 2005. Projects range from basic studies of physiology, ecology, and genetics to applied revegetation trials and weed control procedures.

COMPLETED PROJECT

1. Changing Fire Regimes, Increased Fuel Loads, and Invasive Species: Effects on Sagebrush Steppe and Pinyon-Juniper Ecosystems (Jeanne Chambers, Durant McArthur, Susan Meyer, USFS Rocky Mountain Research Station, Bruce Roundy, Brigham Young University, and 10 other cooperators and investigators)

   This project is comparing historical and current fuel load characteristics and determining the effects of residue perennial vegetation on resource availability and invasibility of weedy species. Most manuscripts and final reports have been submitted. Although cheatgrass germination potential was high for most sites and years, cheatgrass dominance was reduced by presence of perennial grasses and at higher elevations by low temperatures which reduced cheatgrass growth and seed production. Cheatgrass dominance can be minimized by managing to retain residual perennial herbaceous vegetation in big sagebrush communities. A publication on fuel loading and fire history of post-settlement pinyon and juniper woodlands is in preparation.

ONGOING PROJECTS

1. Ecology and Restoration of a Mojave Desert site (E.Durant McArthur, Stewart Sanderson, U.S. Forest Service Shrub Lab, Provo, UT 84401, and Bob Douglas, Dixie Field Office, Bureau of Land Management, St. George, UT)

Monitoring is continuing to determine if and when annual plant dominance will shift to seeded perennial dominance. A new program for clustering associated species is being developed using a Mojave Desert plant community as a demonstration.

2. Ecology and Restoration of Cheatgrass Dominated Sites (Nancy Shaw, U.S. Forest Service Rocky Mountain Station, 316 E. Myrtle, Boise, Idaho 83702 and Scott Jensen, U.S. Forest Service Shrub Lab, Provo, UT 84401, and Mike Pellant, Bureau of Land Management, Boise, Idaho 83706)

This project involves a number of studies designed to protect or restore sagebrush rangelands in southern Idaho and central Utah threatened by cheatgrass invasion or dominance. To encourage use of native grasses in revegetation, studies are progressing on rearing techniques to increase efficiency of native seed production. Large- scale seed production is being developed for forbs which hold promise for revegetation in the Great Basin.

3. Regeneration Biology of Shadscale (Susan Meyer and David Nelson, U.S. Forest Service Shrub Lab, Provo, UT 84401)

Seedling disease studies are underway. A thermal time model has been successful in predicting changes in the chill response of afterripened seed. Publications are being prepared.

4. Regeneration Biology of Blackbrush (Susan Meyer and Burton Pendleton, and Janine Auger., U.S. Forest Service Shrub Lab, Provo, UT 84401)

Data on home ranges and caching behavior of rodents are being collected. Size-age relationships are being developed to model blackbrush migration in relation to climate change.

5. Ecological Genetics of the Cheatgrass Head Smut Pathosystem **(**Susan Meyer and David Nelson, U.S. Forest Service Shrub Lab, Provo, UT 84401)

Smut more effectively infects fall than winter-germinated cheatgrass. Ongoing studies are examining use of a bunt disease and a soil-borne fungus that attacks cheatgrass seeds in the soil during the winter. Publications are being prepared.

6. Germination and Propagation of Native Forbs (Susan Meyer, U.S. Forest Service Shrub Lab, Provo, UT 84401)

Requirements for germination are currently being tested for ecotypes of native forbs, including tall forb species.

7. Increasing Diversity of Mountain Big Sagebrush Stands (E.Durant McArthur, Stewart Sanderson, U.S. Forest Service Shrub Lab, Provo, UT 84401, Bruce

Webb, Brigham Young University, Provo, UT 84602**,** Barbara Wachocki, and Mohammed Sandossi, Weber State University, Ogden, UT)

Effects of tebuthiuron rates and season of application are being monitored on control and treated plots. A publication is being prepared.

8. Fire history of Great Basin ponderosa pine communities (Stan Kitchen, U.S. Forest Service Shrub Lab, Provo, UT 84401)

Historical fire regimes in two eastern Great Basin fire-sheds are being analyzed to determine regional patterns and local effects.

9. Herbicide and Grazing Effects on Increasing Diversity of Aspen Parkland (Val Jo Anderson, Brigham Young University, Provo, UT 84602, and Scott Walker, Utah Division of Wildlife Resources, Ephraim, UT 84627)

The effects of cattle and elk grazing, as well as herbicide applications are being measured on tarweed, mule's ear, and thistle dominance and on plant community composition of aspen parklands.

10. Natural Resource Monitoring, Analysis, and Reclamation Activities at Dugway Proving Ground (Val Jo Anderson, Brigham Young University, Provo, UT 84602)

Effects of disturbance and revegetation for cold-desert communities at Dugway are being studied under the objectives of a cooperative agreement between BYU and the Department of the Army.

11. Restoring Native Diversity of Mountain Meadows (Val Jo Anderson, Brigham Young University, Provo, UT 84602)

Herbicide (Roundup) and mechanical treatments (tillage) are being applied alone and in combination prior to seeding native grasses to convert meadows dominated by smooth brome and intermediate wheatgrass back to native species in Ephraim Canyon, Utah.

12. Native Plant Community Resistance to Weed Invasion (Phil S. Allen and Bruce A. Roundy, Brigham Young University, Provo, UT 84602; and Susan Meyer, U.S. Forest Service Shrub Sciences Lab, Provo, UT 84601)

Low and high densities of 2 native grasses, 2 native shrubs, and 4 native forbs have been established in various combinations. Resource availability and weed resistance are being measured. A manuscript reporting initial effects on weeds is in preparation. Shrub and grass communities reduced, but did not eliminate weed populations.

13. Establishment of Reserve Pastures for Camelids on the Bolivian Altiplano (Val Jo Anderson and Bruce A. Roundy, Benson Institute and Brigham Young University, Provo, UT 84602)

A variety of introduced grasses and shrubs have been seeded or transplanted at 3 sites in the Altiplano. Llama forage preference was measured in 2004. Seed production of the adapted, introduced species at 3 elevation site has been limited. This project will focus on collecting and testing native grasses to improve forage production in the future.

14. Effects of cheatgrass and browsing on big sagebrush growth and seed production (Jim Davis, Utah Division of Wildlife Resources, Daniel Eddington, and Bruce A. Roundy, Brigham Young University, 401 WIDB, Brigham Young University, Provo, UT 84602)

The effects of Plateau herbicide on reduction of cheatgrass on 7 big sagebrush communities are being studied. Big sagebrush leader growth and seed production is being measured on adjacent sprayed and unsprayed plots, and on caged and uncaged shrubs. A thesis is being written on this work.

15. Native seed production (Val Jo Anderson, Robert Johnson, Bruce A. Roundy, and various other cooperators at Brigham Young University, Provo, UT 84602, in cooperation with Scott Jensen, U.S. Forest Service Shrub Sciences Lab, Provo, UT 84601, and Jason Vernon, Utah Division of Wildlife Resources, Ephraim, UT 84627)

Effects of rearing practices on production of native forbs, grasses, and shrubs are being investigated at the Brigham Young University Farm, Spanish Fork, UT. Methods of increasing native stand shrub seed production are being studied on 2 field sites.

