Proceedings
High Altitude Revegetation Workshop No. 15

Edited by
Warren R. Keammerer
Edward F. Redente

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NO. 15

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Edited by

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PREFACE

The 15th biennial High Altitude Revegetation Conference was held at the University Park Holiday Inn, Ft. Collins, Colorado on March 6-8, 2002. The Conference was organized by the High Altitude Revegetation Committee in conjunction with the Colorado State University Department of Soil and Crop Sciences. The Conference was attended by 264 people from a broad spectrum of universities, government agencies and private companies. It is always encouraging to have participants from such a wide range of interests in and application needs for reclamation information and technology.

Organizing a two-day workshop and field trip is a difficult task made relatively easy by the sharing of responsibilities among the members of the HAR Committee.

In addition to the invited papers and poster papers presented on March 6-7, a "field tour" Demonstration of Reclamation Equipment was conducted on March 8, 2002 at the indoor B. W. Pickett Equine Center on the Colorado State University campus. We appreciate and thank the organizers of the field tour.

We would also like to acknowledge and thank all of the people who took time to prepare invited papers and poster papers. These Proceedings are their product, and we express our gratitude to them. The Proceedings include 17 papers and 7 abstracts grouped into seven conference sessions, 9 poster papers and 6 poster paper abstracts.

For current information on upcoming High Altitude Committee events, visit our website at www.highaltitudereveg.com.

Warren R. Keammerer, Ph.D.
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DEVELOPMENT OF A NATIONAL EARLY WARNING AND RAPID RESPONSE SYSTEM FOR INVASIVE PLANTS IN THE UNITED STATES

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ABSTRACT

For the most part, new plants with free living populations in the United States are discovered by chance. As a result, it is sometimes years or even decades before a new invasive plant species is recognized and properly addressed. Usually by that time, the infestation is well established and eradication is not practical. To minimize the establishment and spread of new invasive plants in the United States, the Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW) is leading a national effort to develop and implement a National Early Warning and Rapid Response System for Invasive Plants in the United States. The main objectives of the proposed system will be to detect, report, and identify suspected new plants with free living populations in the United States. Confirmed new state and national records will be assessed to determine their potential threat to various habitats and environments, and to recommend appropriate actions for eradication or management of the species.

INTRODUCTION

Over the past several thousand years, humans have intentionally and accidentally moved many organisms far beyond their historical native range around the world. The majority of these species are either beneficial to human civilization or at most benign in free living populations. However, a small percentage of introduced species pose a threat to the biodiversity of natural areas and/or diminish the production capacity of managed or agricultural ecosystems. Unlike chemical pollutants that degrade in the environment over time, invasive species, now termed *biological pollutants*, have the ability to reproduce and spread. By moving plants and animals far beyond their native ranges, the major biogeographical realms are being blurred, and a biological Pangaea is being recreated that will have negative impacts on biodiversity.

Currently, about 3,800 species of known introduced plants (compared to a native flora of 18,000 species) have established free living populations in North America (J. Kartesz, Biota of North America Program, UNC-Chapel Hill). These represent established exotics that have become invasive (1,450 species are recognized as agricultural weeds) or could become invasive in the future. Researchers at Cornell University have calculated the total cost of invasive species to the American economy to be in excess of $138 billion per year. Preventing the spread and establishment of invasive species throughout the world is thus a critical strategy in protecting the sustainability of agriculture and biodiversity.

INVASIVE SPECIES, COMING TO AMERICA

Since the breakup of the supercontinent Pangaea about 180 million years ago, North America has been geographically isolated from the rest of the world, and thus largely protected from biological invasions. However, that changed in a short time with the beginning of modern European colonization about 500 years ago, and became a serious problem with the onset of modern transportation and travel in the 20th century.

During colonial days, when global trade and travel were minimal, foreign pests, which threatened crop and livestock production, were the primary concern. Invasive species of natural areas had few pathways and opportunities to spread beyond their native ranges in other regions of the world. In those days, before natural areas were invaded by alien invasive species, there was little concern or even notice of the thousands of plant and animals that were being imported for utilitarian purposes such as game fishing (carp), soil erosion [kudzu (*Pueraria montana*)] (Figure 1), windbreaks [Russian olive (*Eleagnus angustifolia*)], medicinal herbs (purple loosestrife (*Lythrum salicaria*)], and for ornamental use [salt cedar (*Tamarix chinensis*)]. In fact, such introductions were widely encouraged. While many of these introductions remain beneficial today, some of them have become invasive and pose a threat to many of our remaining natural and conservation areas - areas that have been reduced to 'islands' in a sea of disturbance.

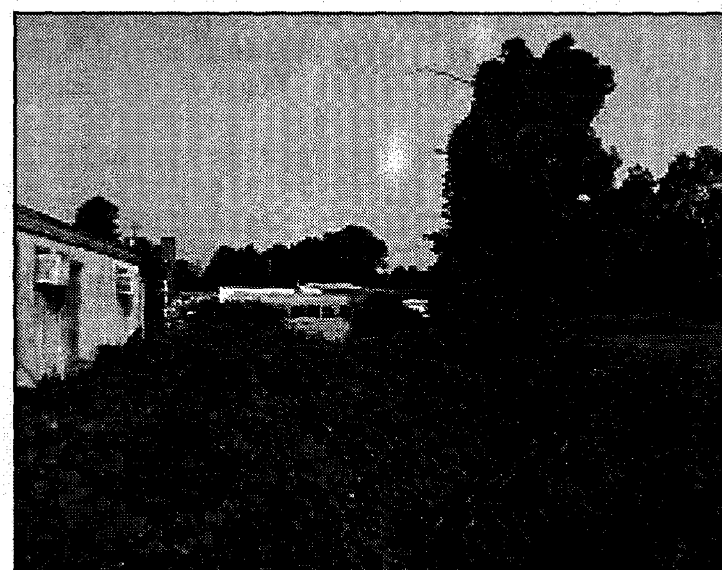

Figure 1. Kudzu (*Pueraria montana*) was imported from Japan in 1876 as an ornamental porch vine, and used later for erosion control throughout the South. Kudzu now infests over 7 million acres and causes over $500 million in control costs and timber losses per year. Photo by R. Westbrooks, U.S. Geological Survey.

THE STORY OF COMMON CRUPINA – A NEW INVASIVE PLANT IN THE NORTHWESTERN U.S

Common crupina (*Crupina vulgaris* Cassini), a perennial composite from southern Europe, was first noticed in the northwestern U.S. in 1968 in Idaho County, Idaho, about six miles east of Grangeville along Highway 13 on the Sammy vonBargen Ranch (Figure 2). [The first known population of common crupina in the U.S., which was collected in Boston, MA, in 1877, did not survive (Pers. Comm., Cindy Rochet, USFS, Medford, OR)]. The plant was first collected at the site on July 26, 1969. In 1970, a cursory survey of the area revealed that a vigorous stand of the plant dominated an area of about 40 acres. [Stickney, P. 1972. *Crupina vulgaris* (Compositae: Cynareae), new to Idaho and North America. Madrono 21:402.]

By 1981, when common crupina was listed as a Federal Noxious Weed and an eradication feasibility study was undertaken by the University of Idaho, the infestation had increased to 23,000 acres. The study, which was completed in 1988, concluded that common crupina *could indeed be eradicated* from the United States. By September, 1991, when a federal/state task force met in Lewiston, Idaho, to discuss the funding of a cooperative eradication project, common crupina had spread to 55,000 acres in Idaho, 8,000 acres in Oregon, 400 acres in Washington state, and 20 acres in California. At that meeting, due to environmental concerns about the impact of pesticides on sockeye salmon in the Salmon River, no consensus was reached by involved agencies, and the crupina project was abandoned. Since that time, crupina has continued to spread, and efforts to find a suitable/effective biological control agent have been unsuccessful. Needless to say, if the original 40 acre infestation of crupina had been reported and summarily eradicated in 1968, the long term impacts of this introduced invasive plant on biodiversity and rangeland productivity in the Northwest could have been avoided. The moral of the story is that invasive species need to be detected early, reported, assessed, contained, and eliminated whenever possible. *Weeds Won't Wait!*

Figure 2. Common Crupina (*Crupina vulgaris*), an annual rangeland weed from eastern Europe that now occurs in Idaho (55,000+ acres), Oregon (8,000+ acres), Washington (400+ acres), and California (20 acres). Inset Photo: Common Crupina in flower.

DEVELOPMENT OF NEW NATIONAL STRATEGIES FOR ADDRESSING INVASIVE SPECIES

In 1997, the U.S. Office of Science and Technology Policy, in response to a petition from over 500 scientists in the United States and abroad, directed the departments of Interior, Agriculture, and Commerce to establish a working group to make recommendations for improving the federal government's ability to address the invasive species issue. As a result of these ongoing deliberations, a national campaign against invasive species was initiated. Eight major goals of the campaign include:

1) Development of an executive order to update the government's position on invasive species (signed by President Clinton, February 3, 1999);

2) Establishment of a National Invasive Alien Species Council to provide direction and oversight to federal agencies in fulfilling their roles and responsibilities for invasive species (established in June, 2000);
3) Increased interagency cooperation at the local, state, and regional levels;
4) Increased federal funding to address emerging invasive species problems;
5) Evaluation of present federal laws and regulations on invasive species;
6) Development of a national management plan for invasive species (adopted by the National Council in January, 2001);
7) Increased efforts to raise public awareness and understanding of the invasive species problem; and,
8) Increased international cooperation on invasive species issues. Interagency initiatives that are recommended by the National, Regional, and State Councils will be coordinated by interagency task forces such as the Aquatic Nuisance Species Task Force and the Federal Interagency Committee for the Management of Noxious and Exotic Weeds (FICMNEW).

One of the major goals of the National Management Plan for Invasive Species is development of a National Early Warning and Rapid Response System for Invasive Species. This paper will provide an update on the ongoing development of a National Early Warning and Rapid Response System for Invasive Plants, that will ultimately become a component of the National Early Warning System for Invasive Species in the United States.

Strategies for Addressing New Invasive Species

In order to develop a National Early Warning System for Invasive Plants, it is important to understand how early warning and rapid response fit into a coordinated framework for dealing with invasive species. The primary strategies for addressing invasive species include prevention, early warning, and rapid response. Since prevention through regulatory exclusion is estimated to be about 5% effective, the critical importance of early warning and rapid response to new invaders cannot be overstated.

A. Prevention is the preferred strategy and the first line of defense against invasive species.

Prevention includes:
- Production of export commodities in pest free zones.
- Preclearance of export commodities at ports of export through permits for entry and certification of pest free status.
- Port of entry inspection and clearance.
- Safeguarded movement of contaminated commodities to proper disposition.

These are the traditional strategies that have been used to minimize the introduction and spread of agricultural pests in the United States.

B. Early warning is the second line of defense against introduced invasive species.

Early warning includes:
- Early Detection, or finding an established population of an invasive species at or near its inception.
- Reporting/submitting a voucher specimen of the established infestation to appropriate agencies.
- Identification of specimens submitted by the detection network by reliable taxonomists.
- Vouchering of confirmed specimens as a historical record.
- Posting of potential new local, state, and national records into an appropriate (web-based) information management system.
- Literature and/or field assessments to determine its potential as an invasive species.

- Interagency partnering at the local, state, regional, national, and international level to ensure that prompt action is taken against confirmed invaders.

C. Rapid Response is the third line of defense against introduced invasive species.

Rapid Response includes:

- Rapid Assessments. Distant and on site scientific and technical support for planning and implementation of on the ground initiatives.
- On the Ground Action. Early involvement of all impacted stakeholders to:
    - Discuss the problem
    - Develop a strategic plan of action
    - Identify/Assemble available technical methodologies
    - Identify funding sources.
    - Implement the action plan.
- Quality Assurance/Quality Control through periodic assessment of progress.
- Modification of the action plan per QA/QC findings.

New Approaches for Early Warning and Rapid Response to New Invasive Plants in the United States

In recent years, there has been a growing awareness that introduced invasive species are having significant and increasing impacts on the U.S. economy, ecosystems and native species, and pose increasing threats to human health. The United States, with the greatest biome-level diversity of any nation and a large inventory of relatively intact ecosystems, is particularly vulnerable to biological invasions. Until recent times, this was not much of a threat due to the relative isolation of the North American continent. However, increased trade and travel have created many new pathways for intentional and incidental spread of exotic species, and have significantly increased the threat of new and recurring biological invasions. Increased international trade in ornamental plants (including seeds) is a special concern because many of the currently known exotic invasive plants in the U.S. were originally imported as ornamentals. Increased trade in ornamental plants with megadiversity countries such as China and South Africa will likely increase this problem. While the majority of introduced species are not harmful to the American economy or the environment, a small percentage of them are very damaging and need to be detected as soon as possible.

Once established, invasive species frequently have long lag times. Introduced species that initially escaped many decades ago are only now being recognized as invasives. Due to this lack of attention on free living exotic species, exotic plants now comprise a growing percentage of the flora of all states (e.g., HI 43%, NY 36%, MO 25%, CA 18%, TX 10%). With continual introductions over the past 100 years, it can be expected that some exotics that are not currently identified as invasive will become significant problems in the future. Thus, there is an urgent need to document and address species that were introduced in past years; as well as the potentially larger problem of the species that are being introduced today. Without a coordinated national system for early detection and rapid response which are integrated with general vegetation surveys, free living exotic plants will continue to incubate until they become the invasive plants of tomorrow – the major weeds of the 21st century and beyond.

Under the current U.S. crop protection system, federal and state plant regulatory agencies work to protect the nation from economically important plant and animal pests and diseases. However, due to a lack of resources and organized constituencies, new invasive plants (both agricultural weeds and invasive plants of natural areas) are seldom addressed on public or private land until populations become widespread and prevention/eradication becomes impractical. The recent appearance of the Brazilian floating fern giant salvinia (*Salvinia molesta* D.S. Mitchell) in 30+ water bodies in nine states, is a notable example of the problem, and has highlighted the serious need for a new and systematic approach for addressing new invasive species, and, in particular, invasive plants (Figure 3).

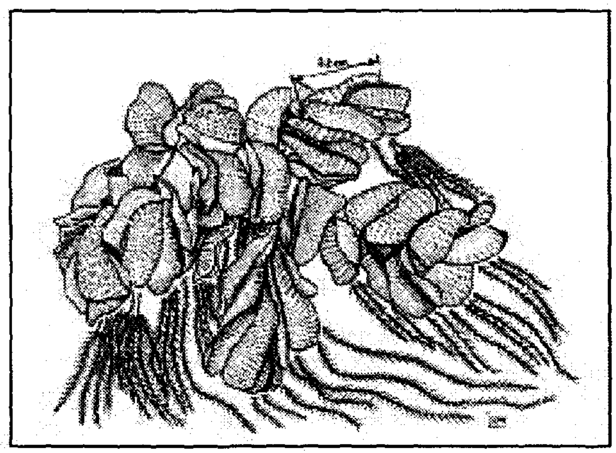

Figure 3. Giant Salvinia (*Salvinia molesta*), a floating fern from Brazil that is widely regarded as one of the worst aquatic weeds in the world, now occurs in at least 30 water bodies in nine states in the U.S.A. (Illustration courtesy of the Center for Aquatic and Invasive Plants, University of Florida).

Plan Development

FICMNEW identified development of an early warning and rapid response system as one of its long range strategic goals at the FICMNEW Planning Retreat, which was held in October 1998, in Shepardstown, West Virginia. To begin this process, the U.S. Geological Survey and the USDA Forest Service hosted an Early Warning and Rapid Response Workshop in Ft. Collins, Colorado, in June 2000. Attendees included Federal, state, industry, environmental and private landowner representatives who had been active in noxious weed or invasive plant issues. Subsequently, the proceedings of the workshop were posted on the FICMNEW Home Page. The Plan described here was first drawn from the major recommendations that were developed at that workshop, as well as relevant recommendations under the National Invasive Species Management Plan. The first draft of the plan was released for limited informal review on November 11, 2001. In mid-March, 2002, a revised draft of the plan was released for wide distribution and review by 150+ agencies and non-governmental organizations. In the near future, the plan will be posted on a number of websites, including the FICMNEW Home Page (http://bluegoose.arw.r9.fws.gov/ FICMNEWFiles/FICMNEWHomePage.html).

Following analysis of comments received, the plan will be provided to the National Council on Invasive Species staff for presentation to the National Council and Invasive Species Advisory Committee. FICMNEW will then be looking for opportunities for demonstration projects to field test the proposed Early Warning and Rapid Response System. Currently, the Invasive Species Council staff is organizing an All Taxa Subcommittee on Early Warning and Rapid Response. As this occurs, FICMNEW will work with them on integrating this plan into an overall national early warning and rapid response plan for invasive species.

System Overview

The overall purpose of the National Early Warning and Rapid Response System will be to provide a coordinated framework of public and private partners at the local, state, regional, and national levels to more effectively address new invasive plants through:

- Early detection and reporting of suspected new plants to appropriate officials
- Identification and vouchering of submitted specimens by designated botanists
- Verification of suspected new state, regional, and national plant records
- Archival of new records in designated regional and plant databases
- Rapid assessment of confirmed new records
- Rapid response to new records that are determined to be invasive.

Once fully implemented across the United States, the proposed early warning and rapid response system will provide an important second line of defense against invasive plants that will work in concert with Federal efforts to prevent unwanted introductions at the ports of entry. With both systems in place, the nation will be better able to defend against future economic and environmental losses due to "plants out of place". Refer to Diagram 1 for an outline of system elements and how information is expected to flow in the system.

Functional Elements of the Proposed National Early Warning System

Ultimately the U.S. National Early Warning System for Invasive Plants will contain a number of elements that are implemented by different groups, organizations, or agencies. See Diagram 1 for a graphical illustration of the major elements and how information is expected to flow through the system. Functional elements and potential activity areas of the proposed system should include:

A. Early Detection, Reporting, Identification, Vouchering, and Information Management.

- A volunteer network of people who observe, study, and collect plants in the USA.
- Established local points of contact (local offices that could promote detection and collection of new plants).
- Designated State Botanists to assist in developing the National Early Detection Networks, and to identify plant specimens submitted through the detection network.
- Identification aids and training for network participants.
- Voucher specimens of confirmed new state and national records.
- Web based distributive information management system comprised on new and existing online plant databases that can be simultaneously queried by one or more centralized search engines.

B. Interagency Partnering and Operations.

- Designation of a National Early Warning Coordinator to coordinate the development and operation of the system.
- Establishment of a National Early Warning Committee to provide oversight and direction in the development and operation of the system.