16. Increasing diversity of crested wheatgrass stands (Bruce A. Roundy and Val Jo Anderson, Brigham Young University, Provo, UT 84602)

Herbicidal and mechanical partial and full control of wheatgrass are being compared in relation to success of sown native species and weed invasion on 2 sites in Utah. Cooperators in Idaho have installed similar experiments. Both herbicidal and mechanical treatments have produced partial and near-complete control of crested wheatgrass, but seedbanks still contain many crested wheatgrass and weed seeds. Native seed emergence, cover, and density, as well as that of weeds will be measured in the summer of 2006 and another year's set of plots will be treated.

17. A regional experiment to evaluate effects of fire and fire surrogate treatments in the sagebrush biome (Jim McIver, Forestry and Range Sciences Lab, La Grande,

OR 97850, and 19 others including Bruce A. Roundy, Brigham Young University, Provo, UT 84602)

A 5-year study of vegetation thresholds after fire and mechanical disturbance to restore function in sagebrush communities at risk from weed and woodland invasion has begun. This large project is funded by the Joint Fire Sciences Program and will measure vegetation, wildlife, insect, soil and hydrologic responses to disturbance on multiple sites in different ecological provinces. Pre-treatment vegetation and soil sampling will begin in 2006 and fire and mechanical treatments will be installed in fall 2006.

18. Hydrothermal modeling of seed germination and root growth (Bruce A. Roundy Brigham Young University, Provo, UT 84602)

BYU undergraduate student mentoring funds and native seed funds are being used to support students testing seed germination rate and seminal root growth rates in relation to heat accumulation (degree hours or days). Using soil water potential as a threshold switch, we are determining whether germination and seedling growth predictions from our models match germination in seed bags, seed germination in small plots, and seedling survival data from 2 field sites. So far, our germination model correctly predicted fall 2005 seed bag germination for most species.

PLANNED OR POTENTIAL PROJECTS

1. Effects of Fuel Control Wood Residues on Annual Weed Invasion. (Bruce A. Roundy and Brad Jessop, Brigham Young University, Provo, UT 84602, Jolie Pollet, Doug Page, and Joe Jensen, Bureau of Land Management, Salt Lake City and Cedar City, UT)

Funding from the JFS has been requested to determine effects of wood residues on soil nutrient and water resources in relation to cheatgrass invasion and dominance.

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UTAH

Utah State University

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INTRODUCTION

This report summarizes research activities related to revegetation and stabilization of deteriorated and altered lands at Utah State University for the calendar year 2005.

ONGOING PROJECTS

1. Integrated Restoration Strategies Towards Weed Control on Western Rangelands (**Robert Nowak {overall project PI}** & Hudson Glimp, University of Nevada, Reno; Paul Doescher & John Tanaka, Oregon State University; **Eugene W. Schupp {Utah State University PI**} & Chris Call, Utah State University; Jeanne Chambers & Robin Tausch, USFS Rocky Mountain Research Laboratory; Dave Pyke, USGS Forest & Rangeland Ecosystem Science Center; Bob Blank & Tom Jones, USDA ARS; Mike Pellant, USDI BLM Idaho State Office; and Dan Ogle and Loren St. John, USDA Natural Resources Conservation Service)

   Our overall goal is to provide a scientific foundation for developing management strategies for control of cheatgrass and other weeds in the Great Basin and for restoration of infested lands to productive native rangelands.

   This study is based on three experiments:

   Experiment 1: Screen 25 accessions of restoration material for competitiveness against cheatgrass.

      Objective: Identify suitable material for a transition stage in restoration from cheatgrass-infested range to diverse native range, and to evaluate generality of results across the Basin.

   Experiment 2: Investigate whether competitive interactions between cheatgrass and native perennials vary with nitrogen availability, perennial diversity, and with presence or absence of secondary weeds.

      Objectives: Determine the role of nitrogen availability in competition

between cheatgrass and perennials; determine if a carefully selected set of perennial species is more competitive than individual species; determine if responses change with varying densities of perennials and cheatgrass (not in Utah); determine if the presence of secondary perennial weeds alter the interactions between cheatgrass and perennials.

Experiment 3: Investigate a series of potential restoration strategies at a larger scale, including prescribed fire, selected species mixtures, etc. This experiment will also be used for economic analyses, environmental education, and extension.

Objectives: Determine the effectiveness and the economic viability of a variety of potential restoration techniques; provide environmental education opportunities for the general public to help them understand rangelands, the threats they face, and restoration potential; provide outreach to public landowners and State and Federal land managers on restoration strategies.

Experiment 1 and 2 are being conducted at two sites in each of four States (Utah, Nevada, Idaho, and Oregon), one relatively drier and one relatively wetter. This will allow cross-Basin comparisons. Experiment 3, because of its size, will only be conducted in a single site north of Reno, Nevada.

Experiment 1 involved sowing at all eight sites the same 21 available accessions of potential restoration materials. The remaining 4 accessions vary slightly among sites, depending on local interest. Seedings were done with and without cheatgrass competition. This experiment was drill-seeded in Fall 2003 and replicate plots were seeded in Fall 2004. Two year results for the 2003 seeding are available as are one year results for the 2004 seeding. Data analysis has begun and monitoring will continue on the 2004 plots this summer.

Experiment 2 involved at all eight sites the core factorial experiment of: 9 perennial treatments (6 species of native perennials as monocultures, the 6 natives as a mixture, crested wheatgrass as monoculture, and no perennials) x 2 nitrogen treatments (with or without mobilization) x 2 cheatgrass treatments (with or without cheatgrass). One of the Utah sites also includes 2 secondary weed treatments (with or without squarrose knapweed, a weed already present at that site) crossed with the treatment combinations in the perennial mixture treatment. This experiment was sown in Fall 2003 and Fall 2004. Data analysis has begun and monitoring will continue on the 2004 plots this summer.

Experiment 3 was initiated in 2005. The plot is north of Reno, NV. No data are available yet.

2. Role of seed predation in restoration of cheatgrass-infested rangelands (Steven Ostoja and Eugene W. Schupp, Utah State University, and William Longland, ARS Reno, NV)

This research builds on the overall restoration project (1) above and involves a series of five experimental studies addressing the impacts of seed-eating ants and rodents on seeds of desirable species and weeds in a restoration context. The core of the project deals with the net effect of rodents on desirable seeded species through their predation and seed caching roles. Field and laboratory experiments are mostly complete and data analysis is in progress.

3. Nutrient interactions and competition between exotic weeds and native grasses (Jeff Burnham and Eugene W. Schupp, Utah State University)

This research project is also an outgrowth of the larger restoration project above (1) and involves two experiments on the effects of nutrients on three-way interactions among bluebunch wheatgrass, cheatgrass, and squarrose knapweed during establishment. A field experiment addresses the effects of ratios of nitrogen and phosphorous while a green house experiment more thoroughly explores a range of nitrogen availabilities. The field experiment is completed and analyses are in progress; the green house experiment is being initiated this Spring.