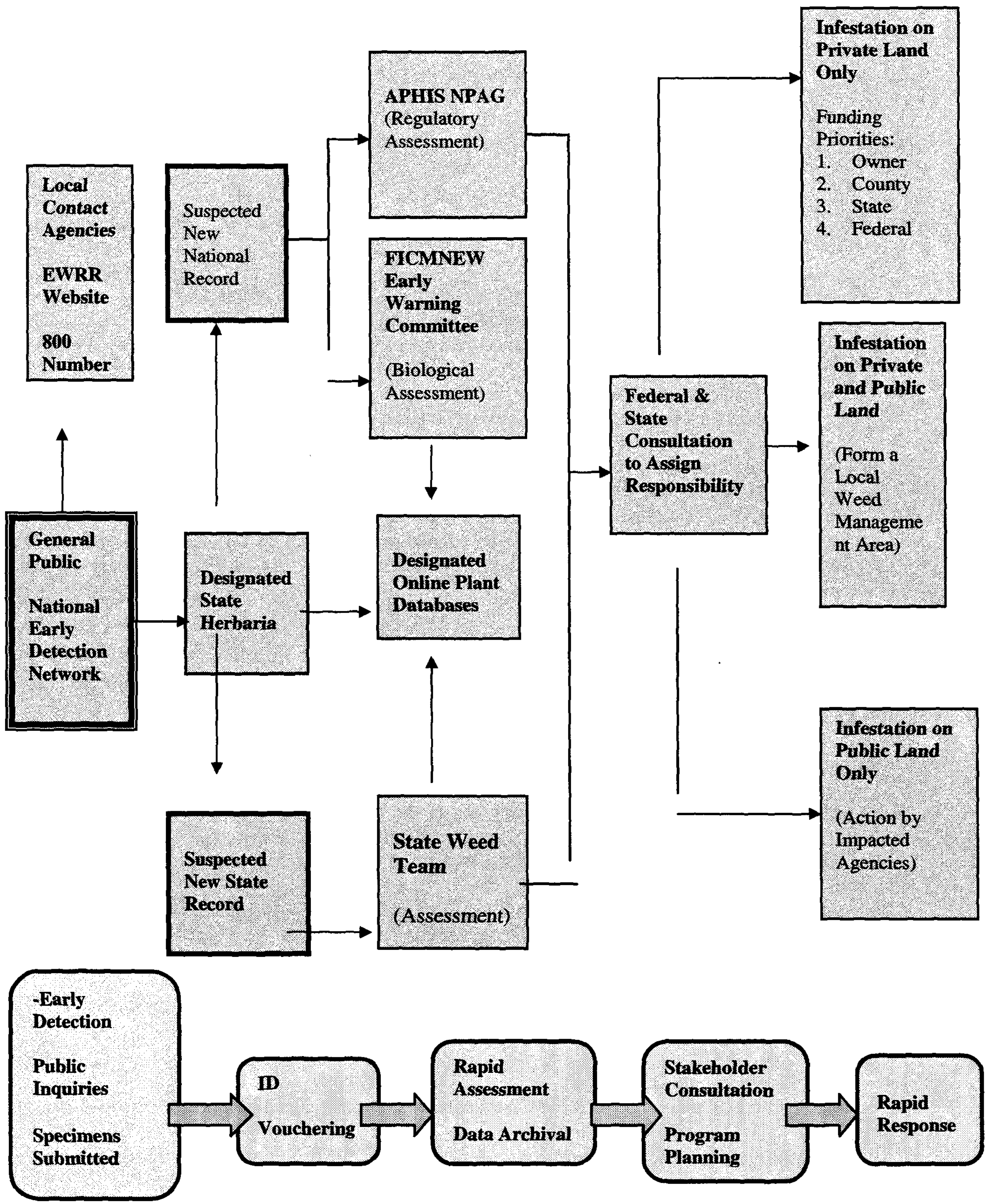

Diagram 1. Proposed National Early Warning and Rapid Response System for Invasive Plants in the United States. (NPAG: New Pest Advisory Group. FICMNEW: Federal Interagency Committee for the Management of Noxious and Exotic Weeds).

- Establishment of State Interagency Partnerships (State Invasive Species Councils, Weed Management Areas) to develop State Early Warning Systems, to coordinate on site assessments, and rapid response to new invasions.
- Development of a State Management Plan for Invasive plants, which includes elements for early warning and rapid response.

C. Rapid Assessments.

- Online and distance technical support for assessing species invasiveness, potential impacts, and available response strategies.
- Development of a classification system based on invasiveness and regulatory categories that permits land managers to assess the threat of specific taxa in a specific ecosystem to determine a proper course of action.

D. Rapid Response to confirmed outbreaks of invasive species.

- Development of protocols and contingency plans for rapid response to new infestations.
- Mechanisms for funding rapid response initiatives.

E. Public Outreach and Access to Information.

In order to detect, assess, and rapidly respond to new incursions of invasive plants in the United States, it is critical that the amazing power of the internet be harnessed. Ultimately, the goal is to provide one stop shopping on the internet for information on invasive species/issues.

- A national outreach and awareness campaign to raise awareness of the problem, and to engage the general public in early detection of new plants.
- Development of a distributive national information management system consisting of web-based databases that collect and maintain information relevant to documenting and assessing invasive plants in North America.

CONCLUSIONS

A National Early Warning and Rapid Response System is being developed for early detection, reporting, identification, and assessment of suspected new plants in the United States. Under the proposed system, populations of confirmed new state and national plant records will be assessed to determine their potential threat to various habitats and environments, and to recommend appropriate actions such as containment and eradication, or monitoring and management. Establishment of new public/private/interagency invasive species partnerships at the local, state, regional, and national level are critical to the success of this effort in the United States. *Development of a web based information sharing system about new and emerging invasive plants would be the first step in creation of an effective North American Early Warning System for Invasive Plants.*

APPROACHES FOR RESTORING AND CREATING WETLANDS IN THE WESTERN UNITED STATES

David J. Cooper

Department of Earth Resources
Colorado State University
Ft. Collins, Colorado

ABSTRACT

Wetlands occupy approximately 0.5 to 1.5 percent of the landscape in most western states and are among the most altered ecosystem types due to changes in stream flows, woody vegetation clearing, gravel and peat mining and filling. Five major wetland types occur in the interior west, including riparian areas, fens, marshes, wet meadows and salt flats, each with distinct hydrologic regimes, geochemical characteristics, flora and vegetation. All of these wetland types have been disturbed in many regions and the restoration or recreation of each type requires the use of particular data sets and analyses and techniques.

Riparian areas occupy floodplains and have been modified by large and small dams, which control stream flow regimes, as well as water diversions which deplete streams, ground water pumping which lowers water tables, and direct physical disturbances caused by diking, gravel mining, vegetation clearing and filling. Restoration can be accomplished by restoring the critical aspects of the hydrologic regime and fluvial geomorphic processes, and by reconnecting rivers with their floodplains. These activities require large-scale coordination by agencies controlling stream flows and landowners/managers downstream. Controlled releases from dams, changes in diversion schedules and releases from ditches have been used. Other riparian enhancement programs have relied primarily on plantings. The restoration of gravel mines requires a detailed understanding of floodplain water table dynamics, surface water-ground water dynamics, and desirable plant species regeneration niches, followed by careful site grading that creates suitable hydrologic regimes for native plant establishment.

Fens have been ditched and drained for agricultural use, or mined for peat production, and others have had their water supplies diverted. Fen restoration requires the reinitiating of peat accumulation processes. Restoration of ditched fens can be successful only if the flow of water can be halted, and water tables in the fens can be returned to their natural dynamics. Peat in western U. S. fens has accumulated at the rate of approximately 15-30 cm/thousand years. Hence the mining of peat bodies removes accumulation that may span the entire Holocene. The sedges and willows that dominate fens rarely reproduce via sexual processes in fens, and mined fens may remain largely barren. Plantings can be successful only if the hydrologic niche of each species to be introduced can be identified and matched to the complex hydrogeologic patterns within the mined fen.

Marshes and wet meadows are most often created as mitigation for wetland destruction, and require seasonal standing water or saturated soils, which are most successfully produced where sites are connected to the water table, but can also be created in perched and ponded environments. There is little information on salt flat restoration.

WETLAND RESTORATION AND MITIGATION PROJECTS – 1998-2001
TELLURIDE MOUNTAIN VILLAGE, TELLURIDE, COLORADO

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ABSTRACT

The Telluride Ski & Golf Company ("Telski") is the owner/operator of the Telluride Ski Area in southwest Colorado. During resort development in the 1980's, alleged violations of the Clean Water Act occurred, resulting in a United States Environmental Protection Agency (the "EPA") enforcement action. As a result of the enforcement action, Telski and the EPA developed plans for approximately 40 acres of wetland mitigation within the Telluride Mountain Village and adjoining lands. The project is outlined in a series of documents, which serve to guide the planning, design, construction and monitoring phases of each mitigation site. By following rigid guidelines established in a collaborative environment, Telski and the EPA are witnessing measurable results, as envisioned at the project's onset. It is a collective hope of all project participants that the approaches and methodologies used for wetland restoration, in the Telluride Mountain Village, can serve as a model for other wetland restoration projects in the future.

INTRODUCTION

On October 15, 1993, the EPA filed a complaint against The Telluride Company, the Telski parent organization. The complaint alleged violations of section 301(a) of the Clean Water Act, by discharging dredged and fill materials into waters of the United States without the required permits or authority. The resulting court rulings and arbitration led to a negotiated settlement between Telski and the EPA in the form of a Consent Decree (April 28, 1997), providing an operational framework for all mitigation activities to be completed by Telski. The primary objective of the Consent Decree is to further the objectives of the Clean Water Act, and to bring Telski into, and to remain in compliance with the Clean Water Act and the provisions of associated federal laws.

The Consent Decree specifically outlines the legal basis and structure that regulates the settlement agreement between Telski and EPA. It explicitly defines acreage requirements, timelines and milestone dates for completion of required tasks, civil penalty obligations, stipulated penalty obligations, definitions and terms to be used throughout the active period of the Consent Decree, and the method for termination of the Consent Decree. Additional documents provide supplementary material to the Consent Decree, the Work Plan for Wetland Mitigation: Telluride Mountain Village, and the Wetlands Management Plan for the Telluride Mountain Village.

Individual mitigation projects, and the standards by which the projects would be designed, constructed, and evaluated are defined in the Work Plan, which acts as a "living document". While most project areas were defined at the time of the court's acceptance of the Consent Decree, individual project construction plans only existed in an engineered pre-planning state. Therefore, the Work Plan allowed for the development of individual project Statement of Mitigation Goals in an iterative process between Telski, EPA and participating consultants. The phased planning approach allowed for strategic timing of individual projects, with longer pre-construction data collection periods for the more challenging sites. The Work Plan also required the development of individual project Post-construction Monitoring Plans, which outlined all monitoring parameters, targets and methodologies for each site.

The Wetland Management Plan was developed to (1) document the extent and types of wetlands and other regulated waters within the Mountain Village, (2) identify cumulative impacts to those wetlands, (3) identify potential threats to wetlands in the Mountain Village, and (4) describe procedures and techniques to be used to avoid, minimize and mitigate impacts such that there is no net loss of wetland functions and values in the Mountain Village. The Wetland Management Plan provides a complete inventory of wetland areas within the Project Area, identification of wetlands that were to be preserved through conservation easements, measures for application of fertilizers, pesticides and herbicides for the purpose of preventing the introduction of such substances into wetlands, outlines for Telski employee awareness training programs, and identification of all unavoidable future disturbance areas, and the mitigation required for those areas.

The structural framework of the Consent Decree and Work Plan have proven essential to the goals of wetland restoration in the Mountain Village. The "rules of the game" were defined and applied at the project's onset, helping to further the process of project completion. The continued success of the Work Plan, lies in its ability to be updated with additional information on a site-by-site basis, as required to achieve overall project success according to the site's Statement of Mitigation Goals.

PROJECT PLAN DEVELOPMENT

At the onset of project planning and construction in 1997, the established Work Plan project timeline specified commencement of data collection and construction activities during the 1997 season. Field data collected in conjunction with the preliminary reports developed for the Department of Justice (the "DOJ") and the EPA (Cooper, 1995), helped direct plans for the initial projects and identify supplementary pre-construction data needs for projects to be designed/constructed later. Additional planning resources were identified in historic aerial photography analysis (Finkbeiner, 1990 and 1995), reference areas, and third-party knowledge of project areas prior to the alleged violations.

Detailed monitoring of vegetation communities and hydrologic conditions in undisturbed reference areas provided the primary means of meaningful project design for all project areas. By developing an understanding of the relationships between particular wetland communities, their species composition and the supporting hydrology, project restoration goals were established based on actual wetland conditions. Pre-disturbance wetland conditions within project areas, were identified and examined on historic aerial photography and classified as a wetland type found in the Mountain Village.

The wetland communities identified as restoration reference areas include Willow-Herb, Willow-Sedge, Willow-Peat, Sedge-Peat and Pond-Sedge types. The Willow-Herb community exhibits a willow overstory with an herbaceous understory. Groundwater conditions in a Willow-Herb site vary greatly throughout the growing season, with depths below surface as great as 1 meter during mid/late summer. The Willow-Sedge complex thrives in shallower groundwater sites, with maximum groundwater depths of .5 meters during late-summer. Willow-Peat and Willow-Sedge sites have stable groundwater depths within the top 40 centimeters of the surface, and are dominated by organic peat soils. Pond-Sedge environments support a variety of sedge and rush species in an emergent environment with a maximum depth of 80-100 centimeters.

A majority of the project sites were in and around the Telluride Mountain Village Golf Course, which required planning for both wetland restoration purposes and the maintenance of a "playable" golf course. Project areas were placed in and around areas of golf play, often to the side of fairways (the mid-portion of any one hole) or bisecting fairways. Plans for the sites were developed via an iterative process between the EPA, Telski and the participating consultants, in a targeted fashion focusing on goals and objectives rather than actual earthwork requirements. While general earthwork parameters were defined for all project areas, the overriding earthwork theme in any project area focused on historic grades within the site. This approach to project development required that the design team be directly involved in the construction process to accommodate the necessary "field-fit" associated with any of the individual projects.

RESTORATION PROJECT CONSTRUCTION

Because non-traditional approaches were used in the development of the restoration plans, customary bid packages could not be distributed to qualified contractors, rather, all construction was managed "in-house". Each project was approached with an understanding of the targets for the site, but with limited understanding of the sub-surface (below existing grade) conditions in the site. Therefore, most project areas were explored by either trenching through a site, or "pot-holing" using an excavator. With the exploration of the project area, depth to any visible historic grades could be determined prior to fill removal and plans could be further refined for material disposal amounts and required project resources.

Project area exploration often also exposed complex drainage networks, installed as a part of the original construction work. Drains ranged from 6 inch plastic pipes originating in seep areas, to 3 foot wide "burrito-drains" (trenches lined with fabric and back filled with cobble). The drainage networks effectively dewatered sites, manipulated natural hydrologic pathways, and negatively influenced restoration efforts if not completely removed in and around all project areas.

As fill materials were removed from a project area, care was used not to over-excavate below the historic grade of the site. By targeting historic grades, hydrologic equilibrium was granted the opportunity to return throughout a site, and targeting historic grades exposed soil seed banks allowing for regeneration of native plant materials. Often, sites were "manicured" following the primary excavation activity to ensure that the maximum amount of non-historic or in-situ material was removed from a project area.

In sites where flowing surface waters were re-introduced into a site (either from drains or culverts), limited bio-engineering was used to reduce erosion potential and to create a stable environment which would promote desired plant growth rates. A combination of coir products (logs and fabric), cobble and mature vegetation effectively created stream channels, pond areas and dispersion zones, while allowing for future changes in the site's morphology. With the completion of the physical construction activities in a site, the site was planted with species identified from reference communities, and at densities appropriate for desired survival and growth rates.

RESTORATION PLANTING

Plant materials used in all the Telluride Mountain Village restoration projects were either grown from seed or cuttings collected from the Silver Mountain Landslide physiographic region. Willow species were grown "in-house" for the first four years of the project in a simple greenhouse. After restoring the greenhouse site, all growing was completed by the contractor who provided the herbaceous species from the project's onset. In general, survival rates for both herbaceous and woody species have exceeded 75 percent over the period 1998 – 2001, which may in-part be due to the local origins of the parent plant material.

Given the elevation range of the project area (9200 – 9450 feet above sea level), planting was completed no earlier than mid-May and no later than September of any given year. Plant densities averaged 4 plants per square yard for herbaceous species and 1 plant per square yard for woody species. In-fill planting was not a common practice, and was only employed when extra plants could be installed without disturbing the existing vegetation communities.

POST-CONSTRUCTION MONITORING

Site hydrology is monitored via groundwater monitoring wells, staff gages and flumes on a weekly basis between May 1 and October 31, annually. All hydrologic data is used to evaluate a site's hydrologic condition throughout the growing season through comparison with reference community hydrologic conditions.

Annual vegetation surveys are conducted in late-July through early-August, and consist of a complete floristic survey of a site's monitoring plots, quantification of sedge shoot growth and tiller densities, willow stem growth, and plant survival rates

Specific language from the Work Plan addresses the final reporting as follows: "Telco's final report for each mitigation area shall include a certification that the final mitigation goals of the project have been achieved and a formal on-site wetland determination defining the boundaries and the area of the completed project."

Certification of a project's final goals ties back to the individual project Statement of Mitigation Goals, where a uniform set of success criteria language addressed the following:

Initial Criteria for Success

(1) 75% survival of the rooted willow cuttings, herbaceous species seedlings and sedge seedlings and/or transplanted plugs,

(2) The annual monitoring of site hydrology demonstrates that the relationship between ground surface and ground water in the mitigation areas falls within the -3" of the -1 standard deviation or within the +3" of the +1 standard deviation of the applicable reference hydrograph(s) described in the Hydrologic Goals portion of the site's Statement of Mitigation Goals. The comparison of the mitigation site hydrology shall be based on concurrent monitoring of the post-construction monitoring wells in the mitigation site and the set of wells that comprise the appropriate reference hydrograph(s) for the site. Figure 1 illustrates a site hydrograph with the associated reference community hydrograph.

(3) Replacement planting, fencing, temporary erosion control measures, have been discontinued for at least two years,

(4) Visual inspections indicate that soil erosion or sedimentation has not occurred or has been adequately controlled on an ongoing basis,

(5) Invasion by non-indigenous wetland and upland species has not occurred or is being adequately controlled on an ongoing basis, and

(6) Growth of each of the target species is progressing in the direction of the final criteria for success of the plantings.

Final Criteria for Success

(1) For willows the final criteria for success have been attained when the plants have achieved an average height growth of more than 15 cm./growing season for three out of four most recent growing seasons and more than two new live stems per plant after three years. For *Carex sp.*, the final criteria for success have been attained when the plants have achieved an average of a 25% increase in the number of live shoots

per growing season after three or more growing seasons. For non-*Carex* herbaceous species, the Initial Success Criteria of 75% survival shall also serve as the Final Success Criteria.

(2) A formal on-site wetland delineation confirms that the boundaries of the jurisdictional waters coincide with the boundaries of the planned mitigation project area.

These success criteria reflect general parameters, which when conceived, created a quantifiable framework for determination of mitigation project success or failure. However, as the mitigation process evolved, EPA and Telski have developed a broader understanding of the reference and restoration sites, their function and the actual conditions exhibited in their individual areas. Furthermore, language relating to jurisdictional wetlands and project boundaries implies a more restricted set of wetland delineation variables than are appropriate for the work completed by Telski. This is due to the policy of restoration to historic grades rather than engineered wetland mitigation sites. While the Work Plan did establish a useful set of criteria for monitoring and analysis, the actual conditions of the site are far more dynamic than the thresholds established via the original guidelines.

CONCLUSIONS

The mitigation projects in the Telluride Mountain Village and the associated Consent Decree and Work Plan presented an opportunity for "true" restoration to occur. Fill removal extended to historic depths and areas, and sites' hydrologic regimes were restored to pre-disturbance conditions in many areas. Following restoration construction, the hydrologic conditions within the site have exhibited stable characteristics during the monitoring period, while planted and native vegetation has matured at rates in excess of the original project growth standards. Through termination of the monitoring obligations at Site 75I, we will be reducing the impacts to the site while allowing a functioning dynamic system to mature and evolve annually in accord with the natural variation of the region's climatological state.