4. A Regional Experiment to Evaluate Effects of Fire and Fire Surrogate Treatments in the Sagebrush Biome (J.D. McIver, Oregon State University; M. Brunson, Utah State University; S. Bunting, University of Idaho; J. Chambers, USFS; C. D'Antonio, University of California Santa Barbara; P. Doescher, Oregon State University; S. Knick, USGS FRESC; R. Miller, Oregon State University; M. Pellant, BLM; F. Pierson, USDA ARS; D. Pyke, USGS FRESC; K. Rollins, University of Nevada Reno; B. Roundy, Brigham Young University; **E.W. Schupp, Utah State University**; R. Tausch, USFS; D. Turner, USFS; M. Wisdom, USFS)

This region-wide project was funded in Summer 2005 and is now being implemented. We are designing experiments to evaluate the effects of fire and fire surrogate treatments on vegetation and fuel responses on sagebrush communities of the Great Basin with the ultimate goal of developing strategies for restoring this endangered ecosystem. Our experiments will: 1) provide managers with guidelines for restoring communities that is relevant across the 100+ million acres of the sagebrush biome; 2) be relevant to the temporal and spatial scales at which managers operate; and 3) reduce management risk and uncertainty of catastrophic wildfire to the greatest degree possible. Although there are numerous integrated objectives, the core objective is to quantify ecological thresholds, through the application of alternative treatments over a wide array of conditions. Specific objecties we will address include:

(1) Identify and quantify the abiotic and biotic thresholds that determine sustainability, or “recoverability” of big sagebrush plant communities in sagebrush-steppe and sagebrush semi-desert environments, specifically related to threats posed by cheatgrass and pinyon-juniper invasion.

(2) Assess the ecological effects of fire and fire surrogates on big sagebrush communities at risk of crossing a threshold of conversion to cheatgrass or pinyon-juniper, beyond which restoration may be difficult or logistically infeasible.

(3) Document how fuel loads change across vegetation treatments and ecological sites in relation to the objectives above.

(4) Elucidate the ecological, social, and economic trade-offs and treatment effects of no action, applying only fire and fire surrogate treatments, and restoration treatments in these sagebrush communities.

(5) Provide insight and guidance regarding use of our results for effective multi-species and multi-scale planning as part of ecosystem management of sagebrush communities in the Great Basin.

Utah State University is responsible for implementing and monitoring a series of sagebrush plots threatened with invasion by cheatgrass in the eastern Great Basin and Snake River Plain. In summer 2006 we will obtain pretreatment data on a set of replicate plots in Rush Valley, Utah, and a second set of plots in the Owyhee Desert, northeastern Nevada. We are presently seeking two additional sites to begin in summer 2007. Treatments are scheduled to be applied in Fall 2006 on the initial plots. Treatments for this part of the study are: (1) control, (2) relatively cool late-summer burn, (3) herbicide at a rate to kill approximately 50% of the sagebrush and (4) rotary mowing at a blade height to kill approximately 50% of the sagebrush. In addition, subplots will be treated with pre-emergent herbicide to the extent allowed by BLM rules.

5. Effect of Vegetation Manipulation on Watershed Processes and Function (Ron Ryel, Jim Long, Fred Baker, and Helga van Miegroet, Utah State University) Funded by Natural Resources Conservation Service.

Conversion of quaking aspen (*Populus tremuloides*) forests to conifer-dominated communities is widespread in much of the Intermountain West. It is estimated that in Utah there has been a 50% decline in aspen-dominated stands in the last 50 years. Resource value loss associated with these changes include water yield, grazing potential, wildlife habitat, species diversity, water quality through increased sediment transport. While the regeneration ecology of aspen is well understood, there is much that we do not know concerning implementation of ecologically and economically sound and socially acceptable treatments. In cooperation with Deseret LLC, we are evaluating a broad range of potential aspen regeneration methods. The fundamental objective is the development of a diversity of effective strategies for regenerating aspen communities where they are currently being displaced by conifers. Treatments will include prescribed burning, timber harvest and biological treatment. In addition to evaluating regeneration potential of various treatments, we must also monitor response to

herbivory, understory development, invasive weed encroachment, conifer regeneration, livestock forage value, wildlife habitat value and use, changes in soil biogeochemistry, sediment transport, and hillslope stability. Pretreatment data are now being collected.

PLANNED OR POTENTIAL PROJECTS

1. Mycorrhizae and fire rehabilitation (Dara Scherpenisse and Eugene W. Schupp, Utah State University)

   Building on the Joint Fire Sciences project above (4) we designing studies to investigate the role of mychorrizae in sagebrush restoration. Likely topics include the relative effects of commercial mychorrizal inocula versus locally cultured mychorrhizae, and the effects of mychorrhizae on the competitive relationships between cheatgrass and desirable perennial grasses.

2. Seed banks and sagebrush restoration (Kristen Pekas and Eugene W. Schupp, Utah State University)

   We also are planning a study as part of the Joint Fire Sciences project above (4) to investigate (i) the relationship between existing vegetation and the seed bank and (ii) the contribution of the seed bank to post-treatment vegetation responses.

WYOMING

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INTRODUCTION

This report summarizes the revegetation and stabilization of disturbed land research activities conducted during 2005 at the University of Wyoming and emphasizes activities of the Department of Renewable Resources. The projects listed below were funded by federal and state agencies as well as private industry including the Abandoned Coal Mine Land Research Program (ACMLRP) and the Agricultural Experiment Station Competitive Grant Program at the University of Wyoming. The ACMLRP support is administerred by the Land Quality Division of the Wyoming Department of Environmental Quality from funds returned to Wyoming from the Office of Surface Mining of the U.S. Department of Interior.

COMPLETED PROJECTS

1. Chemistry of Inorganic Selenium in Alkaline Mine Soils (Shankar Sharma, University of California Merced, CA and George F. Vance, Department of Renewable Resources, University of Wyoming. Laramie, WY 82071-2000)

   Selenium (Se) is a natural geological constituent in many mining areas of the western United States. While Se is an essential micronutrient for humans and animals, its low toxicity threshold poses health concerns. Oxidative exposure of Se in excavated mine soils leads to increased concentrations of selenite and selenate species, which can potentially enter the food chain. In order to ascertain the geochemical processes contributing to Se bioavailability, we examined Se dissolution, speciation, fractionation, adsorption, and solid phase formation in alkaline coal and uranium (U) mine soils from Wyoming. A majority (86%) of the labile Se was determined to be in the exchange phase. Despite 49% of total Se levels identified in siliceous minerals, the exchangeable Se exceeded the critical toxicity limit in >60% samples. SeVI and SeIV were the dominant species in aqueous and exchangeable fractions, respectively; SeVI was the major species released under aqueous or alkaline dissolution conditions, whereas SeIV was primarily related to ligand exchange or complexation processes. Mine soils adsorbed up to 99% of SeIV and 95% of SeVI, and the relative sorption was on an average 6-fold higher for SeIV. High sorbate-sorbent ratios ($K > 10$ kg/10g) suggested a possible multilayer sorption mechanism. Presence of oxides or oxyhydroxides of Ca, Mn and Fe resulted in greater Se retention, which was

mostly augmented by Fe-minerals. Soil solutions were undersaturated with respect to Se solid phases, thereby suggesting that Se precipitation would be less likely to prevail, with adsorption-desorption equilibria plausibly controling Se release into the solution phase. Saturated solids associated with the mine soils included Fe2O3, CuFe2O4, ZnFe2O4, CuFeO2, FeOOH, Fe3O4, CaFe2O4, MgFe2O4, Al(OH)3, Al2O3, CuO, and Cu4(SO4)(OH)6. These minerals could potentially bind Se. CaSeO3A2H2O and CaSeO4 were the only SeIV and SeVI solids that were close to saturation, suggesting these mineral species could potentially control solution Se chemistry during pedochemical weathering. Information from this study can be utilized for developing mine land reclamation policies.