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FIRE AS A MANAGEMENT TOOL

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ABSTRACT

Wildland fire presence and absence are some of the most significant factors influencing the composition and structure of dominant vegetation throughout high elevation ecosystems. Fire presence in many of these ecosystems is experienced in the form of high intensity, stand-replacement fires that frequently result in dramatic vegetation changes. But, these events are often within the range of historical variability and consistent with historic fire regimes. Long-term attempts to exclude fire to prevent perceived adverse effects are now recognized as a principal cause of ecosystem modification. However, the most powerful consequences of fire exclusion occur not as a result of fire occurrence but as a result of the net effects of fire absence in conjunction with delayed fire presence. Altered fire regimes, vegetation and fuel complexes pose an increased potential for fire occurrence at intensity and severity levels outside the historic range and even in excess of any previously experienced on these sites. This situation could be responsible for serious long-term adverse impacts to the site and its vegetation attributes. Restoration of natural processes and near historic conditions is becoming a highly desired and increasingly important land management goal. Acceptable methods for accomplishing restoration encompass a full spectrum of non-fire and fire treatments with varying degrees of success. Fire treatments include prescribed fire, wildland fire use, and unwanted wildland fire. This paper describes specific examples to illustrate fire as a restoration and maintenance tool in high elevation ecosystems.

INTRODUCTION

Throughout history, cultural use of terrestrial ecosystems has been responsible for both subtle and dramatic changes, sometimes undesirable in nature. In many ecosystems, federal land management during the last 150 years has placed emphasis on protection and commodity production. The protection emphasis sought to eliminate the occurrence of large-scale, stand-replacing forest fires that reduced the availability of wood fiber for a developing economy. Emphasis on commodity production accelerated timber harvesting, livestock grazing, and mining. During this time, the interaction of fire exclusion, livestock grazing, logging, mining, road building, drought, insect and disease proliferation, and spread of invasive species interacted to produce significant ecological changes in many high elevation ecosystems.

These forest health problems are most advanced in short-interval fire-adapted ecosystems, predominantly represented by long-needled pine communities (Williams et al. 1993). But, changes are also occurring in mixed fire regimes of higher elevation ecosystems where frequent low to moderate intensity and severity surface fires historically combined with infrequent high intensity stand replacing fires.

High elevation forest communities are characterized as variable-interval fire-adapted ecosystems where individual fire severity ranges between non-lethal surface fires and lethal stand replacing fires. Historically, these ecosystems consisted of a rich pattern of age classes configuring the landscape in a mixed mosaic. Widespread successful fire exclusion in combination with small-scale forest management and localized prescribed burning has resulted in severe alterations of age-class distributions. In areas where historic fire return intervals were shorter, a large-scale shift from a ubiquity of young age classes to dominance by mid-level age classes in the 100 - 170 year range is occurring, especially in the Central and

Southern Rocky Mountains . At cooler and moister locales, historic fire occurrence was probably somewhat lower. In these areas, current age class structure illustrates a trend toward greater proportions of older age class stands, strongly apparent in the eastern portions of the Northern Rocky Mountains and Greater Yellowstone Area.

Age-class modifications taken superficially may not appear unreasonable, but associated ecological alterations are pervasive in these communities, both directly and indirectly. Adjustments in stand structure, fuel accumulation, and rates of insect and disease proliferation and intensification are occurring and are responsible for undesirable amplifications in potential fire intensity, severity, frequency, and spread rates.

Ecological restoration is becoming an increasingly important land management initiative that seeks to apply ecological restoration techniques to restore forest health and reconstruct reasonable approximations of naturally functioning ecosystems. One of the primary goals of restoration is the reduction of fire risk or severity. Changes in forest structure, composition, function, and overall health during the fire exclusion period have negatively altered fire risk and potential fire severity. Worsening conditions of risk resulting from changes in ecosystem structure and composition and fuel conditions are rapidly becoming one of the most significant challenges facing land managers. In fact, a national report published in 1994 stated, "*the vegetative conditions that have resulted from past management policies have created a fire environment so disaster-prone in many areas that it will periodically and tragically overwhelm our best efforts at fire prevention and suppression*" (Report of the National Commission on Wildland fire Disasters 1994). In addition, the potential severity of fires could strongly hamper or limit rehabilitation efforts.

Wildland fire management agencies have initiated a large-scale restoration program in 2001 in response to both presidential and congressional direction known as the National Fire Plan (USDI/USDA 2000). The National Fire Plan addresses recommendations to reduce the impacts of fire on rural communities, ensure that sufficient firefighting resources are available in the future, and to improve protection of ecosystems. The program of action planned includes restoration activities that emphasize fuel treatment as the primary means to achieve restoration. Prescribed fire will be a fundamental treatment for this program but other treatment types including mechanical methods will be used in implementing this initiative.

FEDERAL WILDLAND FIRE MANAGEMENT POLICY

The Federal Wildland Fire Management Policy (USDI/USDA 1995) currently being implemented represents the latest stage in the evolution of wildland fire management. This policy directs federal agencies to achieve a balance between suppression to protect life, property, and resources, and fire use to regulate fuels and maintain healthy ecosystems. Under this policy, all fires not ignited by managers for predetermined objectives are considered wildland fires. All fires ignited by managers are prescribed fires.

All wildland fires have the same classification and receive management responses appropriate to conditions of the fire, fuels, weather and topography and appropriate to accomplish specific objectives for the area where the fire is burning. These management actions are termed the "appropriate management response" and will vary among individual fires. The concept of appropriate management response is integral to this policy. The appropriate management response is defined as the specific action taken in response to a wildland fire to implement protection and/or fire use objectives. This type of management permits a dynamic range of tactical options and allows managers to utilize a full range of responses. Management responses are programmed to accept resource management needs and constraints, reflect a commitment to safety, to be cost-effective, and accomplish desired objectives while maintaining the versatility to change intensity as conditions change.

It is important to note that the appropriate management response is not a replacement term for wildland fire use, or the suppression strategies of control, contain, confine, limited or modified; but it is a concept that offers managers a full spectrum of responses (Zimmerman and Bunnell 1998). It is based on objectives, environmental and fuel conditions, constraints, safety and ability to accomplish objectives. It includes wildland fire suppression at all levels, including aggressive initial attack. Use of this concept dispels the interpretation that there is only one way to respond to each set of circumstances. Appropriate management responses can be developed along a continuum from monitoring to aggressive suppression. Under this policy, opportunities to combine strategies on individual fires are unlimited, as is implementing a variety of options concurrently, and there is no distinction between fire types or strategic responses. Through its application, managers have the ability to maximize the opportunities presented by every wildland fire situation. With this, the federal fire policy now advocates and facilitates greater application and use of fire for accomplishing resource benefits while maintaining and implementing an effective suppression program.

GOALS OF FIRE USE AS A MANAGEMENT TOOL

The goals of using fire as a management tool in high elevation ecosystems are focused on rehabilitating vegetation structure, composition, and conditions; managing fuel complexes; and improving resiliency, stability, and overall ecosystem health. Table 1 shows the major classification of goals.

Table 1. Goals of using fire as a management tool in high elevation ecosystems.

Broad goals	**Specific outcomes**
Vegetative manipulation	Species conversion to desired condition, maintenance of species composition in desired condition
Fuel treatment/management	Hazardous fuel reduction
Ecosystem maintenance	Condition Class and fire regime maintenance
Ecosystem restoration	Condition Class and historic fire regime restoration

Vegetative manipulation includes species conversion and species composition maintenance through the application of fire. Shade-intolerant species can be minimized through fire use by opening forest canopies and promoting those species favored by full sunlight. Serotinous cones, requiring heat from fire to open, can be the source of regeneration of an entirely new forest following occurrence of a high intensity fire, either natural or prescribed.

Hazardous fuel accretion is occurring at alarming rates in many forests. While this problem in high elevation ecosystems is not magnified to the degree shown in lower elevation ecosystems, it is represented in all situations where fire exclusion has been successful. The use of fire is extremely valuable in reducing and checking unnatural and undesirable fuel accretion.

A description that illustrates past, present, and future fuel, fire, and stand dynamics in high elevation ecosystems, either with and without restoration treatments, includes three distinct stages of ecosystem development and functioning: maintenance, alteration, and degradation. These categories closely mirror fire regime "condition classes," developed in several recent publications to indicate degrees of departure from historical fire regimes, as measured in key ecosystem components such as species composition, structural stage, stand age, and canopy closure (Hardy et al. 1998, 2001; USDA Forest Service 1999; Schmidt et al. 2002).

Condition Class 1, the maintenance level, is characterized by vegetation composition, structure, and fuel similar to those of the historic fire regime and do not predispose the system to risk of loss of key ecosystem components. Condition Class 2, the alteration level, reflects vegetation composition, structure, and fuels with moderate departure from the historic regime and the system is predisposed to a higher risk of loss of key ecosystem components. Condition Class 3, the degradation level, shows vegetation composition, structure, and fuels with high departures from the historic regime and the current system is greatly predisposed to risk of loss of key ecosystem components.

Support for the use of fire as the principal method to maintain and restore fire regimes is very high. The exclusion of fire has been responsible for the shifts in Condition Classes and its use and application can serve to restore historic conditions.

OPTIONS FOR USING FIRE AS A MANAGEMENT TOOL

Options for using fire as a management tool in high elevation ecosystems are based on the application of fire use management strategies, including wildland and prescribed fire use. Prescribed fire includes those fires intentionally ignited by managers under a predetermined set of environmental and fuel conditions (prescription), controlled by an array of pre-defined and allocated control forces and /or conditions, and planned to burn only within a specified area within a definite timeframe. Wildland fire use includes those fires ignited by natural causes, almost solely confined to lightning, and managed to accomplish specified resource objectives as long as the fire remains within the capability of the managing unit, within a defined set of environmental conditions, and within a preplanned geographic area. Primary differences between these two strategies involve type of ignition, duration of burning, operational planning and written documentation, intensity and duration of monitoring and evaluation, and internal agency considerations. A specific plan is prepared in response to an ignition for wildland fire use while prescribed fires have plans prepared in advance of ignition. Uncertainty and risk are greater for widlland fire use than for prescribed fires due to the extent and duration of burning in the preplanned area.

Prescribed fire is a justifiable fire treatment in high elevation ecosystems where it can be applied under controllable conditions and can be kept consistent with prescription parameters and objectives. This strategy is capable of replicating natural fire effects and can be successfully managed to accomplish fire restoration goals in these ecosystems when management prescriptions are founded on fire history and current successional status (Brown 1993). However, the potential effectiveness of the prescribed fire has been questioned in terms of its ability to replicate historic patterns of burn heterogeneity (Despain and Romme 1991). Historical use of this strategy has been limited to silvicultural management on a relatively small scale. Objectives have largely involved site preparation in terms of reduction of fuel and competing vegetation, creation of a mineral seedbed, and facilitation of artificial regeneration techniques following mechanical removal of large volumes of overstory wood products. Some efforts have been made to show that prescribed fire can be applied to these ecosystems in support of disease control and forest health improvement (Zimmerman and Chonka 1988, 1989; Zimmerman et al., 1990).

A wildland fire use strategy offers opportunities to realize the full range of historical fire behavior and intensity and potential restoration of fire as a natural process. However, numerous limitations to widespread use of this strategy exist and will, in many cases, necessarily limit application. Issues range from fundamental resource management objectives to techniques and capability of managing long-term high intensity fire events (White and Pengelly, 1992). Conversely, the application of fire in high elevation ecosystems without excluding high intensity events must be accomplished. Spatial limitations can influence management by defining where natural fires will be allowed to fully simulate historic events or be forced into suppression status. Stephenson et al. (1991) present a case in point illustrating that there are ecological costs associated with exclusion of high intensity fire events from certain parts of the landscape. High elevation ecosystems represent a portion of the landscape that cannot be managed without high intensity fire events and where these events cannot be excluded forever.

Management options available for restoration and maintenance primarily include fire use applications, but other alternatives not limited to fire exist including mechanical and physical manipulation. Figure 1 presents general management options for using fire and other treatment types as management tools in fire-adapted ecosystems. This figure can best be described in terms of three spatial and management components: stand maintenance; fire restoration; and ecosystem maintenance.

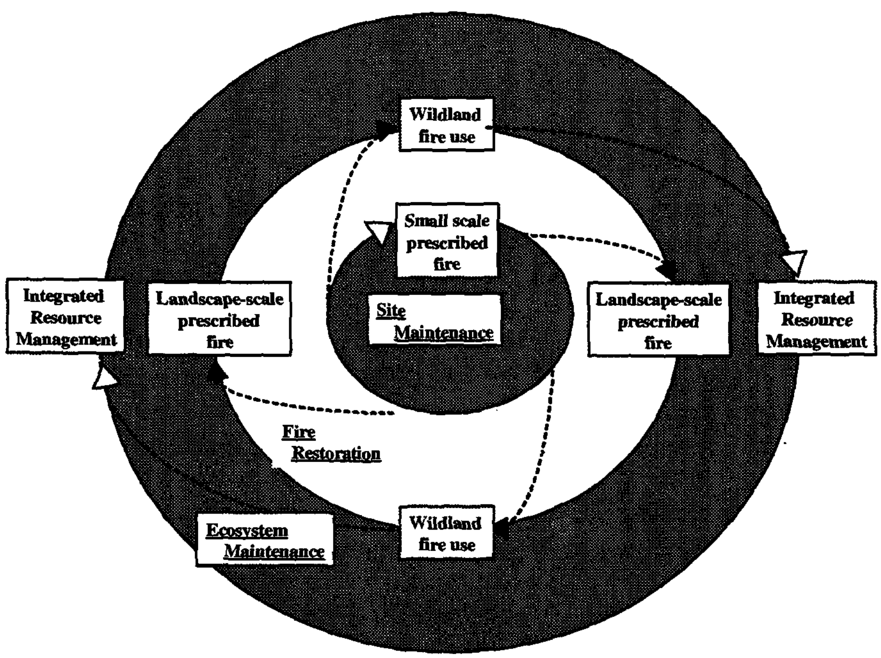

Figure 1. Management options for using fire as a management tool in high elevation ecosystems.

The stand maintenance area (diagram center) clearly illustrates historical management of many fire-adapted ecosystems. Past use of prescribed fire has been concentrated in hazard reduction and site preparation functions in conjunction with timber harvesting and stand regeneration (Crane and Fischer 1986). This use of fire has been restricted to small-scale stand management and maintenance actions. At this scale, the majority of the landscape has been left untreated with fire excluded to the maximum extent possible. Prescribed fire application at this scale represents a patch-type situation that does not replicate historic landscape disturbances such as the occurrence of large-scale stand replacement. Thus, management options here cycle directly back to themselves showing little long-term program expansion. This patch application does approximate a maintenance level of fire application by continually reducing fuel continuity and in many cases, extending the timeframe of total stand replacement from disturbance combinations. Some communities withstand repeated low intensity burns that produce moderate density, high volume stands eventually converted by fire after a relatively long fire-free interval.

The fire restoration area (diagram middle ring) represents escalation of a fire management program to include appropriate fire restoration activities. Prescribed fire, conducted on a landscape-scale, and wildland fire use can successfully advance fire restoration. Prescribed fire on a small-scale can be used to prepare and facilitate implementation of both widland fire use and landscape-scale prescribed fire. These two activities can function individually or in combination to promote mutual successes. Once a program has escalated to this level, fire restoration will begin to mimic historic ecosystem processes and reduce risks from future applications.

The ecosystem maintenance area (diagram outer ring) represents a program of ecosystem conversion and maintenance resulting from large-scale fire restoration. Successful application of natural fire and landscape-scale prescribed fire can solidify full implementation of a fully integrated fire and resource management program. Such a program achieves a necessary balance of all aspects of fire management, including fire exclusion and use. Ecosystem maintenance can be attained with replication of historic processes of age-class mosaic establishment and maintenance, regulation of fuel accretion rates, re-establishment and maintenance of cone serotiny, dynamic successional trends, regulation of insect and disease populations, and maintenance of biological diversity. Integrated management of fire as a natural process is fundamental to this concept. Management actions continue to include prompt suppression of unwanted fires coupled with timely applications of prescribed fire options and may include other non-fire management strategies.

Not all areas are suitable for full implementation of a fire restoration program culminating in balanced fire and resource management. Some areas will be limited to application of landscape-scale prescribed fire and all areas will require continued small-scale stand maintenance and stand conversion prescribed burning. Assessment of risk must accompany all potential evaluations for fire restoration. However, risk-taking initially can yield long-term benefits. As fire management programs expand from the smallest scope of stand maintenance, risk associated with fire applications will decrease with increased prescribed fire activity reducing extensive fuel associations and expediting control capability.

EXAMPLES SHOWING THE USE OF FIRE AS A MANAGEMENT TOOL

Critically important to successful use of fire as a management tool in high elevation ecosystems is s complete understanding of the historic role of fire including fire regimes, fire behavior, fuel dynamics, previous management activities, community dynamics, succession, stand establishment, and insect and disease relationships (Zimmerman and Omi 1998). Certain considerations need to be addressed prior to and throughout all fire use implementation activities. These considerations have been presented by Petersburg (1992) and modified by Zimmerman and Omi (1998) to better fit variable-interval fire-adapted ecosystems. The resultant eight considerations are prerequisite to the process of planning and implementation of fire use in high elevation ecosystems:

- **Historic Ecosystem Configuration** – a description of how the ecosystem was configured prior to the interaction of cultural activities and ecosystem dynamics.
- **Historic Role of Fire** – a description of the historic fire regime, fuel dynamics, and the effects of fire presence.
- **Current Ecosystem Description** – a summary of all quantifiable information regarding the current situation, especially the impacts of fire absence.
- **Desired Configuration or Conditions** – a description of the desired condition or desired natural processes.
- **Future Configuration without Restoration Efforts** – a description of developing trends and estimation of the future ecosystem condition without fire restoration.

- **Test Treatment and Monitor/Evaluate** – an assessment of an initial fire restoration application and continued monitoring at sufficient frequency to permit evaluation of objectives.

- **Full Treatment Implementation** – full implementation at a scale necessary to accomplish desired goals and objectives.

- **Program Monitoring and Evaluation** – monitoring of program effectiveness. Christensen (1995) states that management must be adaptive; any reasonable system must include an integral evaluation mechanism to assess the degree of accomplishment.

Numerous examples exist where the use of fire as a management tool in high elevation ecosystems has successfully accomplished the desired objectives. Several of these examples are significant enough to warrant discussion here. These examples include the wildland fire management programs and accomplishments in Glacier National Park since 1988, in Yosemite National Park since 1973, and in the Bob Marshall Wilderness since 1984.

Glacier National Park

The historic condition of the western portion of Glacier National Park was one of large areas of forest communities on ridges and higher elevation area. Lower areas supported forests intermixed with numerous meadows and openings comprised primarily of herbaceous species but also with sagebrush. Higher elevation areas supported extensive forests comprised of western larch, Douglas-fir, and lodgepole pine. In many areas below 5000 feet in elevation, pure lodgepole pine stands were common. Ponderosa pine, western larch, Douglas-fir, aspen, and Engelmann spruce were also present to varying degrees. Ponderosa pine trees were usually overstory dominants, over 200 years in age found principally on dry benchlands. This species did range onto lower ridges in association with western larch and Douglas-fir and dense shrub understories.

Fire has been a significantly influential ecological factor in determining the present composition and distribution of plant communities throughout the park. Current stand structure and composition reflect burn and re-burn patterns and differential intensity and severity. Uniform age stands represent past stand replacement fires while fire-scarred trees bear witness to past non-lethal surface fires. The patchy, more limited distribution of older stands indicates long-term fire-free intervals, possibly in excess of 200 years.