2. Soil Chemical Changes Resulting from Irrigation with Water Co-produced with Coalbed Natural Gas (G.K. Ganjegunte, G.F. Vance and L.A. King, Department of Renewable Resources, University of Wyoming. Laramie, WY 82071-2000)

   Land application of coalbed natural gas (CBNG) co-produced water is a popular management option within northwestern Powder River Basin (PRB) of Wyoming. This study evaluated the impacts of land application of CBNG waters on soil chemical properties at five sites. Soil samples were collected from different depths (0-5, 5-15, 15-30, 30-60, 60-90 and 90-120 cm) from sites that were irrigated with CBNG water for 2 to 3 years and control sites. Chemical properties of CBNG water used for irrigation on the study sites indicate that ECw and SARw values were greater than those recommended for irrigation use on the soils at the study sites. Soil chemical analyses indicated that ECe and SARe values for irrigated sites were significantly greater ($P<0.05$) than control plots in the upper 30 cm soil depths. Mass balance calculations suggested that there has been significant buildup of Na in irrigated soils due to CBNG irrigation water as well as Na mobilization within the soil profiles. Results indicate that irrigation with CBNG water significantly impacts certain soil properties, particularly if amendments are not properly utilized. This study provides information for better understanding changes in soil properties due to land application of CBNG water. These changes must be considered in developing possible criteria for preserving fragile PRB ecosystems.

3. Deviations from Empirical Sodium Adsorption Ratio and Exchangeable Sodium Percentage Relationship in Wyoming Soils (G.K. Ganjegunte and G.F. Vance, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-2000)

   Accurate information on exchangeable sodium percentage (ESP) assumes a great importance in ameliorating the sodium-affected soils. Representative soil samples were collected at six depths (0-5, 5-15, 15-30, 30-60, 60-90 and 90-120 cm) from five sites in the Powder River basin in Wyoming that have been irrigated with saline-sodic water (ECiw >2 dS/m and SAR >20) for up to 3 years. Exchangeable sodium percentage were determined by using direct method by using NH4OAc

and ESP-SAR empirical relationship given by U.S. Soil Salinity Laboratory Staff. Direct method ESP values were significantly lower ($P<0.05$) than ESP determined by empirical relationship. The differences between direct and empirical ESP values have been attributed to greater salinity of the study soils in the upper 30 cm and presence of smectites as the dominant clay minerals in these soils.

4. Influence of Reclamation Management Practices on Carbon Accumulation and Soil Fertility on Coal Mine Lands in Wyoming (P.D. Stahl, G.F. Vance, L.J. Ingram, S.V. Huzurbazar, and C.J. Bilbrough, Department of Renewable Resources and Department of Statistics, University of Wyoming, Laramie, WY 82071 and Land Quality Division, Department of Environmental Quality, Cheyenne, WY)

   The overall goal of this proposed research was to examine the influence of a number of surface coal mine reclamation management practices on carbon accumulation, organic nutrient pools and soil fertility in reclaimed soils. To accomplish this goal, we examined the influence of these common management practices (grazing, mulching, direct haul/stockpiled topsoiling, and shrub mosaic seeding) on organic carbon and nutrient concentrations in soil, determine the mechanisms by which organic matter and nutrients accumulate in these soils and evaluate the potential for enhancing carbon and organic nutrient storage in reclaimed surface mine lands.

   Information obtained through this research will provide reclamationists with effective strategies for building soil carbon and organic nutrients and contribute significantly to the current scientific understanding of soil carbon and organic nutrient dynamics in reclaimed soils. The observed phenomenon of organic carbon accumulation in reclaimed soils on surface mined lands should be viewed as a mechanism by which the coal mining industry is contributing to the reduction in CO_2 in the atmosphere through increased carbon storage and improvement in soil fertility.

5. Structure and Function of Microbial Communities in Mine-Impacted and Pristine Environments: A Comparative Study (E. McClain, P.D. Stahl, C.S. Chandler, P.S. Colberg, Department of Biology, Ft. Belknap College, Harlem, Montana 59526, Department or Renewable Resources and Department of Zoology and Physiology, University of Wyoming 82071)

   The goal of this project is to assess the impacts of mining activities on soil microbes at the Zortman-Zandusky mine site, which is adjacent to the southern border of the Ft. Belknap Indian Reservation. Researchers will compare soil samples from the mine site with those collected from a nearby, non-impacted site. Samples from each site will be analyzed to determine: 1) microbial community composition, 2) microbial biomass, 3) degree of nutrient cycling, and 4) potential for bacterial sulfate reduction. By invetigatig each of these four parameters over a two year period, researchers will increase their understanding of the impacts of mining activities on soil microbes and their ability to perform ecosystem

functions. Knowledge gained from this study will provide valuable information to tibal leaders, state regulators, and reclamation engineers as they attempt to determne the bet plan for restoring the Zortman-Zandusky mine site and protecting human health and natural resources downstream.

6. Invasion of rush skeletonweed (*Chondrilla juncea* L.) into sagebrush communities of the Snake River Plain, Idaho (A.L. Hild, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071)

Following wildfire on the Snake River Plain, the entrance of annual exotic grasses may be followed by secondary invasion of more problematic perennial weed species, making revegetation efforts difficult. Rush skeletonweed, a wirey-looking member of the Asteraceae, is a comparative new-comer among noxious weeds in the region. It was first reported in Spokane, Washington in 1938, and in Banks, Idaho in 1961. From Banks, it reached Boise in the mid-70s and continues to spread south and east across the Snake River Plain. Rush skeletonweed (*Chondrilla juncea*) has been observed to increase drastically after fires in sagebrush steppe, however specifics on recruitment are not well-documented in the scientific literature. This information is important for timing of control efforts, reseeding, or other management activities on rangelands. Therefore, we're investigating the demographics of rush skeletonweed invasion on the Snake River Plain, near Boise, Idaho. The region once supported vast acreages of Wyoming big sagebrush, but many of these lands have been converted to annual grasslands due to increased fire frequency, historic heavy grazing, and the invasion of non-native plants over the last hundred years. To assess the invasion process in our rangelands, we've established study plots in 11 skeletonweed stands on the Snake River Plain. We chose stands that straddle the fireline of wildfires that burned in the summer of 2003 so that we could document how the invasion process differs in burned and unburned areas. We monitored plots on both sides of the fireline, and measured density on five randomly-located belt transects on each of the 11 pairs of plots. We counted rush skeletonweed individuals every two weeks from early October until late December, 2003-2005. We conducted demographic studies of the species in all populations found on the SRP in field searches and conducted controlled growth chamber studies of seed bank and germination. Publications are in progress.

7. Salt Cedar Control in the Big Horn River Basin, Wyoming (A. Hild and T. Whitson, D. Kazmer. and C. Ladenburger, Department of Renewable Resources and Department of Plant Science, University of Wyoming, Laramie, WY 82071)

Saltcedar (Tamarisk spp.), an exotic shrub introduced for ornamental plantings in the early 1800s has since become naturalized in riparian habitats throughout the western states, displacing native vegetation, altering hydrology of riparian areas, and limiting the function of riparian habitat. Reclamation of riparian systems depends upon effective control of this noxious species and other exotic associate species and our ability to reseed following weed control. Coupled with

revegetation efforts, control of saltcedar is essential to returned ecosystem function to limited wetland systems in the semiarid west. The study examined saltcedar invasions near the northern limits of its naturalized range in the Big Horn Basin, Wyoming. By documenting the soil physiochemical characteristics beneath this exotic shrub and associated native species and bare ground, we document revegetation potential following shrub control. We took density counts and recorded cover of saltcedar and associated shrubs in saltcedar stands in different native stand types. Comparisons of chemical soils parameters were presented at the Society for Range Management meetings in 2004. The study suggests that the soils beneath older (large) tamarix shrubs are more saline and have greater EC than under native shrubs, except beneath greasewood plants. Even so, soil chemistry indicates that most stands could be sucessfully reseeded with native species following saltcedar control. An MS student on this project completed her thesis in 2003 and her publication is in press in 2006.

8. Native Plant Recruitment & Population Structure as Influenced by Weedy Invasions Temperate Arid Rangelands (A. Hild and N. Shaw, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071)

Because of the 1979 wildfires and cheatgrass invasions, the shrublands of the USDI-BLM Snake River Birds of Prey National Conservations Area have been reduced by more than 50%. Shrubs such as winterfat that dominated this area form shrub mosaics that provide essential habitat for small mammalian prey base of nesting raptor species. The recruitment of new shrub seedlings is critical to maintaing shrubland demography to support this trophic pyramid. We examined the germination ecology of local winterfat populations to determine the effect of seedbed microenvironments on germination of naturally dispersed or planted seeds. In mid November 2000, seeds from 3 NCA locations were placed in mesh bags and planted on the soil surface or covered lightly with soil. Bags were recovered monthly through mid March 2001, and germination was compared among treatments and control seeds stored dry or given a 14 day prechill prior to incubation. Germination response was generally similar for the 3 locations. Over the 4-month period, germination of dry controls averaged 28% of live seeds. Five percent of dry seeds germinated following a 14-day prechill with an additional 56% germinating during incubation. Field germination of surface planted seeds was 4% in December and 100% by March. Covering seeds with soil accelerated the process with all live seeds germinating by February. Field planted seeds not germinating prior to recovery did so rapidly in incubation. Late fall planting with light soil covering exposes seeds to cool, moist seedbeds that enhance germination, permitting rapid emergence when favorable combinations of moisture and temperature conditions are encountered in early spring.

ONGOING PROJECTS

1. Simulated Weathering of Saline and Sodic Minesoils from Northwestern New Mexico and Northeastern Arizona (B.D. Musslewhite, BHP-Billiton San Juan

Coal Company, P.O. Box 561, Waterflow, NM 87421; T.H. Brown, Poudre Valley Environmental Sciences, Inc., 4419 View Point Court, Fort Collins, CO 80526; G.W. Wendt, Peabody Western Coal Company, P.O. Box 650, Kayenta, AZ 86033; C.R. Johnston, Western Research Institute, 365 N. 9th St., Laramie, WY 82072)

The effects of weathering on alkaline minesoil (root-zone material) chemistry are poorly documented in the literature. Study of the important relationship between electrical conductivity (EC) and sodium adsorption ratio (SAR) have largely been focused on agricultural and rangeland soils. Chemical and physical properties of minesoils are unique and quite different from natural soils formed over hundreds of years through pedogenic processes. These differences largely occur because relatively unweathered overburden is exposed during mining processes and subsequently used as a lower root-zone medium (minesoil) during soil reconstruction. Some of these materials are classified as sodic and therefore are considered unsuitable rooting media for establishment of native vegetation. Weatherable minerals (i.e., pyrite, calcite, gypsum, and other geologic substrates) present in minesoils can effectively remediate or mitigate an elevated SAR condition by maintaining EC levels in the soil solution to promote clay particle stability and by providing sources of exchangeable calcium and magnesium. Coversoil (e.g., topsoil) enhances remediation through physical and chemical buffering between sodic root-zone material and the reconstructed soil surface. A laboratory column study was used to evaluate weathering potential of ten minesoil materials from three mining operations in the northwestern New Mexico and northeastern Arizona. Columns were prepared with 15 cm of coversoil over 30 cm of minesoil and subjected to simulated precipitation. Chemical evaluations of weathered materials show significant reductions in EC and SAR and overall improvement of minesoil quality. Chemistry of drainage water from three coversoils shows these materials behave as a chemical buffer above the underlying sodic materials. Coversoils provide a source of calcium and other electrolytes that promote physical stability and enhance remediation of sodic minesoil materials.

2. Salinity and Sodicity Interactions of Weathered Minesoils in the Four Corners Region (B.D. Musslewhite, BHP-Billiton San Juan Coal Company, P.O. Box 561, Waterflow, NM 87421; J.R. Vinson, New Mexico Mining and Minerals Division, 1220 South St. Francis Dr., Santa Fe, NM 87505; C.R. Johnston, Western Research Institute, 365 N. 9th St., Laramie, WY 82072; T.H. Brown, Poudre Valley Environmental Sciences, Inc., 4419 View Point Court, Fort Collins, CO 80526; G.W. Wendt, Peabody Western Coal Company, P.O. Box 650, Kayenta, AZ 86033; G.F. Vance, Dept. of Renewable Resources, University of Wyoming, Laramie, WY 82071-2000)

Relationships between electrical conductivity (EC) and sodium adsorption ratio (SAR) changes over time in reconstructed soils at surface coal mining operations are insufficiently documented in the literature. Some minesoils (i.e., rootzone

material) are classified as saline, sodic, or saline-sodic and have been considered unsuitable rooting media for establishment of native vegetation. Weatherable minerals (i.e., pyrite, calcite, gypsum, and other geologic substrates) commonly present in minesoils can mitigate elevated SAR levels by maintaining or increasing electrolytes in the soil and provide sources of exchangeable calcium and magnesium. Coversoil (e.g., topsoil) enhances this mitigation through physical and chemical buffering of minesoils. Weathering characteristics of minesoils and rooting patterns of key reclamation species were evaluated at sites from three surface coal mines in northwestern New Mexico and northeastern Arizona. Unweathered minesoils were grouped into 11 classifications based on EC and SAR. Comparison of saturated paste extracts from unweathered and weathered (6 to 14 years after reclamation) minesoils show significant ($p < 0.05$) reductions in SAR levels and increased EC. Weathering increased the apparent stability of saline and sodic minesoils thereby reducing risks of aggregate slaking and clay particle dispersion. Root density of fourwing saltbush (Atriplex canescens), alkali sacaton (Sporobolus airoides), and Russian wildrye (Psathyrostachys junceus) were generally unaffected by increasing minesoil EC and SAR levels. Saline and sodic minesoils can be successfully reclaimed when covered with topsoil and seeded with salt tolerant plant species.