A fire history study completed by Barrett (1983) in western Glacier National Park documents nearly 300 years of fire activity. The general pattern of fire occurrence shows frequent and often extensive underburning followed by occasional stand replacing fires. Fire frequency and severity have not been evenly distributed over time. Between 1655 and the early 1800's, there were few large, stand destroying fires. After this period, large-scale stand replacement fires returned and replaced about 32 percent of the North Fork's forests and partially replaced about 10 percent. Current stands of lodgepole pine and larch date from fires in the 1800's and early 1900's. Average fire intervals vary but include occurrence of large fires of 1000-10,000 acres about every 16-23 years and major fires larger than 10,000 acres every 39 years (Barrett 1983).

Since the 1930's, five major fires have occurred in this area, even with the advent of organized fire suppression. In 1967, 6300 acres were burned while in 1988, 27,500 acres were burned in the Red Bench fire. In 1994, the Howling, Anaconda, and Adair 2 Fires combined to burn over 11,000 acres and in 2001, the Moose Fire burned into the park and affected over 50,000 acres.

Forest composition has not been significantly altered by fire exclusion to this point in time. However, many stands have not experienced fire for nearly the maximum historical fire-free period. Fuel buildups, although not yet excessively large, are increasing and isolated areas of dramatic escalation can be found. A significant mountain pine beetle infestation during the 1970s and 80s was responsible for mortality of over 50% of the mature lodgepole pine component in this area and is promoting accelerated fuel accretion.

The desired configuration will be to have low elevation sites meadow conditions restored and maintained by removing encroaching lodgepole pine trees and reintroducing fire into higher elevation stands. Fire restoration efforts are designed to re-establish and maintain historic ecosystem processes.

Management ignited prescribed fires were initiated in 1983 and resumed in 1992. Fires were successfully managed in nearly the full spectrum of fire types (low to high intensity surface fires, passive and active crown fires). The 1983 Logging Prescribed Fire has been described by Wakimoto (1984) and Kilgore (1986). This fire and later prescribed fires demonstrated that management ignited prescribed fire could be applied to lodgepole pine sites on a small-scale and achieve desired objectives. Management ignited prescribed fires applied on a much larger scale have not yet been carried out but proposals have been developed and planning is ongoing.

Wildland fire use was operational in the park prior to 1988 but seemingly did not play a major role due to spatial designations and acceptable prescriptions. Little experience was gained from the pre-1988 wildland fire use program.

Following the 1988 fire season, all National Park Service units prepared new Fire Management Plans. Approval of these plans was prerequisite to re-implementation of natural fire programs. Glacier NP's fire plan was completed, approved, and implemented in 1991. All wildland fires occurring in the park since 1988 (including the Red Bench fire) have had the appropriate suppression response taken to ensure protection of life and property, maximum firefighter safety, and efficient fiscal management. From 1989 to 1991, in the absence of a new fire management plan, wildland fire management was limited to suppression strategies only. Choosing the appropriate suppression strategy rather than automatically defaulting to the most aggressive posture has created opportunities for post-fire management actions that would have otherwise not existed. Since the implementation of the 1995 Federal Fire Policy, Glacier NP's fire management program from a one-dimensional, suppression-only approach to a substantially integrated application of multiple wildland fire management strategies.

After 1991, the park staff managed numerous wildland fire uses although until 1994 none demonstrated the potential to burn for extended durations or to affect large areas. In 1994, the Howling fire occurred which severely tested the park's natural fire strategy and management capability. Management of this fire under the wildland fire use strategy permitted continued burning for 138 days. It grew to 2238 acres in size and burned primarily in surface fuels as an understory fire. Two additional fires, managed as containment and confinement suppression actions, burned nearby the Howling Fire on Adair Ridge. These fires exhibited differential fire behavior dominated by varying levels of intensity of understory burning with the occurrence of several isolated crowning fire runs. These fires eventually burned together with the Howling fire for a combined total area of over 11,000 acres.

Without the opportunity afforded by having wildland fire burned areas in close proximity to the natural management area, management of the Howling fire would have involved much greater risk. Experience gained from the 1994 fire season, and the Howling fire in particular, has proved invaluable in recent wildland fire use programmatic modifications and improvements (Zimmerman and others 1995).

Continuing efforts to restore fire to this area involve further use of the current mosaic of wildland fire and prescribed fire burned areas. Figure 2 shows the mosaic of natural fire and management ignited prescribed fire applications and wildland fire burned areas from 1984 to 2001 interspersed through an area of over 300 square miles. Ecosystem restoration and maintenance efforts will continue to escalate and wildland fire management and application will play a significant role.

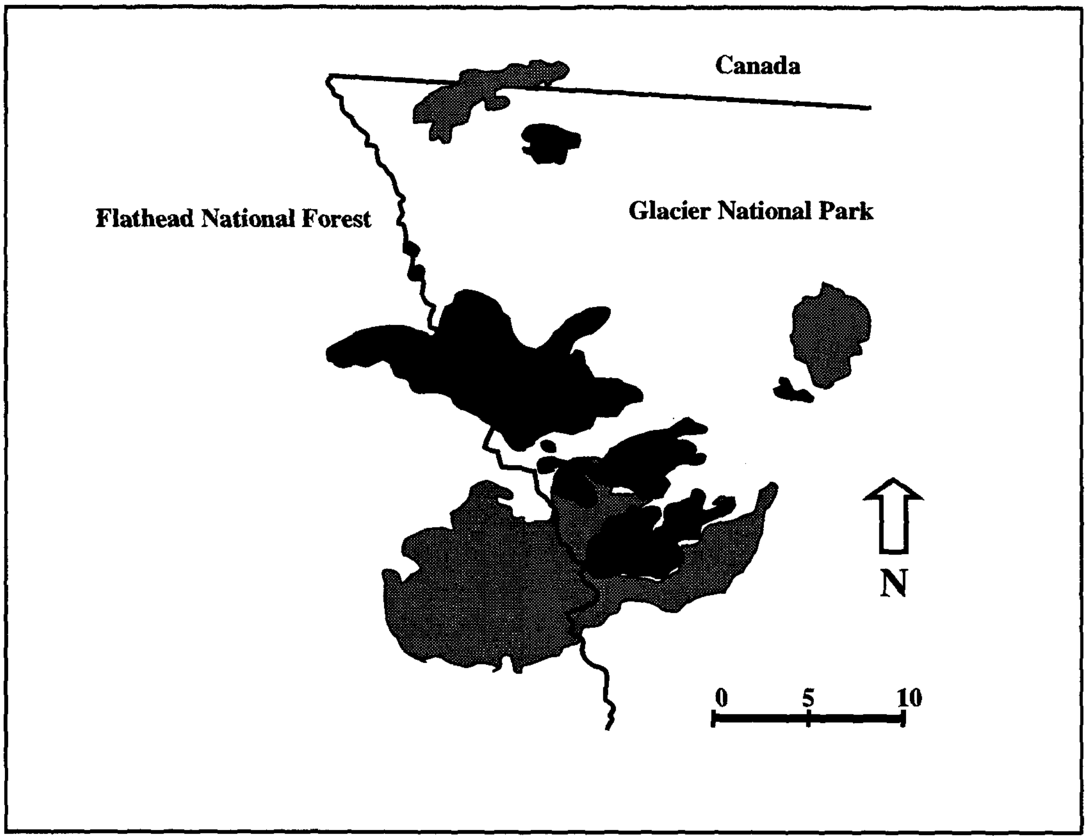

Figure 2. Large fire history in the North Fork of the Flathead River drainage in northwestern Glacier NP from 1988 to 2001 (includes prescribed fires, wildland fire use, and wildland fires). Note the mosaic of fires and the constraints placed on some fires by the presence of other burned (black versus gray).

Yosemite National Park

The historic condition of the Illilouette Creek drainage of the south-central portion of Yosemite National Park was one of large areas of forest communities of a variety of species on ridges and higher elevation areas intermixed with some meadows in valley bottoms. Higher elevation areas supported extensive forests comprised of Jeffrey pine, Red fir, and lodgepole pine.

Fire has been a significantly influential ecological factor in determining the present composition and distribution of plant communities throughout the park. Current stand structure and composition reflect burn and re-burn patterns and differential intensity and severity. This area of the park has been managed under a natural fire program since about 1968. Uniform age stands are not dominant and fire mosaics in the form of differing age classes, stand structure, and species composition bear witness to past fire occurrence.

The desired configuration will be to have low elevation sites meadow conditions restored and maintained by removing encroaching trees and down and dead fuels and maintaining fire presence in higher elevation stands. Fire restoration efforts are designed to maintain historic ecosystem processes.

Wildland fire use was operational in the park prior to 1973 but seemingly did not play a major role due to spatial designations and acceptable prescriptions. Following the 1988 fire season, all National Park Service units prepared new Fire Management Plans. Approval of these plans was prerequisite to re-implementation of natural fire programs. Yosemite NP's fire plan was completed, approved, and implemented in 1991. All wildland fires occurring in the park since 1991 have had the appropriate management response taken to ensure protection of life and property, maximum firefighter safety, and efficient fiscal management. From 1989 to 1991, in the absence of a new fire management plan, wildland fire management was limited to suppression strategies only. After 1991, the park staff managed numerous wildland fire uses and some demonstrated the potential to burn for extended durations and affect large areas. The most significant fires have been the Ill Fire, the Mount Starr King Fire, and The Hoover Fire.

Continuing efforts to restore fire to this area involve further use of the current mosaic of wildland fire and prescribed fire burned areas. Figure 3 shows the mosaic of natural fire and wildland fire burned areas from 1973 to 2001 interspersed through the Illilouette Creek drainage. Ecosystem restoration and maintenance efforts will continue to escalate and wildland fire management and application will play a significant role.

Bob Marshall Wilderness

The historic condition of the Bob Marshall Wilderness in north-central Montana was one of large areas of forest communities on ridges and higher elevation area. This area has a long history of naturally occurring wildland fires. Fire suppression efforts over the years have not reduced the number of fires but have lowered the burned area. This reduced burned area has been responsible for significant alterations in the vegetation composition, stand structure, and fuel accumulation.

Fire behavior of subsequent fires has shown an increase and has reduced the natural vegetation mosaic. Mixed severity constitutes the most common fire regime throughout the Bob Marshall Wilderness. This fire regime includes a mixture of several types of fire intensities, including lethal and non-lethal. In the 19 years since the Prescribed Natural Fire (PNF) program was approved for the Bob Marshall Wilderness, 71,757 acres have burned on the east side. This is an average of 4220 acres per year. During the 1988 fire season, 71,398 acres or 99.5% of the total acres were burned. This is representative of large, infrequent historic stand replacement events. Non-lethal low intensity fires historically occurred every 5 – 30 years, mixed severity fires every 30 – 100 years, and stand-replacement fires every 100 – 400 years. Fire suppression has been effective in eliminating the occurrence of the non-lethal fires and caused unnaturally high fuel loadings to result. In the entire Bob Marshall Wilderness Complex, 387 fires have burned since 1981 for a total of 211,354 acres. The 1988 fire season accounted for 85% of the total acres during this time period. Average acres burned during this time are about 11,000 acres.

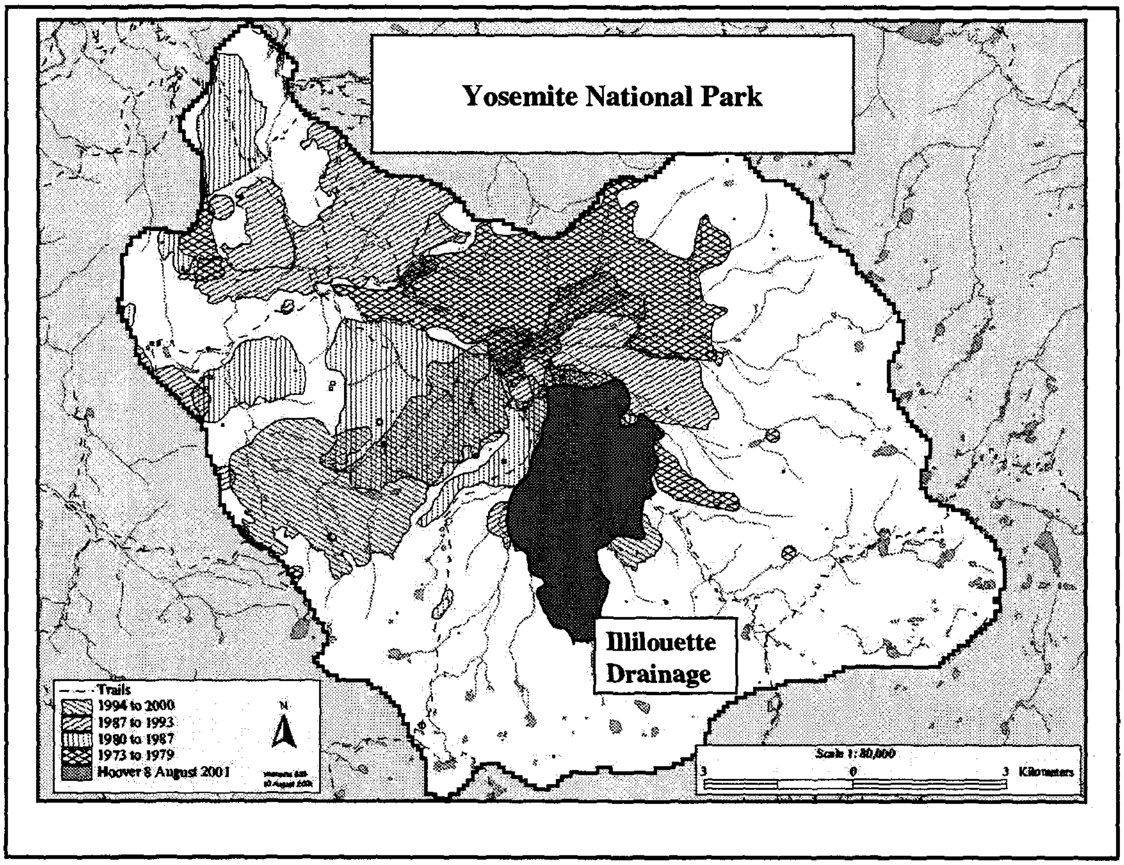

Figure 3. Large fire history in the Illiliouette Creek drainage in south-central Yosemite NP from 1973 to 2001 (includes wildland fire use and wildland fires). Note the mosaic of fires and the reburning that has occurred in many areas. This illustrates differential fire behavior and fire return events (figure prepared by Mark Grupe Yosemite NP GIS Specialist).

The desired configuration will be to have historic conditions restored and maintained by restoring fire into higher elevation stands. Fire restoration efforts are designed to re-establish and maintain historic ecosystem processes. Fire restoration will create reductions in fuel loading, changes in fuel arrangement, additional mosaic of forest stands, discontinuous fuels, and promote the occurrence of lower intensity fires in the future.

Continuing efforts to restore fire to this area involve further use of the current mosaic of wildland fire and prescribed fire burned areas. Figure 4 shows the mosaic of natural fire and management ignited prescribed fire applications and wildland fire burned areas from 1984 to 2001 interspersed through the Bob Marshall Wilderness Complex. Ecosystem restoration and maintenance efforts will continue to escalate and wildland fire management and application will play a significant role.

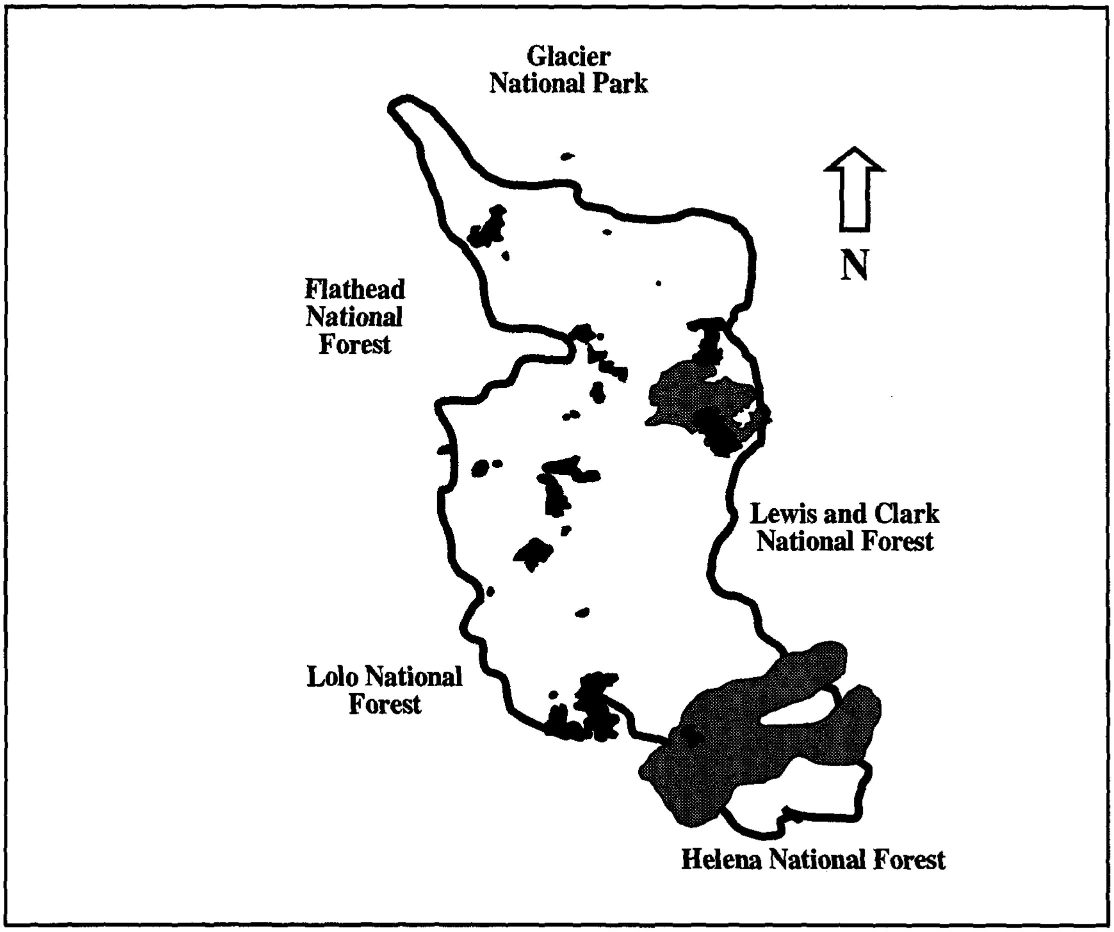

Figure 4. Large fire history in the Bob Marshall Wilderness Complex in north-central Montana from 1984 to 2001 (includes prescribed fires, wildland fire use, and wildland fires). Note the mosaic of fires and the constraints placed on some fires by the presence of other burned (black versus gray).

Large wildland fires in these high elevation ecosystems, while having immediate and short-term adverse impacts must be considered in terms of potential long-term opportunities to support integrated resource management. Burned areas adjacent to proposed prescribed fire applications, wildland fire use zones, or in close proximity to developed areas afford immense opportunities to management.

Success can be measured both by the increase of fire on the landscape and subsequent ecosystem changes. Accomplishments in all three examples clearly follow the model of fire restoration and ecosystem maintenance illustrated in Figure 1. These wildland fire management programs are actively incorporating small-scale stand management, landscape-scale management ignited prescribed fire, wildland fire use, and prescribed fire where appropriate and capitalizing on post-wildland fire management opportunities to achieve an integrated resource management level of ecosystem restoration and maintenance.

SUMMARY

Management of fire is a useful strategy for restoring the role of fire as a natural process in high elevation ecosystems. In fact, strategies for maintaining biodiversity in managed landscapes that overlook fire will not succeed. Fire presence and absence are some of the most significant influences on the composition, structure, and condition of fuels and vegetation in high elevation ecosystems.

Fire restoration and ecosystem maintenance in high elevation ecosystems represent a highly complex proposition, but one that can be successfully accomplished if multi-dimensional and multi-scale management options are applied. Prescribed fire and wildland fire use afford opportunities to apply fire for beneficial purposes. If planned operations are carefully designed and founded upon sound investigation of past fire history, current successional status, and established resource objectives, fire restoration can be accomplished. Developing management strategies that take full advantage of unwanted burned areas provide further opportunities for improving capabilities to accomplish both protection and resource management objectives. More importantly, however, is the value unwanted burned areas offer in terms of risk reduction and increasing probabilities of successful decision outcomes.

Stand-replacement fires must be included as an integral part of the array of prescribed fire strategic options. This type of fire, perhaps even unavoidable, poses considerable risk to result in undesirable and unpredicted outcomes (Despain and Romme, 1991). But, it should be remembered that any time prescribed fire is applied in forest ecosystems, there is risk involved.

Not all sites in high elevation ecosystems are suitable for fire restoration actions. Those areas significantly altered by development, under intensive management, or subject to high visitor impacts are not viable candidates for this type of management. However, those areas that fit suitability requirements warrant attention to fire restoration criteria and options. Where possible, fire restoration activities must be considered and implemented. Prescribed fire, wildland fire use, and wildland fires can accomplish the goals of fire use in high elevation ecosystems including, vegetation manipulation, fuel treatment and management, and ecosystem maintenance and restoration. Incorporation of stand maintenance and fire restoration actions will lead to successful integrated fire and resource management programs that accomplish ecosystem maintenance. Examples of successful fire use exist and others indicate a high probability of success.

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REVEGETATION ON THE CERRO GRANDE FIRE, NEW MEXICO - WHEN THE SMOKE CLEARS, BAER TAKES ON THE HOT ISSUES

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ABSTRACT

Introduction of grazing and suppression of fire in the Jemez Mountains since the late 1800s has increased forest density, which, in turn, has altered sediment and water cycling in the headwater basins. Increasingly dense forests on the hillslopes reduced available water for surface runoff and retained sediment on-site, resulting in the obliteration of first-order channels. With the loss of the forest following the Cerro Grande fire, this channel-filling sediment becomes available for erosion. In short, the headwater basins have been on a sediment binge since the late 1800s. The fire set the stage for a purge cycle. The townsite of Los Alamos and the Los Alamos National Laboratory are located near the base of these headwater basins. Community infrastructure and laboratory facilities, such as water wells, utility corridors, recreational developments and nuclear reactors, have been placed in canyons that have received negligible flow from the headwaters during the last century. This close proximity of the town and laboratory to the headwater basins defines a wildland-urban interface with greatly increased potential for storm flow and flood impacts, particularly in watersheds with a large percentage of high burn severity, and that will have short reaction times between rainfall and storm flow runoff. These are the conditions that mobilized an enormous amount of resources and personnel to carry out Burned Area Emergency Rehabilitation (BAER) after the Cerro Grande fire.

HI MEADOW FIRE REHABILITATION/REVEGETATION

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ABSTRACT

The Hi Meadow Fire started June 10, 2000, as a result of a discarded cigarette and burned 10,900 acres (5440 Federal and 5460 private). A BAER (Burned Area Emergency Rehabilitation) evaluation was started before the fire was extinguished. The final report was used in determining areas for rehabilitation and revegetation. About 1250 acres were identified as needing work on private lands and another 1250 acres on federal lands.

Rehabilitation / revegetation efforts for the Hi Meadow Fire were hampered by the time of year the fire occurred in relation to the ideal time for seeding operations. A seeding operation began the latter half of June 2000 and was completed by the first part of July. The seeding mix was selected according to species that should exist in the area, availability and price of seed, threatened and endangered species requirements, and was agreed to by USDA Forest Service and Natural Resources Conservation Service.

After the seeding was completed contract workers were brought in to contour fell trees, install rock check dams, and install straw wattles. This labor force started late-June and worked until the end of September, with about 2500 acres impacted by their work.

Problems that occurred during rehabilitation operations were afternoon rain showers and lightning, logistics with aerial wattle deployment and aerial seeding, plugging of the aerial seeder, and fumigant treatment on temporary seed cover. Some remedies for the problems are use of like size seed and avoidance of fumigants.

To utilize the increasing desire to assist in rehabilitation work for the area, a volunteer workday was planned around Governor Owens' Colorado Cares Day. Work for the volunteers included raking in the grass seed and installing straw wattles on private and state lands. About 170 volunteers provided 1360 hours of service to this effort.

About 10 months later, another volunteer workday was scheduled again for the private and state lands. This day was arranged to assist landowners in planting trees they had purchased and trees donated by numerous corporate sponsors. 262 people provided another 2096 hours of volunteer labor to plant roughly 7500 trees on the affected land.

Colorado State Forest Service is planning an additional free tree day for landowners in the affected area this spring. Funding for this project is coming from the National Fire Fund for treating and improving burned areas.

INTRODUCTION

The Hi Meadow Fire started June 10, 2000, not because of a lightning strike but because of a tossed cigarette that was not totally extinguished. By the time the fire was out, two and a half weeks later, 10,900 acres of forested land had burned including 58 structures (52 houses and 6 outbuildings).

Fifty percent of the land that burned was under federal ownership and the remainder under state, county, and private ownership. The North Fork of the South Platte River was the basic divider between the federal and other lands.

Before any rehabilitation efforts could begin, an analysis of the damage needed to be completed, thus the creation of the BAER (Burned Area Emergency Rehabilitation) Team. The BAER Team was composed of specialists from the USDA Natural Resources Conservation Service (NRCS) and Forest Service (FS) as well as the Colorado State Forest Service (CSFS). These specialists included soil scientists, biologists, soil conservationist, foresters, and range conservationist.

Upon development of the BAER Team Report, staff from these agencies as well as other entities with interests in the area, worked together to develop the rehabilitation plan. This plan included the installation of erosion control measures and revegetation plans. Identified erosion control measures were contour tree felling, straw wattle installation, rock check dams, detention basin/pond reconstruction, culvert replacement, and grass seeding.

Through this planning process, it was determined that some of the practices could not be completed in a cost-effective manner or would create a logistical and liability problem. The detention basin/pond reconstruction was the main item due to reconstruction requirements to bring structures up to current code. Culverts were also a problem relating to ownership and code. Because of these problems, these measures were subsequently removed from the plan and not completed.

REHABILITATION PROJECT

Species Selection

Grass species were selected based on whether they were native, adapted, available and cost. Our first choice was for species that are considered native grasses that would normally habitat a Ponderosa pine understory. Expected species included western wheatgrass, slender wheatgrass, Arizona fescue, Thurber fescue, little bluestem, blue grama, Parry's oatgrass, mountain muhly, junegrass, big bluegrass, nodding brome, etc.

Next we looked at availability of the grasses and cost of those that were available. This is where we started having difficulties. Arizona fescue was not readily available and rather costly. Thus it was removed from our seeding list. Parry's oatgrass and mountain muhly are not commercially available. Junegrass, big bluegrass, and nodding brome were not available in quantities needed. Hence we developed the final grass mix of 35% western wheatgrass, 25% slender wheatgrass, 20% blue grama or little bluestem, and 20% hard fescue.

During this whole process we were reminded to consider the presence of "Threatened & Endangered Species" for the area. Only one species came up, the Pawnee Montane Skipper, which likes the lower elevations just off the river in areas of blue grama and dotted gayfeather. Thus the decision to use blue grama in the grass mix. Dotted gayfeather was too expensive to add.

The estimated cost for the grass seed was $95/acre with the blue grama and $110/acre with the little bluestem. Since both mixes were used in combination with a temporary cover of white oats the final cost per acre was about $110-125/acre. White oats was included in the mix to provide for a quick temporary cover that would not promulgate from seed after the original seeding.

Financial Assistance

To be able to accomplish all the planned work, funding from the Natural Resources Conservation Service Emergency Watershed Protection (EWP) Program was needed. But a local sponsor was necessary as was buy-in from the local community. The Jefferson Soil Conservation District offered to be the program sponsor and the local community was already asking what they could do to help.

Through contacts and phone calls, cash donations were collected totaling $155,000 and in-kind services were calculated at $25,000 to meet the 25% match needed for EWP funding. Sources of donations included Jefferson Soil Conservation District, Denver Water, City of Aurora, State of Colorado, and West Arapahoe Soil Conservation District.

Operation Aerial Seeding

Through an agreement with the USDA-FS they would provide the helicopter and pilot for the entire seeding operation. With that control they determined when the helicopter was available for seeding or when it would be used for deployment of wattles. Wattle deployment was a precedent to keep sawyer crews busy installing erosion control measures on the land.

A problem we encountered with the seeding operation was with seed flow. For some reason seed was continually plugging up in the seeder and not providing good coverage on the land. From what we could determine, we assumed the problem was being caused by the awns of the blue grama and little bluestem.

Lesson Learned – Use seed that is similar in size and de-awned.

Another problem we had to deal with was weather. Afternoon showers and the usual accompaniment of lightning shut down all operations for 30 minutes to 2 hours. Any water that may have managed to get in the seeders was a guarantee to cause plugging.

The main concern we had during this entire seeding operation was the time of year we were attempting to complete the seeding. Based on all guidance we had available, the seeding operation should have been a failure. But with the good weather, opportune rains, and a lot of luck, we managed to get grasses germinated and up before winter freeze. This brought up yet another concern, winterkill due to an early freeze.

Wattle deployment was an elaborate operation completed by lashing three bundles of three wattles together and linking them to the helicopter via a remote hook. Over 4000 wattles were deployed and installed on both the public and private lands.

Lesson Learned – Staking through the wattles is critical in securing them in place.

Volunteer Assistance

Through the Governor's second annual Colorado Cares Day, we were able to mobilize 170 volunteers. These volunteers donated 1360 hours to help install 350 straw wattles and contour rake +100 acres of grass seeding.

To help coordinate this effort, community groups and agencies along with the Jefferson Soil Conservation District coordinated ground transportation into the burn area, refreshments for work crews, and medical assistance if needed.

Lesson Learned – Raked areas had a higher germination rate than non-raked areas.
Lesson Learned – Checking groups in and out with crew leaders important.

The second volunteer workday was brought about, through the interest of some corporations wanting to provide some assistance in reforesting the burned area. Thus our tree-planting project was born. Through the involvement of local community groups, schools, churches, soil conservation district, CSFS, and the corporations, we were able to mobilize a workforce of 262 people to plant 7500 trees in one day. All participants were treated to a barbecue from one of the local restaurants.

Tools for the tree planting day were acquired from the USDA-FS fire cache. About 150 – 170 tools were available and at the end we had only lost 1 pulaski and 5 shovels. Crew leaders were provided for each group of 5-7 people with training provided on how to plant trees and where to locate them. To maintain the defensible space no tree was to be planted closer than 50 feet to any structure and to promote a healthy forest, trees were to be spaced at least 20 feet apart.

Species selection of planting stock was determined by what should be in the area to provide a diverse and healthy forest stand. Trees used included Ponderosa pine and Rocky Mountain juniper as the primary species we acquired. Other trees people purchased were Douglas-fir, lodgepole pine, and Colorado blue spruce to name a few.

Lesson Learned – Better control of tool dissemination and retrieval needed.
Lesson Learned – Crew leaders needed to better oriented with area.
Lesson Learned – Set and communicate reasonable project expectations.
Lesson Learned – Plant only adapted species.

OUTCOMES OF REHABILITATION

Seeding and Planting

Seeding and planting operations in general were successful, but there were a number of problems that we needed to overcome. Our lessons learned were determined to be valuable to us and others who undertake this type of task. Overall the grass seeding is about a 50-60% success with some areas exceeding all expectations and others showing little or no response.

The tree planting exercise was entered into with an expected survival rate of 25% at best. In some areas we are seeing better survival, but like anything else there are those areas with nothing. By introducing the trees we are hoping to give the natural process a jumpstart.

Regrowth

Regrowth from burnt root crowns has made up about 40% of the current greening. The mosaic style fire that occurred was a gift since it did not get hot enough to totally eliminate the root crowns, allowing plants to regrow. Blue grama, little bluestem, yucca, wax currant, mountain mahogany, kinnikinnick, goldenpea, and geranium are just some of the native plants beginning this regrowth.

As with any regrowth there are those species that are considered to be successional plants, which we do have in this area. These plants are not considered to be a problem, but the increased occurrence of weeds is one we much monitor. In working with the Jefferson County Open Space Weed Management Specialist, the Jefferson Soil Conservation District has provided landowners cost share assistance to control noxious weeds along with grass seed to reseed those areas.

Wildlife

The quick resurgence of wildlife into the area has been a good sign that no catastrophic environmental damage has been done. Numerous deer and elk have been readily seen in the area as well as remnants of other wildlife, bear and mountain lion. Birds have seen the largest influx of population, mostly related to the increased number of insects, i.e., Pine and Ips beetles.

Other small mammals are spreading into the area from the non-burned area, as it is becoming more vegetated and stabilized. We expect a continued increase in the amounts and types of wildlife in the area.

RECLAMATION ACTIVITIES AT THE CALIFORNIA GULCH SUPERFUND SITE IN LEADVILLE, COLORADO

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ABSTRACT

Acid mine drainage (AMD) has negatively affected the upper Arkansas River in Lake County, Colorado for more than one hundred years with lowered pH's and heavy metal migration from the mining district of historic Leadville, Colorado. Since the early 1990's various Potentially Responsible Parties (PRP), environmental firms, and contractors have been working in conjunction with the Environmental Protection Agency (EPA) and the Colorado Department of Public Health and Environment (CDPHE) under CERCLA (Superfund) to remediate contaminated surface water flowing from California Gulch, Lake County, Colorado and its tributaries.

Two areas within the California Gulch Superfund Project covered in this paper are: Oregon Gulch and Stray Horse Gulch. In order to effectively control the AMD within these areas, EPA Region 8 implemented site-specific programs that included: rehabilitation and preservation of mine dumps and structures, water diversion channels around historic mine dumps and piles, detention and retention ponds for clean and contaminated water, and an aggressive revegetation program designed to reduce erosion and improve water quality within the area. Much of the work conducted in the mining district has been highly successful, with improved water quality and mine structure preservation, while other aspects of the project have experienced shortcomings such as: aesthetic modifications disagreeable with the local community and revegetation areas infested with exotic weed species.

INTRODUCTION

Leadville, Colorado a mountain town with a rich history in mining has endured many booms as well as busts to its local economy. For over a century, mineral extraction east of town has taken its toll on the environment. Throughout the mining district, large piles of mine spoils and tailings reveal where mines once operated. Typically, the larger the pile, the deeper and often more prosperous the mine operation was. These exposed mine piles are where the problem lies. Acid Mine Drainage is the end product of water exposed to these piles, either through the groundwater or surface water flows. Eventually the AMD flows into the Arkansas River Drainage resulting in lowered pH levels and increased heavy metal concentrations.

Under the Comprehensive Environmental Response Compensation Liability Act (CERCLA), EPA Region 8 has integrated an extensive response to the AMD problem by implementing an aggressive engineering and construction program that has involved numerous consulting, engineering, and contracting firms, as well as private and educational entities. The objectives have been the same from the start: clean up the water, preserve the historical features, and reduce further erosion of mining district soils. Much of this was achieved through geosynthetic-lined channels for diverting run-on water away from mine spoils, riprap-lined channels to collect contaminated water off of the piles, retention ponds for holding runoff water, vegetation mats and geotextile fabrics to reduce erosion, and revegetated capped piles to hold tailings material in place and improve water quality.

The mining district of Leadville is comprised of several areas. The main and most noteworthy is California Gulch, which is the main tributary flowing out of Leadville that feeds into the Arkansas River south of town. California Gulch is significant because it drains most of the tributaries within the mining district. Oregon Gulch and Stray Horse Gulch are two of the contributing tributaries to California Gulch's collection. Oregon Gulch and Stray Horse Gulch are the topics of this paper, and thus will often be referred to as Operable Unit 10 (OU-10), and Operable Unit 6 (OU-6) respectively. Both of these Operable Units required a remedial effort that strived to control the leaching of heavy metals, and to manage the acid runoff from the mine waste piles. The difficulty of this project lies in the fact that these areas are between 10,000 to nearly 12,500 feet above mean sea level (msl). Not only does this restrict the work season for reclamation, but also the growing season for revegetation, mixed with monsoonal summer rains, deep winter snows, and an otherwise inhospitable environment, the success of this project is worth noting.

SITE CONDITIONS

Located east of Leadville, the site conditions for much of the California Gulch Superfund site consist of gradual slopes and valleys climbing to the Mosquito Pass mountain range. In its natural state these slopes are classified as Troutville Series soils which have "moderately coarse textured glacial till – sand, stones, cobbles, and gravel, and are well drained soils" (SCS, 1975). In its present state these areas are interlaced with mine waste piles and dumps. The natural vegetation throughout the mining district consists of lodgepole pine, Engelmann spruce, subalpine fir, sagebrush, rabbitbrush, common juniper, and an assortment of grasses and forbs. The south and west facing slopes are drier, less vegetated and more susceptible to erosion, and the north facing aspects are primarily forested and shaded. Once disturbed, the vegetation on and around the waste piles is virtually non-existent, with the exception of islands of biodiversity where soils have accumulated over time and native propagation has occurred.

The climate of Leadville is of the semi-arid, continental type characterized by deep snows and subzero temperatures in the winter, and cool to mild temperatures with desiccating winds in the summer. The one exception is the monsoonal rains in late July and August that are especially detrimental to the erosion and transport of mine waste into riparian environments. The high altitude sun and cloudless days can readily evaporate any available moisture for plant uptake, and the cool mountain evenings and soil temperature can hamper seed germination.

SURFACE WATER IMPROVEMENTS

Before construction began, free flow AMD water migrated into the Arkansas River at an alarming rate. In California Gulch the Yak tunnel produced the bulk of it, with a steady stream emanating from the underground workings of the tunnel. Once the mines had ceased their extraction practices, dewatering also ceased, and thus the water table would rise and AMD water would find the surface. Since then, Asarco (American Smelting and Refining Company) has built a water treatment plant downstream of the Yak tunnel to treat the effluent before sending it downstream to the Arkansas River. While the treatment plant has had great success in treating the tunnel effluent, the capital costs and logistics of the region make this an impractical solution for the entire district. For example: the numerous waste rock, spoils and tailings dumps littered throughout the mining district that for years have eroded into nearby creeks and streams and ultimately flow into the Arkansas River cannot possibly be treated with individual treatment plants.

Throughout the Stray Horse Gulch remedial activities area, various groups have documented the effects of lowered pH and increased metal concentrations in the run-on and runoff water by sampling water both on the surface and underground. In particular, Colorado Mountain College (CMC) has played an integral part in this sampling program. The following tables illustrate the contaminants of concern, as well as a couple of key sampling points within Stray Horse Gulch.

The following data was compiled for this paper by Brent Scarbrough of Frontier Environmental Services, Inc. Contributors involved in the coordinated sampling included Rocky Mountain Consultants, Inc. (RMC), working on behalf of Colorado Department of Public Health and Environment (CDPHE); and Colorado Mountain College (CMC) Natural Resource Management Institute (NRMI), working on behalf of U.S. Environmental Protection Agency (U.S. EPA). Laboratory testing was conducted by the U.S. EPA Region 8 Laboratory. (RMC, 2001)

Table 1. Storm Water Runoff Contaminants of Concern prior to remedial actions.