3. Tracking Salt And Sodium Build Up Due To Irrigating With Coalbed Natural Gas Product Water: Soil Solution Lysimeter And Soil Saturation Paste Extracts Studies (G.K. Ganjegunte, G.F. Vance and L.A. King, Department of Renewable Resources, University of Wyoming. Laramie, WY 82071-2000)

Irrigation with coalbed natural gas (CBNG) co-produced water is becoming a popular management option by many gas companies operating in northwestern Powder River Basin (PRB) of Wyoming. Depending upon the local conditions and production rates, a CBNG well may be productive for 2 to 20 years, with an average lifespan of 7 years. At present there are over 20,000 CBNG wells permitted or drilled in the PRB region and it is estimated that another 50,000 to 100,000 new wells will be drilled in the future. The total CBNG water production in the PRB is expected to peak at about 47,000 ha-m in 2006 and the cumulative CBNG-water production during the period 2002-2017 is estimated to be 366,000 ha-m. CBNG water is dominated by sodium and bicarbonates ions and the average discharge of a single CBNG well ranges from <1 to 100 liter per minute, with pH ranging from 6.8 to 9.0, electrical conductivities (EC) from 0.4 to 4 dS/m, sodium (Na) adsorption ratio (SAR) from a low of 5 to an extreme high of 70 and total dissolved solids (TDS) concentrations from 270 to 2720 mg/L. Application of poorer quality CBNG water can have significant impacts on soil physical and chemical properties. Changes in soil chemistry due to land application of CBNG waters were investigated using lysimeters that were installed at depths 15, 30, and 60 cm. Soil solutions collected during June to Aug 2004 from soil solution lysimeters were analyzed for EC and SAR. The soil solution chemistry data were compared with the EC and SAR data obtained from saturation paste extracts of soil samples collected at the same depth. The data

indicated the build up of salts and Na in the upper horizons in irrigated fields. The EC values of lysimeter soil solution samples were greater than EC values of saturation paste. However, SAR of lysimeter soil solution and saturation paste extracts were comparable. The results of this study will be useful to understand the potential changes in soil properties due to land application of CBNG waters and to develop possible mitigating criteria for preserving the impacted PRB ecosystems.

4. Land Application of Saline-Sodic Coalbed Natural Gas (CBNG) Co-Produced Waters: Impacts to Soil Chemical Properties (L.A. King, G.K. Ganjegunte, and G.F. Vance, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-2000)

   Driven by growing national demand for energy, substantial coalbed natural gas (CBNG) reserves in the Powder River Basin (PRB) of Wyoming (WY) and Montana (MT) are being actively developed. Wyoming's PRB had over 13,000 CBNG producing wells in 2004 with more than 50,000 future wells projected. The large volumes of saline-sodic CBNG co-production water extracted with CBNG are anticipated to exceed 366,000 ha m in the PRB by 2018 and require development of suitable water handling strategies. Land application with sprinkler irrigation systems is a common method for managing these waters. This study examined impacts to various soil chemical properties resulting from up to 4 seasons of land application with saline (EC = 1.6 to 4.8 dS/m) and sodic (SAR =17 to 56) CBNG water. Treated (irrigated) and representative control (non-irrigated) areas were established at 6 study sites and examined in the 2003-2004 field seasons. Soil and vegetation types, water application rates, and water and soil treatment strategies were variable across study sites so parameters from each treated area were compared directly to those from representative control areas. Comparisons were also made between early season 2003 and end of season 2004 treated areas parameters. Soil texture, pH, EC, SAR, and ESP were measured at various depth intervals to 120 cm. Multiple year applications of CBNG water produced consistent trends of increased soil EC, SAR, and ESP values at variable depths up to 120 cm. Consistent trends of reduced pH values on treated areas (vs control) were also noted. Differences were significant ($P<0.05$ or $P<0.10$) at variable depths on most sites. Impacts were reduced on the site with coarse textured soils. These findings indicate concern for effective Na+ and soluble salt leaching success with current management and treatment strategies on these study sites. Degraded soil chemical properties will require difficult mitigation during reclamation efforts following cessation of CBNG water applications.

5. Land Application of Saline-Sodic Coalbed Natural Gas (CBNG) Co-Produced Waters: Impacts to Soil Physical Properties (L.A. King, G.K. Ganjegunte, and G.F. Vance, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-2000)

Active development of large coalbed natural gas (CBNG) reserves in the Powder River Basin (PRB) of Montana and Wyoming is being driven by growing demand for development of unconventional gas fields. These reserves are an important supplement to the Nation's traditional natural gas production. Currently, about 20,000 CBNG wells are either permitted or drilled in the PRB and projections indicate greater than 50,000 future wells. CBNG extraction is associated with significant volumes of saline-sodic co-produced water (CBNG water), anticipated to exceed 366,000 ha m in the PRB over the next 15 years. Development of suitable water handling strategies will be required. Land application using conventional sprinkler irrigation systems is commonly utilized for managing these waters. This study examined impacts to soil physical properties after 1 to 4 years of land applications using saline (EC = 1.8 to 4.0 dS/m) and sodic (SAR =15 to 38) CBNG water. Treated (irrigated) areas and representative control (non-irrigated) areas were established at 6 study sites and examined during the 2003 and 2004 field seasons. Because soil and vegetation types, water application rates, and water and soil treatment strategies were variable across study sites, parameters from each treated area were compared directly to those from representative control areas. Soil physical parameters including texture, bulk density, and Darcy flux rates were measured at various depth intervals to 120 cm. Surface infiltration rates were also examined. Multiple year (up to 4) land applications of saline-sodic CBNG water increased soil EC and SAR values in surface horizons of treated (vs control) areas. These increases were associated with significant reductions (P=0.05) in surface infiltration rates and significant (P=0.10) reductions in Darcy flux rates (treated vs. control areas) at all study sites and most depth intervals to 120 cm. These findings indicate concern for effective Na+ and soluble salt leaching success with current management and treatment strategies on these study sites. Degraded soil physical properties and diminished rates of soil water movement will require mediation during reclamation efforts following cessation of CBNG water applications.

6. Biological Responses to Land Application with Saline-Sodic Coalbed Natural Gas Co-Produced Waters (L.A. King, G.K. Ganjegunte, and G.F. Vance, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-2000)

Large coalbed natural gas (CBNG) reserves are being aggressively developed in the Powder River Basin (PRB) of Montana and Wyoming. About 20,000 CBNG wells are either drilled or permitted with > 50,000 future wells projected. Significant volumes of saline-sodic co-produced water are associated with CBNG extraction and are anticipated to exceed 366,000 ha m in the PRB over the next 15 years. Managing these volumes will require development of suitable water handling strategies (e.g., land application using conventional sprinkler irrigation systems). This study examined responses of native grassland vegetation communities after up to 5 years of land applications with saline (EC = 1.8 to 4.0 dS/m) and sodic (SAR =15 to 38) CBNG co-produced water (CBNG water). Treated (irrigated) areas and representative control (non-irrigated) areas were established at two study sites in 2003 with three additional sites added for the

2004-2005 field seasons. Because soil and plant types, water application rates, and water/soil treatment strategies were variable across study sites, parameters measured from each treated area were compared directly to those from representative control areas. On these study sites, multiple year applications of CBNG water produced consistent trends of increased EC and SAR in the upper 30 cm of soil profiles. Land applications of CBNG water had limited impact on AM fungi infection rates of selected perennial grass species, with only one of four species (western wheatgrass) indicating significantly (P=0.05) reduced infectivity and on only one treated area (vs. control). CBNG water applications significantly increased aboveground biomass production and aerial cover of both perennial grasses and total vegetation on treated areas (vs. control areas) on most sites in most years. Comparisons between non-perennial grass production on treated and control areas varied by site and year; however, non-perennial grass cover was significantly greater on control areas (vs. treated) on three of five sites in both 2004 and 2005. Treated area (vs. control area) species richness comparisons indicated no consistent response to CBNG water applications. Diversity as measured by evenness from aerial cover data, however, was greater on all control areas (vs. treated) at all sites but one in both 2004 and 2005. Evenness measured from frequency data was greater on control areas (vs. treated) on three of five sites in both years. Both Shannon's and Simpson's diversity indices from aerial cover data were greater on control areas (vs. treated) on all sites in 2005. Results using frequency data were mixed. Direct gradient analyses using canonical correspondence analysis (CCA) were utilized to evaluate study site and native plant species impacts related to SAR, EC, pH, % clay, and bulk density in the upper 30 cm of soil profiles. Investigating tolerances of native plant species to modified soil conditions created by land applications of saline-sodic CBNG water will help provide essential information needed to enhance vegetation diversity and reclamation potential of treated sites.