Contaminants Of Concern	Range (mg/kg)	Average (mg/kg)
Arsenic	0-3.690	0.334
Cadmium	0-2.499	0.073
Lead	0-116.736	10.212
Zinc	0-131.925	11.020
pH	0.9-8.5	5.0

Table 2. Water Quality Data at Adelaide Park One Week After Peak Runoff.

	Adelaide Park – SHG 7*				
	Average 1996 (μg/L)	5/20/98 (μg/L)	5/26/99[1] (μg/L)	5/11/2000 (μg/L)	5/23/2001 (μg/L)
Arsenic	3.2	ND	ND	5.0	5.0
Cadmium	13.1	22.4	38.3	37.0	25.9
Lead	19.5	20.7	39.1	40.0	22.2
Zinc	1290	2290	4230	2410	2470
pH	6.5	5.4	5.0	5.2	5.4

*Note: SHG 7 is located near the headwaters of Stray Horse Gulch, and thus is more representative of an undisturbed area.

Table 3. Water Quality Data at 5th Street Headwall, Outlet of Stray Horse Gulch.

	5th Street Headwall – SHG 9A*				
	Average 1996 (μg/L)	5/20/98 (μg/L)	5/26/99[1] (μg/L)	5/11/2000 (μg/L)	5/23/2001 (μg/L)
Arsenic	45	ND	12	ND	5
Cadmium	1220	1580	911	1040	372
Lead	859	817	567	435	253
Zinc	160,000	218,000	125,000	170,500	47,700
pH	3.0	2.2	3.1	3.2	3.4

*Note: SHG 9A is located at the outlet of Stray Horse Gulch, and thus is representative of an area disturbed by mining.

(Stray Horse Gulch experienced significant thunderstorm events during the summer of 1999. The May 26, 1999 and June 16, 1999 sampling events were taken during two of these high flow runoff events. Average total suspended solids exceeded 4,330 mg/l.)

OREGON GULCH TAILING IMPOUNDMENT OU-10

Under CERCLA, the Resurrection Mining Company awarded the design and engineering for OU-10 to Montgomery Watson and Shepherd Miller, Inc. to be contracted to Nielsons, Inc. in 1998, and completed in 1999. "The Oregon Gulch Tailing Impoundment is located approximately one-half mile south of Leadville and is part of Operable Unit 10 of the California Gulch Superfund Site. The impoundment was regraded in the summer of 1998 and then covered with a geosynthetic clay liner (GCL) and geocomposite drainage layer. An 18-inch thick layer of topsoil was then placed over the top portion of the impoundment. An 18-inch thick layer of 3-inch minus rock was placed on the embankment. The topsoil was amended with 20 tons/acre of manure and the site was seeded in the fall of 1999. This remedial action followed the EPA's Record Of Decision (ROD) for Oregon Gulch Operable Unit 10 of the California Gulch Superfund Site dated August 1997" (Shepherd Miller, 2000).

"The construction activities at OU-10 were completed in accordance with the design drawings and specifications presented in the Remedial Design for Oregon Gulch Operable Unit 10, and modifications to the specifications that were required to improve implementation of the Remedial Design based on site-specific field conditions"(Montgomery Watson, 1999). These activities included: removal and treatment of approximately 600,000 gallons of tailing pond water within the impoundment, excavation and removal of pond sediments, excavation and removal of tailing contaminated sediments from the channel and overbank areas, and construction of riprap-lined channels. Erosion control was implemented using straw bales and silt fencing. Limestone was used in some of the channels as a passive treatment system. Filter fabric and riprap was used to armor the channels. Also, erosion control matting, mulching and seeding was incorporated in all overbank and outlying areas.

The primary remedial action of OU-10 was the construction of a tailing impoundment. Approximately 98,800 cubic yards of material was removed from the tailing pond. The surface was regraded and prepared for placement of a geosynthetic clay liner. The prepared surface was then filled with materials from the tailing pond, lower Oregon Gulch, and California Gulch. Approximately 32,700 cubic yards of topsoil was placed in an 18-inch layer on the top surface of the impoundment, and approximately 20,600 cubic yards of rock cover was placed in an 18-inch layer on the embankment slopes (Montgomery Watson, 1999). Finally, a seep collection system with associated pipes and fittings, and a series of diversion ditches was incorporated with the design of this reclamation project.

RECLAMATION ACTIVITIES IN STRAY HORSE GULCH OU-6

Starting in the summer of 1996 and continuing to present, EPA Region 8 has implemented a phased approach of site-specific remedial projects throughout the OU-6 Stray Horse Gulch drainage. Frontier Environmental Services, Inc. (Frontier) has been involved in the design, implementation, and construction aspects of the OU-6 Remedial Actions for Phases II through V (1998 through 2001).

Through the superfund process, EPA investigated the various California Gulch Superfund sites with respect to:

- Public Health
- Environmental impact of acid mine drainage on the Upper Arkansas River ecological system
- Environmental impact of wind deposited heavy metal contamination on the local community of Leadville

- Evaluated and studied each of the identified sites for each of the Operable Units for ARARs environmental remedial alternatives selection (ARARs – Applicable or Relevant and Appropriate

Requirements are the environmental regulations from programs other than Superfund that may be desirable to apply to activities at Superfund sites).

- Provided for the design, engineering, and construction drawing of proposed remedial alternatives
- Solicited public comment to the alternatives
- Implemented construction of the selected environmental remedial alternatives

(Frontier, 2000).

Much of the reclamation conducted in Stray Horse Gulch under the storm water management concept, consisted of a series of diversion channels, retention and detention ponds, recontouring of mine waste piles, reinforced concrete pipe (RCP) lines, and a cap design. The retention ponds were lined with clay to retard sub-soil seepage, and sized such as to maximize surface evaporation. Run-on water was rerouted with geotextile-lined and vegetated channels to keep non-contact surface water channeled away from AMD generating materials, and to maximize the efficiency of the storm water management collection area. Mine tailings contact water was collected in a similar fashion, with geotextile-lined riprap armored channels to collect the contact storm water and construction of retention/detention ponds to contain the mine tailings and waste rock contact water. Structural weirs were employed to add an element of support to the channels and large boulders were implemented as velocity dissipaters in channels where the grade required it. Overflow weirs were included in all retention/detention ponds to provide emergency earthen embankment spillways. Finally, in areas where rock-lined channels were inappropriate, below-grade RCP storm water lines with drop box/man-hole covers were installed to divert both contact and non-contact mine tailings surface water around mine tailings areas.

In addition to improving the environmental stresses within Stray Horse Gulch, the basis for selected construction design was influenced by historical preservation interests and comment provided by private citizens, the City of Leadville, Colorado; Lake County, Colorado; and the State of Colorado Historical Preservation Office. Design support activity provided by the construction effort included acceptable in-the-field construction techniques and methods for the preservation and rehabilitation of historic mine features (Frontier, 2000).

REVEGETATION

Oregon Gulch OU-10

The success of revegetation on the Oregon Gulch Tailing Impoundment from September 2000 is illustrated here after one growing season: total canopy cover was nearly 70 percent, with litter cover averaging 17.6 percent. Rock cover was 2.5 percent and the amount of bare ground present was 10.2 percent. The most dominant species was knotweed (*Polygonum erectum*) at 15.1 percent cover, yellow sweetclover (*Melilotus officinalis*) at 12.2 percent cover, lambsquarter (*Chenopodium album*) at 7.8 percent cover, mountain brome (*Bromus marginatus*) at 6.3 percent cover, alfalfa (*Medicago sativa*) at 6.2 percent cover, cheatgrass (*Bromus tectorum*) at 5.0 percent cover, and slender wheatgrass (*Elymus trachycaulus*) at 3.8 percent cover (Shepherd Miller, 2000). The plant canopy cover was measured with the point method using a vegetation sighting scope. Cover was measured by transect method where a total of 100 points were indiscriminately collected along six 100 meter long randomly placed transects. Cover was measured for each individual species encountered. With a nearly 75 percent total plant cover, whether weeds or natives, these are excellent results after one growing season.

Stray Horse Gulch OU-6

In Stray Horse Gulch, these results were not as easily duplicated after one growing season. Reclamation in OU-6 was achieved by providing a basic topsoil (biosolid) layer amended with fertilizer (BIOSOL), then seeded, and in some cases mulched, or applied with straw/coconut mats. After recontouring and/or removing mine materials, often what was left was an undesirable, dry, rocky, hard to revegetate piece of earth that had lost its organic material to historical mining and storm water system construction activities. Trying to replace what originally took centuries to build is not easy, and often not achieved for many years. Without an adequate supply of topsoil, two approaches that have been implemented for revegetation in Leadville are: the ameliorative and adaptive approaches. Ameliorative is chemically altering the soil to correct the problems within it, and the adaptive approach involves selecting plants, which are adapted and tolerant of the site conditions (Williams and Bellitto, 1996). "Although developed and used in Europe since the 1960's, it is believed the first successful utilization of these approaches on the North American continent was at the California Gulch Superfund site located near Leadville, Colorado in 1992." (Williams and Bellitto, 1996).

The Hamms tailing pile located on East 5th Street in Leadville has been an ongoing project in the OU-6 remedial work plan. After recontouring and adding the necessary water diversions, between 30-50 tons/acre of composted sewage sludge (Summit Grow – from Summit County) was added by a front-end loader, and spread by hand. Next Biosol was added at approximately 1500 pounds/acre by broadcast method and then seeded (by broadcasting) at an application rate of 40 pounds pls/acre. On slopes greater than 3:1 that rate was increased. This was and still is the largest revegetation project in Stray Horse Gulch, and continually requires re-seeding. In 1998, after the first season of growth, only patches of seeded growth had taken root, and more seed was added. The following year 1999 displayed vigorous growth throughout the pile, however much of it was due to the aggressive nature of the weeds that were not part of the seed mix. It was postulated that the weed seed emanated from the compost mixture. The weeds that were most prevalent on the pile in 1999 were: Shepherdspurse (*Capsella bursa*) an annual from the Mustard family, Blue mustard (*Chorispora tenella*) also an annual mustard, and most especially Field pennycress (*Thlaspi arvense*) another annual from the Mustard family. In 2000 and 2001 there was strong evidence that the native plants were making a comeback, but some thistle and many mustards were still thriving.

The seed mix used for nearly four years in OU-6 was:

Common Name & Variety	PURE	GERM.	ORIG.
• Tufted Hairgrass	18.40%	87%	CAN
• Beardless Wildrye, Shoshone	16.85%	95%	MT
• Creeping Meadow Foxtail	10.20%	85%	WY
• Regreen	9.42%	92%	MT
• Mammoth Wildrye, Volga	9.32%	93%	CO
• Sheep Fescue, Covar	5.63%	77%	WA
• Mountain Brome, Bromar	5.63%	77%	CAN
• Rocky Mountain Penstemon, Bandera	5.35%	81%	CO
• Cicer Milkvetch, Monarch	4.82%	90%	WY
• Arizona Fescue, Redondo	4.56%	95%	CO
• Slender Wheatgrass, San Luis	4.42%	98%	WA
• Blue Flax	3.33%	80%	WA

Also, used in conjunction with the OU-6 seed mix is the very well established Climax mix. For high altitude applications, these species have been selected to perform the best. This is an example of the adaptive approach to revegetation.
The Climax mix:

Common Name & Species	% BY WEIGHT
• Rye (*Secale cereale*)	20
• Smooth Brome (*Bromus inermis*)	13
• White Dutch Clover (*Trifolium repens*)	10
• Creeping Foxtail (*Alopecurus arundinaceus*)	9
• Creeping Red Fescue (*Festuca rubra*)	8
• Hard Fescue (*Festuca ovina*)	7
• Timothy (*Phleum pratense*)	5
• Orchard Grass (*Dactylis glomerata*)	5
• Cicer Milkvetch (*Astragalus cicer*)	4
• Arizona Fescue (*Festuca arizonica*)	4
• Kentucky Bluegrass (*Poa pratensis*)	3
• Redtop (*Agrostis alba*)	3
• Big Bluegrass (*Poa ampla*)	3
• Canada Bluegrass (*Poa compressa*)	2
• Canby Bluegrass (*Poa canbyi*)	2
• Yarrow (*Achillea lanulosa*)	2

By selecting acid and drought tolerant species of plants, as well as cold season natives the EPA and the U.S. Forest Service in consultation with Colorado State University's Horticulture Department developed this high altitude seed mix. Some of the more prosperous plants in the mix are: Tufted Hairgrass (*Deschampsia caespitosa*), which thrives in acidic environments, Cicer Milkvetch (*Astragalus cicer*), a legume that adds nitrogen to the soil, and Sheep Fescue (*Festuca ovina*), a drought and cold tolerant bunchgrass that works well in reclamation. Along with low pH tolerance, a few plants in the mix that are well suited to high levels of Pb, Cd, Zn, and As are: Red Fescue (*Festuca rubra*), Timothy (*Phleum pratense*), and Yarrow (*Achillea lanulosa* or *millefolium*) which have all had great success in Leadville. The plant cover on the Hamms was not "officially" or scientifically measured for results of this paper, however, based on its visual success other revegetation projects within OU-6 were replicated in much the same manner. On the outward slopes of each of the pond embankments of the Pyrenees, RAM and Greenback, Mikado, and Highland Mary mines, the revegetation is excellent, and virtually free of weeds. The reason for this reduction in weeds was that no Summit Grow was used in this revegetation work, only straw or in some cases coconut mating with BIOSOL and seed.

DISCUSSION

Improvements to both OU-10 and OU-6 are clearly evident from a visual standpoint. The AMD problem is slowly, but very steadily improving, and the erosion of mine waste piles is decreasing because of increased contouring, stabilization, and vegetation, as well as less contact with surface water through water diversion. Sediment loading of rivers and streams has decreased during major storm events, the pH has been rising while dissolved and total metal concentrations have decreased. These are the positive attributes of the work completed thus far.

In evaluating the successes of this project, the fact remains that some public opinion on the work conducted here has been negative. In 1997, the work completed by the EPA in Phase I (1997) on the Wolftone, Maid of Erin, and Mahala waste piles drew staunch criticism from the local community. The recontouring of these piles was intended to simulate turn of the century workings to preserve the historical significance of the mining district, yet also reduce the erosion of the material. After the addition of a wear resistant dolomitic cap, the piles, especially the Maid of Erin resembled a "wedding cake". The preservation of the cultural and historical structures and piles within the mining district has been a stalling point for the progress of reclamation, so with lessons learned, a more aggressive water diversion program was employed rather than specifically addressing waste pile materials.

In assessing the effectiveness of the revegetation program in the California Gulch Superfund project the weed problem is worth discussing. Unknown to the Phase II work crew of the OU-6 project at the time, composted sewage sludge (Summit Grow) that was spread throughout the entire Hamms reclamation site contained weed seed. This seed came from the compost solids and not the commercial products such as BIOSOL or erosion control materials. In addition, none of the above mentioned weeds are found in the Stray Horse Gulch or surrounding areas naturally or to any great extent through introduction. However, with the application of the Summit Grow these plants have thrived in these areas of revegetation. According to the completion report of OU-10 the same thing happened there, but with species more indicative of Front Range plants. The big question here is: Does having weeds that are known to be exotic and invasive pose a threat to the reclamation process through the potential spread to outlying areas? Many of these weed seeds are very persistent, and thus without proper heat in the thermophilic stage of composting, they will survive and spread as seen in this and other projects. Through several years of observation on the OU-6 project, there has been no indication that the weed species have spread from the isolated revegetation projects and there is evidence that the native plants are slowly out competing them for resources. The thought here is that if these potentially prolific plants can establish a plant base to hold onto the soil medium and produce biomass with each years "die-off", then perhaps this will help the natives to eventually overtake and out compete these annuals for the life of the reclamation. Once vegetation is established, the reduction in erosion will benefit the water with reduced turbidity, reduced metal loading, increased pH, etc. Keeping any vegetation in mine land reclamation, whether native or introduced is beneficial. Many of these waste rock and tailing piles are completely devoid of any organic material, keeping a cap of clean soil and vegetation in place to shed water and contain the tailings is the ultimate goal of revegetation.

Finally, in evaluating the progress of work performed at the California Gulch Superfund site, it's evident that there is still remedial work left to be accomplished. Many sulfide containing and/or pyritic rock piles are still littered throughout the area contributing AMD exposure to the Arkansas River Drainage. However, with the retention of much of the contaminated water and several seasons of strong revegetation in what was once an otherwise barren landscape, the California Gulch Superfund remedial efforts are working. In addition, the Mineral Belt recreation area running through the mining district is adding an increased awareness of the cultural and historical significance of the mining district for people who visit. Overall, the Superfund action for OU-10 and OU-6 is not only helping to clean up the soil and water, but also improving the visual landscape.

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SENECA II MINE RECLAMATION PROGRAM

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HISTORY

Seneca II Mine is a surface coal mine situated 7 miles southeast of Hayden in Northwest Colorado at an elevation of 7,500 to 8,800 ft. Seneca II Mine began production in 1968, producing coal from the Wadge and Wolf Creek coal seams in the Williams Fork coal formation. Two draglines were utilized in mining the rough terrain of Davis Mountain. The coal seams dip at 20-35 percent throughout the mine site, making reclamation activities challenging. Routt County receives an average of 150 inches of snow each winter and the growing season is short with approximately 60 frost-free days. All of the coal produced at Seneca II Mine was hauled directly to the Hayden Station Power Plant, which is operated by Excel Energy. During the 30 years Seneca II Mine was in production, over 30 million tons of low sulfur, high BTU coal was delivered to the Hayden Station. During operation of Seneca II Mine, from 1968 to 1998, Seneca disturbed and reclaimed over 1,800 acres of mountain shrub land. Through various changes in the law and technology advances, Seneca has produced outstanding reclaimed lands (Figures 1a and 1b). The efforts of the past 10 years are the focus of this paper, particularly the native species revegetation efforts and research, shrub planting, livestock grazing plan, and wildlife habitat enhancements. More background and parent company information is available on the Peabody Energy Website. (http://www.peabodyenergy.com)

PROGRAM HIGHLIGHTS

Revegetation Program

The mountain shrub zone entails a plethora of valuable plants for revegetation, and Seneca strives to revegetate with native species. Seneca has concentrated on reestablishing native grasses, such as Western wheatgrass, Bluebunch wheatgrass, Mountain bromegrass, Sheep fescue, and others. Along with the grasses, Seneca reclamation specialists incorporate numerous forbs such as Yarrow, Rocky Mountain Penstemon, Arrowleaf Balsamroot and many more (Table 1). Of particular interest is the outstanding survival and success of native shrub plantings in the past five years. Seneca reclamation specialists contracted with Bitterroot Native Growers in Corvallis, Montana, to custom grow seedlings from seed collected at Seneca II Mine. Local genotypically adapted seed, shrub plot preparation, intensive weed control, site location, and topsoil amendments have resulted in a survival rate in excess of 70 percent. Throughout the past ten years, Seneca and Bitterroot have planted 191,030 seedlings on Seneca II Mine reclaimed sites (Table 2). Native seedling establishment has high priority at Seneca II Mine. Snowberry, Scrub Oak, Serviceberry, Chokecherry, Aspen, Woods Rose, Big Sage and Antelope Bitterbrush are the primary species for revegetation. Seneca and Bitterroot personnel have conducted research over the past few years to improve the survival of native shrubs on reclaimed land. Studies were undertaken to assess survival rates, herbivore control methods, optimum topsoil depth, and microbial relationships, which resulted in Seneca II receiving the 1996 Outstanding Revegetation Initiative Award from the Colorado Division of Minerals & Geology. Seneca II also received the Office of Surface Mining Excellence in Surface Mining Award in 2000.

Table 1. Seneca II Mine typical seed mix.

Common Name	Variety	Origin	Seeding Rate (lbs. PLS/acre)
Seed Mix No. 1			
Thickspike Wheatgrass	Critana	Montana	1.00
Western Wheatgrass	Rosana	Washington	2.00
Bluebunch Wheatgrass	Secar	Washington	1.00
Slender Wheatgrass	San Luis	Montana	2.00
Mountain Brome	Bromar	Montana	2.00
Great Basin Wildrye	Magnar	Utah	2.00
Big Bluegrass	Sherman	Washington	0.25
Green Needlegrass	Lodorm	Montana	2.00
Arrowleaf Balsamroot	Native	Colorado	0.50
Tailcup Lupine	Native	Colorado	1.00
Blue Flax	Appar	Washington	0.50
Sheep Fescue	Covar	Washington	0.25
Alfalfa	Travois	Canada	0.10
Orchardgrass	Pomar	Oregon	0.25
Rocky Mtn. Penstemon	Bandera	Colorado	0.25
Palmer Penstemon	Cedar	Colorado	0.10
Yarrow	Native	Colorado	0.10
Canada Bluegrass	Reubens	Idaho	0.10
Pacific Aster	Native	Colorado	0.10
Shrub Mix No. 1B			
Winterfat	Native	Colorado	2.00
Serviceberry	Native	Colorado	0.50
Mountain Snowberry	Native	Colorado	0.50
Mountain Big Sagebrush	Native	Colorado	0.25
Antelope Bitterbrush	Native	Colorado	1.00

Table 2. Shrub planting and total acres seeded for reclaimed lands and native rangelands at the Seneca II Mine. 1990-2001.

Year	Number of Seedlings Planted	Number of Acres Seeded
1990	11,081	87
1991	19,748	33
1992	9,782	70
1993	10,500	0
1994	10,616	59
1995	9,600	11
1996	16,657	0
1997	19,618	77
1998	29,680	200
1999	12,498	103
2000	31,000	5
2001	10,250	43
12-year Total	191,030	688

Livestock Grazing Program

Since 1988, cattle have grazed the reclaimed land at Seneca II Mine. Currently, Seneca operates two pastures: the Wadge Pasture, which includes more than 300 acres of reclaimed land, and the Pecoco Pasture, which includes more than 200 acres of reclaimed land. Vegetation monitoring of these sites supports the fact that grazing, when controlled, can be beneficial to reclaimed land (Table 3). Between 150 and 200 steers graze this prime rangeland each summer. These pastures provide 2.4 times more forage for grazing than surrounding native rangelands.

Table 3. Production summaries for reclaimed lands and native rangelands at the Seneca II Mine.

Year	Production on Reclaimed Lands (lbs/acre – dry wt.)	Production on Native Rangelands (lbs/acre – dry wt.)
1990	2740	1252
1991	2874	1232
1992	3164	876
1993	3576	1454
1994	2716	1110
1995	4570	1460
1996	3385	1367
1997	3410	1574
1998	4220	1720
1999	2724	1752
Decade Mean	3338	1380

Wildlife Enhancements

Seneca reclamation specialists designed and implemented several interesting and effective wildlife enhancements. Yellow-bellied marmots abound in the reclaimed area and Seneca improved their habitat by providing "rock chuck condominiums," piles of rock which are excellent den sites for marmots. In addition to the outstanding vegetation for forage, Seneca II Mine provides water sources for wildlife. Stock ponds constructed within the state guidelines provide water for an array of wildlife from rainbow trout to Rocky Mountain elk. Mule deer and elk take advantage of the abundant forage, water, and cover provided by Seneca's reclaimed land. The Wadge Impoundment, a 200 acre/foot final pit impoundment, will be left, after final bond release, as a public recreation area, according to preliminary discussions with the Colorado Division of Wildlife. A final "stamp of approval" was given to Seneca reclamation when specialists discovered two Colombian sharp-tailed grouse leks (dancing/mating grounds) established on reclaimed sites.

Long-term Benefits and Transferability of Technology

Research was conducted into mycorrhizal relationships in native shrubs, topsoil requirements for shrub survival, and browse repellants. This research resulted in a successful shrub establishment program at Seneca II Mine. The resulting technology has helped improve the reclamation at Seneca Coal Company's active mines (Yoast and IIW), and was shared with other operators through the Society for Range Management 1999 symposium. The High Altitude Revegetation Workshop biennial field trip visited Seneca reclaimed lands in 1997. During 2000 and 2001, Seneca Mine cooperated with the Colorado Division of Minerals & Geology and Colorado State University in an extensive shrub establishment study. This study will evaluate different methods of planting and site preparation. All operations in the mountain shrub ecosystem will benefit from the work and research conducted at Seneca II mine.

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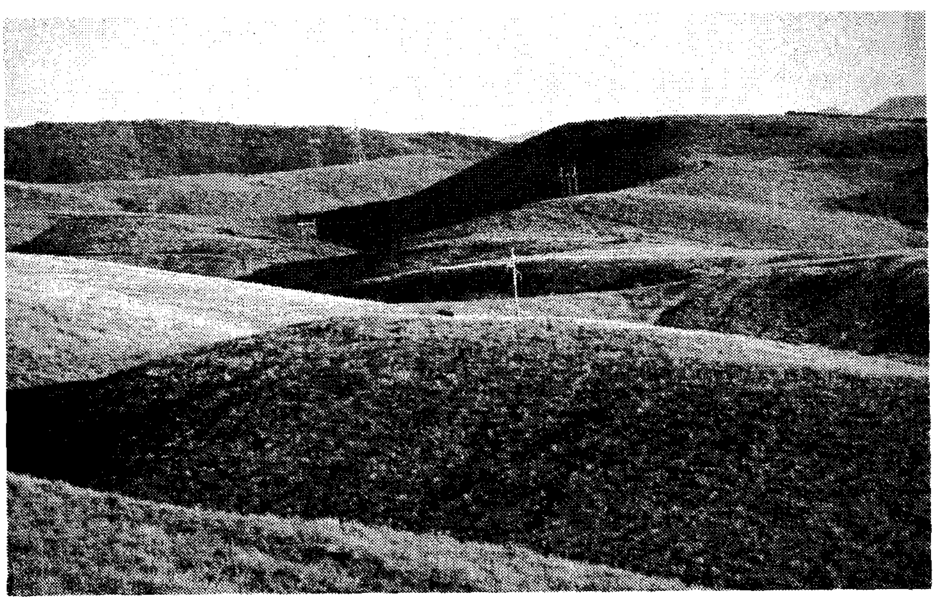

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Figures 1a and 1b. Reclaimed areas at the Seneca II Mine.

GLENWOOD CANYON: A LOOK BACK

Jim Lance

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ABSTRACT

I-70 Glenwood Canyon "The Final Link" had its ribbon cutting ceremony in 1990. The revegetation work associated with this project was started in 1981 and completed around 1990. Some of the oldest planting and seeded areas are now over 20 years old. Without any scientific monitoring since 1989, the only record of what has happened is in observing what is there. Over the past 13 years the comments and questions various groups have asked allow me to see through "their eyes." It has been interesting to hear what they think was a success (shrub establishment) and what they think are problems (thinning grass and invading exotic species). It has also been interesting to observe the perceptions of the various groups as the landscape has matured. It is difficult for some to envision the stark rock pile that we started with to what is there today. I will recap some of the things, both positive and negative, that CDOT did and why if I had to "do it all over again," there are very few things that I would change or do differently.

INTRODUCTION

As part of the Interstate Highway System, I-70 was substantially completed from its Pennsylvania beginning to Cove Fort, Utah at its western terminus, before Glenwood Canyon was designed. Because of the significance of Glenwood Canyon as a natural resource, it was named as a "scenic corridor" in the Federal Register and extraordinary measures were taken in the design of the roadway. An "environmental" group brought a lawsuit to Federal Court to try and stop the building of I-70 through Glenwood Canyon. There were five points of settlement in the judge's opinion. One of the points was the requirement that the revegetation effort be "state of the art" and would require annual reports to be sent to attorneys and others as they directed.

Ecologically the Canyon is the river gorge of the Colorado River, with steep walls that can be as much as 1,600 feet high. The canyon runs in a northeast to southwest direction, with elevations ranging from 6,000 feet on the east end to 5,800 feet on the west end. The vegetation is a mixture of Big Sage *(Artemisia tridentata tridentata)* and Greasewood *(Sarcobatus vermiculatus)* on the drier more saline east end. In the more mesic middle there are Pinyon Pine *(Pinus edulis)*, Rocky Mountain Juniper *(Juniperus scopulorum)*, Box Elder *(Acer negundo)*, Narrowleaf Cottonwood *(Populus angustifolia)*, and Douglas Fir *(Pseudotsuga menziesii)* trees as well as a great variety of shrubs, forbs and grasses. The western end of the Canyon tends to be mostly shrubs and in places Pinyon and Juniper trees dominate. The shrubs represented include Gambel Oak *(Quercus gambelii)*, Serviceberry *(Amelanchier alnifolia)*, Chokecherry *(Prunus virginiana)*, Whitestem Gooseberry *(Ribes inerme)*, Bush Rock Spirea *(Holodiscus dumosus)*, Littleleaf Mockorange *(Philadelphus microphyllus)*, True Mountain Mahogany *(Cercocarpus montanus)*, Mountain Snowberry *(Symphoricarpos oreophilus)*, and many others.

This shrub zone is an interesting ecological niche, with vertical and horizontal layers that have many mutualistic interactions. The basal layer of vegetation is comprised of Snowberry, Creeping Mahonia or Oregon Grape *(Mahonia repens)*, Whitestem Gooseberry and other sub-shrub and forbs species. Above the westbound lanes, the slopes are predominantly south facing and have a 27-degree slope that maximizes early spring solar energy. These conditions warm the thin, organic soils and the basal layers of plants, break dormancy and start anthesis. This process is carried on in a continuum up the vertical structure to the overstory. Usually in mid-May, Gambel Oak leafs out and flowers, offering shade and protection to the understory as the season progresses. This is a very difficult vegetation complex to try and replicate in a restoration situation. The only large (six to eight foot) oaks that were commercially available at the time were collected. These plants were expensive and of questionable vigor and longevity. I have a section of a six-inch diameter piece of oak trunk on my desk as a reminder. This piece has approximately 120 annual rings in it. The oaks we planted are going to take awhile to get to the point where they function as the undisturbed oak does. A lot of effort went into preserving as much of the existing vegetation as possible. There were limits established before construction start and monetary penalties assessed for vegetation that was removed outside of the clearing limits. The penalty money went into restoration efforts, not just less money to the contractor.

CONCLUSION

Since we have not had any formal monitoring of the Canyon revegetation since 1989, the following are just my observations throughout the 20 years since the first plantings and test plots went in.

Techniques I would use again:

- Biosolid-woodchip compost amendment added to the topsoil. We started out with a 50/50 mixture. This is too much compost, although the plants at the Grizzly Creek Rest Area survived well and showed no negative effects. The first season after planting I noticed several individuals, with mesh sacks, frequenting the shrub beds. I found out that they were collecting, and selling at large profits, quantities of morel mushrooms. The compost and the drip irrigation created a favorable environment for growing mushrooms. I would be very cautious about "compost." Without extensive testing of the product, you are never sure about what you might end up with. CDOT received a 100 cubic yard load of supposedly finished compost that when a temperature reading was taken, it revealed a 160 degrees F. The whole turkey feathers on the outside of the pile were my first clue. When writing specifications for composted material be careful and explicit about what will and will not be accepted. Testable parameters such as fertility, C: N ratios, organic matter levels, pH, salt levels, Cation exchange capacity, and maximum levels of metals, are all things that should be considered when specifying composted material. We could have used 49 parts topsoil and one part compost blended together and still would have had topsoil with 3% organic matter. Amended topsoil such as this should be very adequate for most native species at a greatly reduced cost.

- Drip irrigation from clean water sources for plant establishment, 3-5 years. Filtration of water can be a problem for drip applications.

- Filter fabric keeps soil intact and air from plants roots when planting in riprap or other coarse material. It also offers a way to provide some depth and moisture reserves in the root zone of the planted species.

- Rock mulch helps to keep moisture in and harvest some of the runoff water from the hard surfaces, it also insulates or tempers against extreme temperatures that can occur at sites such as this. Surfaces can vary as much as 50 degrees F in twelve hours.

- Grow more/plant more of the following plants - Chokecherry, Gambel Oak, Pinyon Pine, Rocky Mountain Juniper, Serviceberry, Threeleaf Sumac, Whitestem Gooseberry, Woods Rose and Prickly Rose.

- Live Crib Walls in more places along the rivers edge.

- Cellular confinement products to keep topsoil in place.

- Porous ceramic pellets in the plant backfill to retain moisture, lasts longer, better microbial "habitat" than the gel or starch based products. There are lots of inferior products out there. Become informed before choosing a product.

- Systemic browse deterrent tablets.

- Coconut or coconut/straw soil retention blankets in places of concentrated flows.

- Willow cuttings at the proper time of year for riverbank stabilization and habitat creation in the riparian zone.

- Direct seeding of the following species - Dogbane *(Apocynum sp.)*, Hairy Golden aster *(Heterotheca villosa)*, Prairie Sage *(Artemisia ludoviciana)*, several Penstemons, Rocky Mountain *(P. strictus)*, Beardlip *(P. barbatus)*, Firecracker *(P. eatonii)*, and Showy *(P. pseudospectabilis)*, and Showy Goldeneye *(Heliomeris multiflora)*.

Things I would <u>not</u> do again:

- Mix grass, forbs, and shrub seed together in a mixture. I would increase the native grasses from 35-50 seeds/square foot to 90-150 seeds/square foot. I would use the forbs and shrub seed in special areas that would provide the best opportunity for growth only, not in with the grass mix.

- Use nursery stock of Rubber Rabbitbrush *(Chrysothamnus nauseosus)*, and Prairie Sage.

- Use tubelings for shrub seedlings. We saw a great deal of loss when this size plant material was used. There were many plants of this size that had knotted root systems and just did not seem to be "good" plants.

- Substitute species that do not belong, even if adapted to the site.

- Plant later than 01 September, especially with the smaller plants.

Things that I would try "next time:"

- Gambel Oak in elongated containers, with mycorrhiza inoculation, to provide a larger root mass. Containers as large as 3-4 inches in diameter and 4 feet long would work. Impractical? Maybe, but I would like to see what kind of growth you could get from them.

- Plant more wildflower/forbs seed along the recreation trail.

- Try to create a more natural plant community, especially the horizontal and vertical structure of the older oak stands, with the multi-species understory.

- Red twig Dogwood *(Swida sericea)* "wattles," 6-8 inch bundles of twigs with the cut ends alternated and bound with string and then buried in the soil, were successful in the test plots with supplemental irrigation. An 18-30 inch plant was produced in one growing season by using this method.

- Inoculate the growing media with the appropriate mycorrhiza for all nursery grown plants. Literature shows that 14 of the 17 shrubs grown benefit from mycorrhiza.

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BENTONITE MINE SPOIL REVEGETATION AND LONG-TERM ASSESSMENT

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ABSTRACT

Abandoned bentonite mine spoils are perhaps the most difficult material to successfully rehabilitate because of the nature of the spoil and the climate of the region where bentonite is mined. The major U.S. deposits of bentonite are in the tri-state region of Montana, South Dakota, and Wyoming, an area that is characterized by an arid to semi-arid climate. Bentonite deposits are associated with Cretaceous Age shallow seas which results in the spoil material being of high salinity, high sodium, and high clay content. These conditions combine to create severe water relation problems in the spoil and osmotic stress to plant seedlings. In 1979, research was initiated to evaluate the potential of sawmill residues and gypsum as spoil amendments that would enable water movement into the spoil, ameliorate the high sodium, and allow leaching of the salts and sodium from the root zone. The technology developed by this research has been shown to be effective in rehabilitating abandoned bentonite spoils and has been used to reclaim over 5000 hectares of these lands in Wyoming. Long-term assessment has shown that the highly saline, sodic nature of these spoils can be successfully ameliorated and these lands restored to productivity.

INTRODUCTION

Bentonite deposits in the Northern Great Plains are the result of volcanic activity approximately 75 million years ago. Volcanic ash deposited in shallow, saline seas that were present over much of this area was chemically altered and eventually formed bentonite (Davis, 1965). The chemistry of the seawater at the time of deposition, depth of seawater over the deposited ash, and the physiochemical composition of the ash produced a wide variety of bentonite grades and account for the dispersed nature of the deposits and hence the dispersed mining pattern. Mowry shale is the predominant formation containing high-quality bentonite in the Black Hills area of Montana, South Dakota and Wyoming (Knechtel and Patterson, 1962; Mapel and Pillmore, 1964). Land surfaces common with bentonite deposits are generally low grasslands and ponderosa pine (*Pinus ponderosa* Laws) savannahs which are utilized by domestic livestock and wildlife.

Mining began in the Northern Great Plains in the 1940s (Davis, 1965) before reclamation legislation and regulations existed. Many people think that coal mining in this region is the major extractive industry that disturbs the land; however, the National Academy of Sciences (1974) reported that more land was disturbed in Montana in 1973 by bentonite mining than by coal mining and that more orphaned spoil had accumulated over the years from bentonite mining than from coal. Thousands of hectares of land were disturbed by bentonite mining before any reclamation laws were passed in the early 1970s. Bentonite mining may result in the most difficult to reclaim mined lands in the region because of the adverse chemical and physical properties of the spoil material, the limited inherent topsoil, and the arid/semiarid climate of the area (Table 1). Bentonite is surface mined from shallow pits with scrapers, dozers and front loaders, which results in a relatively large area of surface disturbance.

Table 1. Physical and chemical characteristics of pretreatment bentonite spoil samples, Upton, Wyoming, 1981 (Smith, 1984)

Parameter	**Mean and Standard Error**
Particle-size separates* (%)	
Sand	10.8 ± 0.8
Silt	29.6 ± 0.8
Clay	59.6 ± 1.1
Saturation percentage (%)	80.9 ± 1.7
NO_3-N (mg kg $^{-1}$)	7.7 ± 0.4
NH4-N (mg kg $^{-1}$)	2.6 ± 0.1
Total Kjeldahl-N (mg kg $^{-1}$)	751.1 ± 5.8
P (mg kg $^{-1}$)	8.1 ± 0.3
C (mg kg $^{-1}$)	10.1 ± 1.0
pH	8.1 ± 0.3
Electrical conductivity (dS m^{-1})	13.4 ± 1.1
Water soluble cations (mg kg $^{-1}$)	
Ca	187.9 ± 9.2
Mg	73.6 ± 4.2
Na	3613.7 ± 101.3
K	32.0 ± 0.8
SAR	63.1 ± 1.2

*Particle-size separates obtained from five observations. All other parameters are a mean of 144 samples.

Natural revegetation or man-assisted reclamation attempts of non-topsoiled, non-amended bentonite spoils has resulted in poor plant establishment or complete failure of revegetation efforts (Dollhopf and Bauman, 1981; Sieg et al., 1983). Therefore, spoil modification was deemed necessary to enable success in revegetating these spoil materials. Early attempts at revegetating bentonite spoil materials using organic amendments showed some promise (Hemmer et al., 1977; Dollhopf and Bauman, 1981; Bjugstad et al., 1981). Use of topsoil over abandoned bentonite spoil material was not seen as a viable option because no topsoil salvage occurred during the mining and in most cases topsoil borrowing was and still is not considered feasible because of the limited resources and the fact that considerably more land area then requires revegetation (Richmond, 1991).