7. Impacts of Coalbed Natural Gas Co-Produced Water on Cropland Irrigated Soils in the Powder River Basin, Wyoming (C.R. Johnston and S. Jin, Western Research Institute, 365 N. 9th St., Laramie, WY, 82072, G.F. Vance and G.K. Ganjegunte, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-2000)

Abstract: Water quality is a major concern with regard to development of coalbed natural gas (CBNG) in the Powder River Basin. Large quantities of water are being produced and discharged as a by-product in the process of releasing natural gas from coal. Current practices of discharging large volumes of water into drainage channels or using it to irrigate cropland areas has the potential to elevate salinity and sodicity in soils. Elevated salinity affects the ability of plants to uptake water to facilitate biochemical processes such as photosynthesis and plant growth. Elevated sodicity in irrigation water adversely affects soil structure necessary for water infiltration, nutrient supply, and aeration. Salinity and sodicity concentrations are important in that a sodic soil can maintain its structure if the salinity level is maintained above the threshold electrolyte concentration. In this

study, cropland soil and CBNG co-produced water were treated with gypsum and sulfur. Plots were monitored to evaluate the effects of gypsum and sulfur on pH, electrical conductivity (EC), sodium adsorption ratio (SAR), and sulfate concentrations. Changes in soil chemistry due to addition of different qualities of irrigation waters and CBNG water and soil amendments were monitored using a split plot experiment. The CBNG co-produced water used for irrigation had an EC of 1380 :S/cm and SAR of 24.3. Baseline and post treatment soil samples were collected to a depth of 60 cm within each study plot, analyzed, and characterized for physical and chemical parameters. Comparisons between baseline and post irrigation data after one season indicated treatment of the irrigation water increased the rate at which Na is moved through the profile. The addition of gypsum and sulfur as both a water treatment and soil amendment proved to be the most effective. Both EC and SAR increased with all treatments in the top two sampling depths. Applying a leaching fraction at the end of each irrigation season should be tested for its effectiveness at moving Na+ below the rooting zone.

8. Innovative Technology Development to Maximize Beneficial Use of Produced Water from Coal Bed Natural Gas Operations in the Powder River Basin, Wyoming (G.F. Vance, R.C. Surdam and G.K. Ganjegunte, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071-3354 and Wyoming State Geological Survey, Laramie, WY 82073)

Wyoming has experienced rapid growth in the development of coal bed natural gas (CBNG), particularly in the Powder River Basin (PRB). Exploration and production is expected to increase not only in the PRB, but also in other areas of Wyoming. A contentious issue associated with CBNG production is what to do with all the produced water that must be removed in order for coal seams to degas. The primary concern with CBNG produced waters is the amount and influence sodium (Na+) (as defined by the sodium adsorption ratio (SAR)) has on soils, vegetation, wildlife and livestock in different environments, e.g., streams, agricultural lands, rangelands, and other PRB ecosystems. We are proposing research that will examine the use of calcium (Ca2+)-rich zeolitic materials as Na+ exchangers. Reduction in the amount of Na+ and a lowering of SAR will result in CBNG produced waters that can be beneficially used by the industry, land owners, and for downstream users. Proposed research will involve the completion of three (3) tasks including: 1) determination of cation exchange capacity (CEC), exchangeable cations, and volumetrics of selected zeolites (i.e., clinoptilolite) deposits; 2) evaluation of the potential for cation exchange reactions between CBNG produced water and natural clinoptilolite-rich deposits to reduce CBNG water SAR's; and 3) design of an economic, viable water treatment scenario based on cation exchange between natural clinoptilolite and CBNG produced waters.

9. Recovery of Belowground Ecosystem Components Under Different Plant Communities on Reclaimed Coal Mine Lands (P.D. Stahl, L.J. Ingram, S.V. Huzubazar and C. J. Bilbrough, Department of Renewable Resources and

Department of Statistics, University of Wyoming, Laramie, WY 82071 and Land Quality Division, Department of Environmental Quality, Cheyenne, WY)

The ultimate goal of mineland reclamation is reestablishment of a productive, healthy, and sustainable ecosystem suitable for postmining land use. All ecosystems are composed of a producer component and a decomposer component and these subsystems are obligately dependent upon one another. Any approach to better understanding or better evaluation of ecosystem functioning, especially nutrient cycling, requires serious consideration of both aboveground and belowground ecosystem components. Although a combined aboveground–belowground approach is crucial to an understanding of ecosystem-level processes, most ecological work has been traditionally conducted without much explicit consideration of the belowground component . This is also true of our understanding of reclaimed ecosystems on coal mine lands. We propose to examine recovery of belowground ecosystem components (nutrient cycling, microbial community structure, and soil structure) under different plant communities found on reclaimed coal mine lands. Our study will include plant communities considered to be of good quality and of lower quality as well as communities having already been bond released. This approach has been chosen to ascertain whether there are differences in recovery of belowground ecosystem structure and function under these disparate communities. Examination of statistical relationships between plant community characteristics and belowground ecosystem components to will be conducted to determine if the plant community characteristics accurately reflect recovery of belowground structure and function.

10. Mechanisms for stabilization and accumulation of organic carbon in reclaimed mineland soils (P.D. Stahl, G.F. Vance and S.V. Huzubazar, Department of Renewable Resources and Department of Statistics, University of Wyoming, Laramie, WY 82071)

The overall objective of the research described in this proposal is to determine the specific mechanisms by which SOC (as the major constituent of SOM) is accumulating in reclaimed soils in surface coal mine lands in Wyoming. This objective will be accomplished by testing four hypotheses we have developed based on data collected in our previous studies of SOM dynamics in reclaimed mine soils and studies of SOM dynamics in intensively managed agricultural soils in the literature.

In addition to providing important benefits to the Wyoming coal mining industry, the mining industry in general, and potentially to global environmental quality, this proposed research will provide significants benefits to the University of Wyoming. Just as Wyoming is the nation's leading producer of coal, continued research on this topic as described in this proposal will cement the University of Wyoming's reputation as a national leader in the field of land reclamation research.

11. Structure and Function of Microbial Communities in Mine-Impacted and Pristine Environments: A Comparative Study (E. McClain, P.D. Stahl, C.S. Chandler, P.S. Colberg, Department of Biology, Ft. Belknap College, Harlem, Montana 59526, Department or Renewable Resources and Department of Zoology and Physiology, University of Wyoming 82071))

The goal of this project is to assess the impacts of mining activities on soil microbes at the Zortman-Zandusky mine site, which is adjacent to the southern border of the Ft. Belknap Indian Reservation. Researchers will compare soil samples from the mine site with those collected from a nearby, non-impacted site. Samples from each site will be analyzed to determine: 1) microbial community composition, 2) microbial biomass, 3) degree of nutrient cycling, and 4) potential for bacterial sulfate reduction. By investigating each of these four parameters over a two year period, researchers will increase their understanding of the impacts of mining activities on soil microbes and their ability to perform ecosystem functions. Knowledge gained from this study will provide valuable information to tibal leaders, state regulators, and reclamation engineers as they attempt to determine the bet plan for restoring the Zortman-Zandusky mine site and protecting human health and natural resources downstream.

12. Using native grasses to competed with Russian Knapweed invasions (S. Tyrer, A.L. Hild, L. Munn and B. Mealor, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071)

The establishment and growth of native species in soils where Russian knapweed (*Acroptilon repens* (L.) DC.) has been removed is unclear, making revegetation of areas where this weed has been controlled difficult. In a greenhouse study, we examined emergence and growth of two native forbs, *Gaillardia aristata* Pursh. and *Dalea purpurea* Vent. and two native shrubs, *Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young and *Kraschenninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit. Soils used in this experiment were obtained from within Russian knapweed invasions and adjacent non-invaded areas near Greybull and Riverton, Wyoming, and Greeley, Colorado. Because prior studies suggest zinc (Zn) accumulations within Russian knapweed invasions may negatively affect native species, plants grown in invaded and non-invaded soils in the greenhouse study were analyzed to ascertain whether more Zn accumulated in species grown in soils from invaded areas than non-invaded areas. To clarify whether Russian knapweed alters soil properties we also examined soil physical and chemical properties of invaded and non-invaded areas at each site. All species germinated and established in soils from Russian knapweed invasions. We suggest in areas where Russian knapweed has been removed, the soil properties should not limit the emergence and establishment of native non-graminoid species. This project concludes in 2006 and publications are in progress.

13. Effectiveness of selected native plants as competitiors with non-indigenous and invasive knapweed and thistle species (A. Hild, T. Smith, and A. Ferraro-Serrano, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071)

We are examining the impact of native grasses as competitors with both Russian Knapweed and Canada thistle to improve revegetation success following weed control. This study seeks an optimal positive synergistic strategy for the control of Canada thistle using a combination of the stem boring weevil *Ceutorhynchus litura* and two competitive native grasses. We hypothesize that combined stressors uniting the stem boring weevil with warm- or cool-season grass competition may cause a greater impact on the weed than either the weevil or competitive grass acting alone. To test this concept, we conducted a greenhouse study comparing the impacts of nine treatment combinations of thistle plants exposed to grass competition and weevil herbivory alone or in concert. In a greenhouse study we used the cool-season *Hesperostipa comata* and warm-season grass *Sporobolus airoide*s collected from inside and outside invasion sites in order to assess differences in competitive ability between plants from the two locations. Thistles subjected to weevils alone had more stems per pot by week eight than the thistles without weevils, due to re-sprouting from roots. Vegetative growth of thistle plants (height and estimated biomass) differed between neighbor and weevil treatments, suggesting that combined control methods may provide a synergistic impact on Canada thistle. Combined reseeding of native grasses with biocontrols may improve revegetation success.

PLANNED OR POTENTIAL PROJECTS

1. CBNG Water Utilization: Irrigation, Water Treatment, and Soil Amendments (G.F. Vance, Department of Renewable Resources, 1000 E. University Ave., University of Wyoming, Laramie, WY 82071-2000 and S. Jin, Western Research Institute (WRI), 365 N. 9th St., Laramie, WY, 82072)

Abstract We propose to evaluate the consequences of land applied coalbed natural gas (CBNG) waters on Powder River Basin (PRB) soils and vegetation. Utilizing the “Research Site” at the Cooksley Ranch, we will determine the influence CBNG waters had on soil physical, chemical, and biological properties and plant responses two years after CBNG water application. Because water quality issues are at the forefront of developing CBNG reserves, we will evaluate water treatments (e.g., solution grade gypsum addition and acidification via a sulfur burner) and soil amendments (e.g., gypsum and agricultural grade S surface applications) in reducing the potential impacts of CBNG water used in irrigating agricultural lands. When used for irrigation, the salinity (electrical conductivity [EC]) and sodicity (sodium adsorption ratio [SAR]) of the CBNG water may be detrimental to soils, plants, and the associated microbial communities by

impacting soil chemical, physical, and biological properties, which can limit plant growth. Our research will utilize the established Cooksley Ranch site located near Ucross, WY that was developed in a DOE-funded project titled “Assessment of the Environmental Impacts of Coalbed Methane Development in the Powder River Basin”. Research initiated studied the use of CBNG water for irrigation, water treatments, and soil amendments on soil chemical changes. We will resample the 20 research plots that received CBNG waters, with water treatments and soil amendments, and compare them to controls that utilized long-term irrigation waters (e.g., Piney Creek). We will determine soil chemical (pH, EC, SAR), physical (infiltration, hydraulic conductivity, Darcy fluxes), and biological (surface and subsurface plant biomass production and species composition, soil microbial communities, root nodulation) properties to establish changes over time. It is important that waters applied to soils meet favorable EC/SAR combinations that allow for proper plant growth while maintaining soil quality. This study will evaluate water treatment technologies and soil amendments to determine the combination that results in the greatest beneficial use of CBNG waters.

2. Enhancing the Beneficial Use of CBNG Waters (G.F. Vance, Department of Renewable Resources, 1000 E. University Ave., University of Wyoming, Laramie, WY 82071-2000, M.A. Urynowicz, Department of Civil and Architectural Engineering, University of Wyoming, and R.C. Surdam, Wyoming State Geological Survey, Laramie, WY)

Abstract Legislation has been proposed within the Wyoming Senate to form “a high level task force investigation into alternative uses of water produced in coal-bed methane production”. Beneficial use of CBNG waters is essential for enhancing gas production and environmental sustainability. For this project, we will develop an economic, viable water treatment system based on cation exchange between a natural zeolite and CBNG waters. A primary concern with CBNG waters is the amount and influence sodium (Na+, specifically sodium adsorption ratio (SAR)) has on soil, vegetation, wildlife and livestock in different environments, e.g., streams, agricultural lands, rangelands, and other Powder River Basin (PRB) ecosystems. We will develop an innovative approach to reducing CBNG water SAR and field test the technology. Current research conducted in the Environmental Soil Science Laboratory (ESSL) utilizes Ca-rich zeolitic materials for Na+ removal from CBNG waters. Research shows that there is a significant reduction in the amount of Na+ and a considerable lowering of SAR in CBNG waters after these waters are processed with the Ca-rich zeolitic materials. Our research will include determination of exchange and kinetic reactions between CBNG waters and the Ca-rich zeolite to formalize and quantify the exchange process, and to design and engineer a bench and field-scale prototype for implementing CBNG water treatment using our zeolite reactor. Both UW and Wyoming State Geological Survey (WSGS) personnel have been participating in the initial phases of CBNG water treatment research. Renewable Resources and Civil and Architectural Engineering personnel, along with students

and technical support staff, will participate in the DOE research, design, implementation, and success of this project in collaboration with the WSGS. Our project emphasizes the RFP's Agency Priority "CBNG Water Management and Disposal" with specific reference to water treatment technologies for reduction in SAR. Industry, land owners, and downstream users will benefit from this new method of reducing Na+ and lowering SARs of CBNG waters.

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