RESEARCH HISTORY

Schuman and Sedbrook (1984) demonstrated the effectiveness of sawmill wastes (sawdust, woodchips, and bark) in improving the physical characteristics of the spoil through the enhancement of water infiltration and vegetation establishment. Their study evaluated the effect of 0, 112 and 224 Mg ha $^{-1}$

wood residue amendment on spoil water content and vegetation production. The residue should not exceed 25% sawdust because it is important that the amendment prevent the clay spoil from sealing and crusting and small particles would simply be coated with clay and become sealed. This preliminary study by Schuman and Sedbrook (1984) demonstrated the importance of a bentonite mine spoil amendment program to achieve rapid and successful reclamation. To be successful, the spoil amendment program must increase water infiltration for germination and plant establishment/production (Table 2 and 3) and leaching of soluble salts. Water infiltration into the spoil must be adequate for plant establishment, calcium amendment dissolution, and leaching of the displaced sodium; if all of these functions are not achieved then the amendment program will not be effective.

Table 2. The effect of wood residue amendment of bentonite spoils on the soil-water content, Upton, Wyoming, 1980 and 1982 average (Schuman and Sedbrook, 1984).

	Spoil depth, cm		
	0-20	20-40	40-60
Wood residue treatment (Mg ha^{-1})	**Water content(g kg $^{-1}$)**		
0	115a*	138a	139a
112	212b	166b	143a
224	232b	180b	155a

*Means among sawmill residue rates within a spoil depth followed by the same letter are not significantly different, $P \leq 0.05$.

Table 3. Seeded species aboveground biomass (kg ha^{-1}) on bentonite mine spoils as affected by sawmill residue amendment, 1980 to 1983, Upton, Wyoming (Schuman and Sedbrook, 1984).

Year	**Sawmill residue rate (Mg ha $^{-1}$)**		
	0	112	224
1980	17a*	381a	392a
1981	15a	703b	554b
1982	12a	1006b	1332b
1983	3a	760b	1202b

*Means within a year followed by the same letter are not significantly different, $P \leq 0.05$.

After such promising preliminary results from the simple amendment program using sawmill residues to improve physical characteristics of the bentonite spoil. Schuman and co-workers (Smith et al., 1985 & 1986) established a second detailed study where they hoped to refine the rates of sawmill residue and nitrogen fertilizer necessary to accomplish successful reclamation of these spoils (Figure 1). This study evaluated the effectiveness of four sawmill residues rates (0, 45, 90 and 135 Mg ha^{-1}), four nitrogen fertilizer rates (0, 2.5, 5.0, and 7.5 kg N Mg^{-1} sawmill residue) and two seed mixtures (native and introduced grass mixture) on reclamation success. Nitrogen was applied based on sawmill residue rates to establish a range of C:N ratio treatments; where no sawmill residue was added, nitrogen was applied

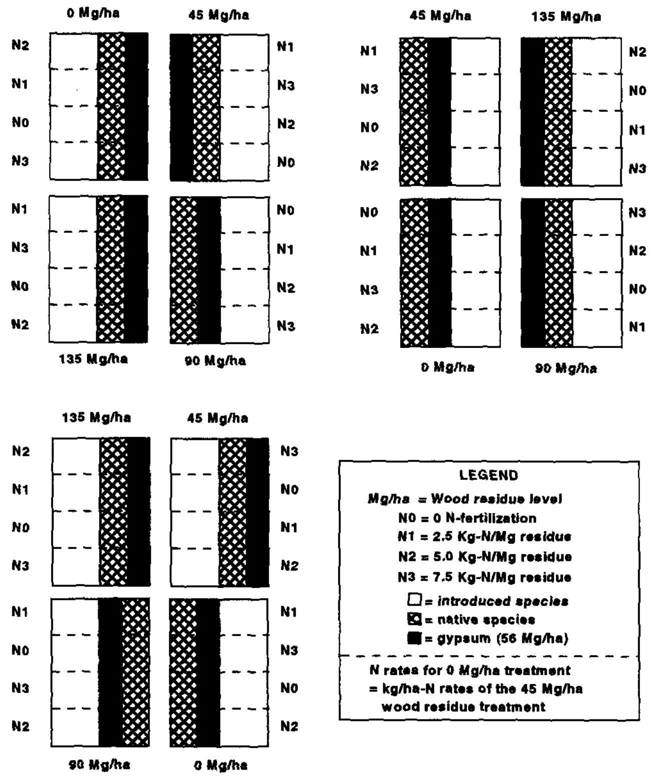

Figure 1. Field plot design for evaluating the effectiveness of wood residue, N fertilizer, and gypsum amendments on ameliorating the physical and chemical properties of bentonite spoils (Schuman, 1985)

at the same rate used on the 45 Mg ha $^{-1}$ wood residue treatment. See Smith et al. (1985) for complete details of study design, implementation, and detailed findings.

RESEARCH FINDINGS

General Plant Responses

In general, overall plant response in this more detailed study (Smith et al., 1985) of sawmill residue amendment was similar to that observed in the preliminary study by Schuman and Sedbrook (1984). Seedling density was improved by the sawmill residue amendment because of the positive attributes on water infiltration, crusting, and bulk density. Grass seedling density was greater for the three sawmill residue treatments (41, 60 and 70 plants m $^{-2}$) compared to the control treatment where no residue was applied (14 plants m $^{-2}$). Perennial grass production increased as sawmill residue rate increased, with maximum production occurring at the 135 Mg ha $^{-1}$ rate. Perennial grass production also responded to nitrogen fertilizer rates with peak biomass being achieved at the 2.5 and 5.0 kg N Mg $^{-1}$ sawmill waste rates during years of average precipitation.

All successfully established grass species in the initial growing season were rhizomatous except for tall wheatgrass [*Thinopyrum ponticum* (Podp.) Barkw. D.R. Dewey]. This suggests that rhizomatous species are better suited than bunchgrasses for revegetation of these high shrink-swell bentonitic spoils. Rhizomes have been noted to exhibit physical resistance to breakage and if broken tend to regrow and increase production (White and Lewis, 1969). This phenomenon has been also documented on clay soils in the region by the dominance of sod-forming grasses (Weaver and Albertson, 1956). Smith et al. (1986) stated that species potentially useful for reclaiming bentonite mine spoils should possess at least some of the following characteristics: sod-forming morphology, drought and salt tolerance, adaptation to clay texture, and adaptation to a shallow, poorly drains soil/spoil environment. For detailed individual species responses to the amendments see Smith et al., 1986).

General Spoil Responses

Initial spoil responses to sawmill residue amendment was exhibited in three ways: increased water storage, decreased salinity due to leaching, and increased sodicity. Increased water storage was demonstrated in both the preliminary study and in the second study; however, in the second study this increased water infiltration resulted in significant leaching of the soluble salts from the surface 15 cm of the spoil (Figure 2). However, the 3-year decline in electrical conductivity (EC) was followed by an increase in EC at all

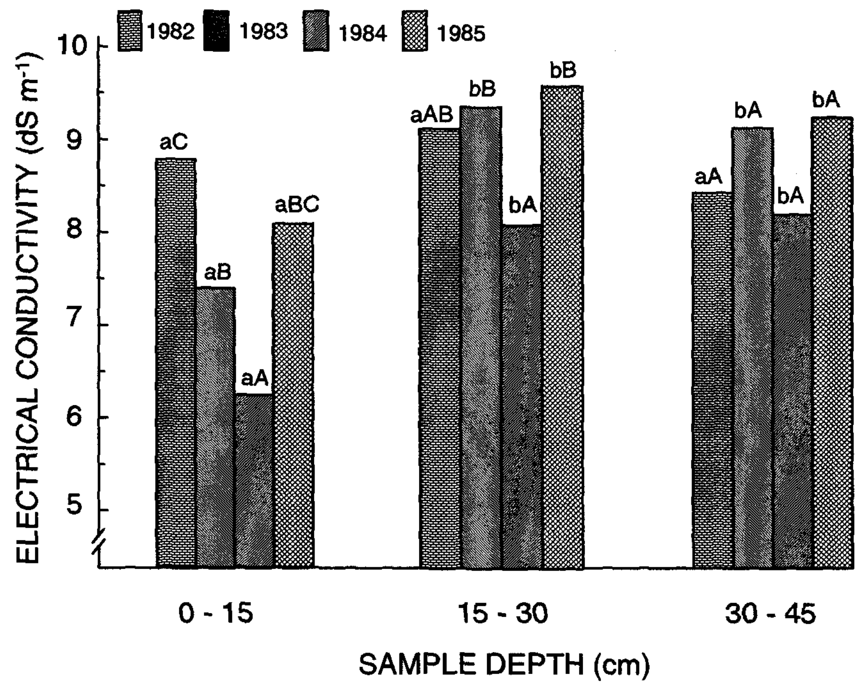

Figure 2. Mean EC averaged across wood residue and N fertilizer treatments, 1982 to 1985, at three spoil depths. Means with the same lowercase letter among years or same uppercase letter within years are not significantly different, $P \leq 0.05$ (Belden, 1987).

spoil depths because of the severe drought that occurred in 1985, which resulted in upward water movement in response to the high evapotranspiration demands (Belden, 1987; Belden et al., 1990). Even though the drought caused an upward migration of soluble salts in the spoil profile, EC of the surface 15-cm depth did not exceed the pretreatment levels or those observed in 1982. The observed leaching of soluble salts from spoil is desirable; however, the leaching process in amended spoil resulted in an increase in the spoil sodium-absorption-ratio (SAR) over the 4-year period (Figure 3). Soluble sodium represented over 90% of the soluble cation pool in the spoil so that as leaching occurred the relative proportion of sodium in the system compared to calcium and magnesium became greater, resulting in the increased SAR observed. An increase in SAR can have significant long-term effects on spoil physical quality and sustainability of the plant community. This observed increase in SAR indicates that chemical amendments (calcium source) would be necessary to ensure reclamation success of these spoils.

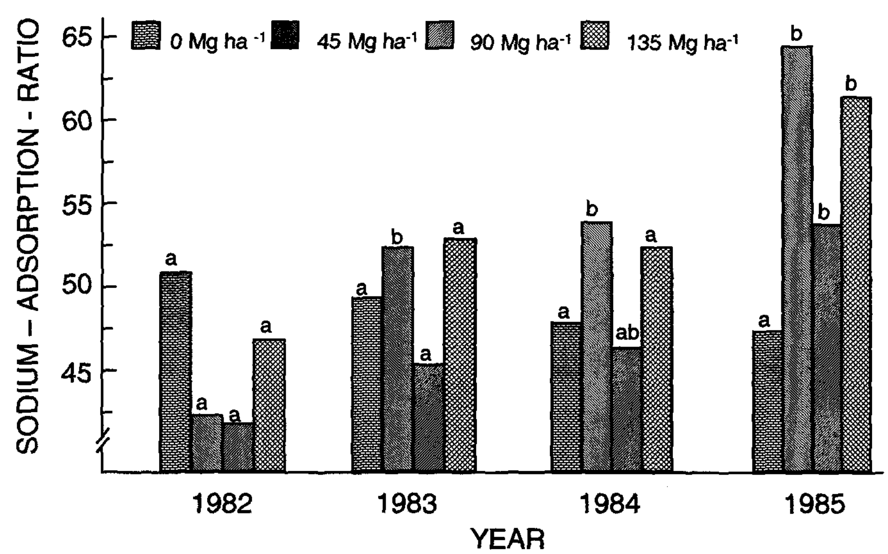

Figure 3. Mean SAR averaged across N fertilizer treatments and depth, at four wood residue levels, 1982 to 1985. Means among years with the same lowercase letter are not significantly different, $P \leq 0.05$ (Belden, 1987).

Effects of Gypsum on Spoil Sodicity

Because of the exhibited increase in spoil sodicity over the 3-year period, 1982-1985, the research study was modified to include a calcium amendment. Gypsum was surface-applied, in April 1987, at the rate of 56 Mg ha $^{-1}$ to 40% of each of the native grass seed mixture plots (Figure 1). Gypsum amendment level was based on calculations to reduce the exchangeable-sodium-percentage (ESP) of the spoil to 15. By utilizing existing research plots we were able to evaluate the effects of gypsum on previously established vegetation and reclamation sites as a potential intermediate remediation practice and utilize the long-term baseline spoil data to evaluate the effectiveness of gypsum in ameliorating spoil sodicity.

Gypsum amendment significantly increased EC at all spoil depths (Figure 4). This increase was expected and was weighed heavily in the decision of whether to include a calcium amendment in the initial design of this research. Such additions of soluble salts could result in reduction of germination and seedling establishment considering the very high inherent levels of soluble salts in the spoil (13.4 dS m $^{-1}$). This phenomenon may explain the poor response in initial seedling establishment observed by Dollhopf and Bauman (1981) when they evaluated the effectiveness of inorganic amendments on bentonite spoil mitigation. However, the effects of gypsum on EC would be less than shown in Figure 4 because the gypsum would normally have been incorporated into the surface 30-45 cm of spoil rather than surface applied. This initial increase in EC was followed by a significant decrease over the next 2 years due

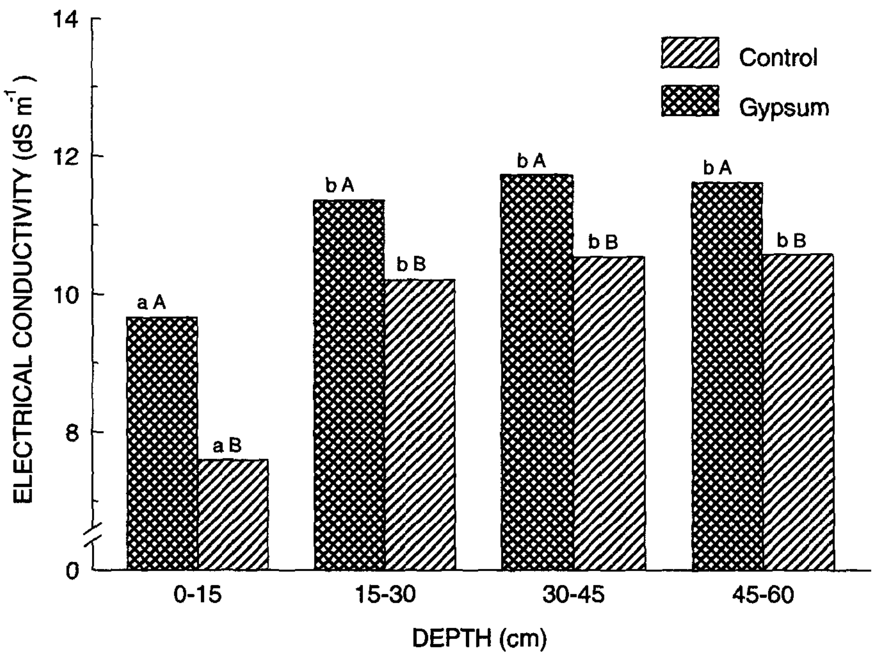

Figure 4. The effect of gypsum amendment on the EC of wood residue amended bentonite spoil at four spoil depths, 1988 to 1990. Means with the same lowercase letter within a treatment or same uppercase letter within a depth are not significantly different, P≤ 0.10 (Schuman and Meining, 1993).

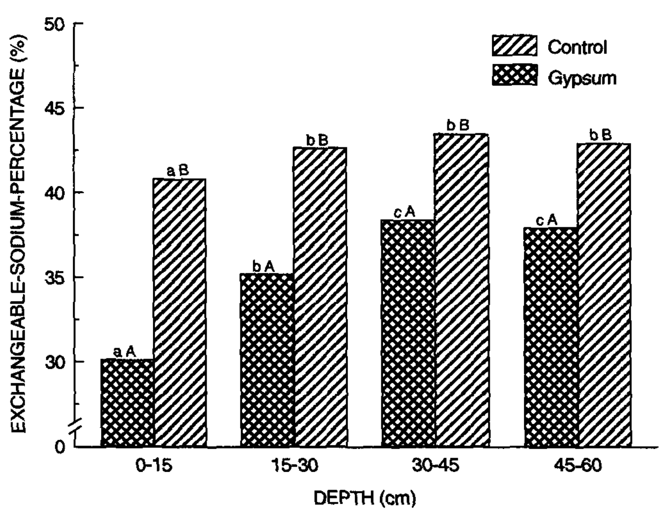

Figure 5. The effect of gypsum amendment on the ESP of wood residue amended bentonite spoil at four depths, 1988 to 1990. Means with the same lowercase letter within a treatment or same uppercase letter within a depth are not significantly different, P≤ 0.10 (Schuman and Meining, 1993).

to leaching (Schuman and Meining, 1993). The gypsum amendment was effective in ameliorating the ESP of the spoil profile (Figure 5) and began showing benefits with 13 months after treatment.

Perennial grass biomass exhibited a 181% average increase in response to the gypsum amendment for the 3-year period, 1988-1990. This enhanced production was at least partially in response to improved physical characteristics of the spoil which resulted in a large increase in stored soil water on gypsum treated plots (Figure 6).

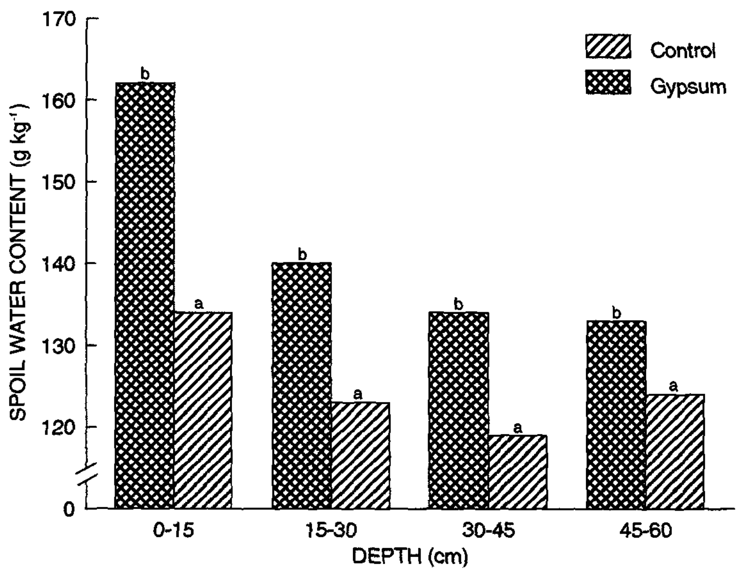

Figure 6. Response of spoil-water content of revegetated saline-sodic bentonite spoil to gypsum amendment, 1988 to 1990. Means within a spoil depth with the same lowercase letter are not significantly different, $P \leq 0.10$ (Schuman and Meining, 1993).

Sawmill Waste Decomposition

Sustained long-term success of these reclaimed lands depends on the development of a "soil" and continued amelioration of sodicity, salinity and texture. The "new soil" must also develop active microbial functions to ensure nutrient availability through sustained nutrient cycling. Therefore, evaluation of sawmill residue decomposition was selected as a measure of microbial function. Wood residue decomposition after 1, 2, 3, and 5 years was 10.7, 11.0, 16.5, and 26.3%, respectively (Schuman and Belden, 1991). The single nitrogen fertilizer application in 1981 had a pronounced effect on decomposition during the 5-year period (Figure 7). Whitford et al. (1989) found that in semiarid rangelands where moisture availability affects nitrogen immobilization and mineralization, high C/N ratio soil amendments can be beneficial. They suggested that the more resistant sources of organic mulches/amendments are superior to readily decomposed material because they provide a slow release of organic particles that serve as energy sources for the microflora. These sawmill residues serve as a high C/N ratio material and have aided revegetation of these bentonite spoils, which has resulted in the production and accumulation of root and litter material that is more readily decomposable.

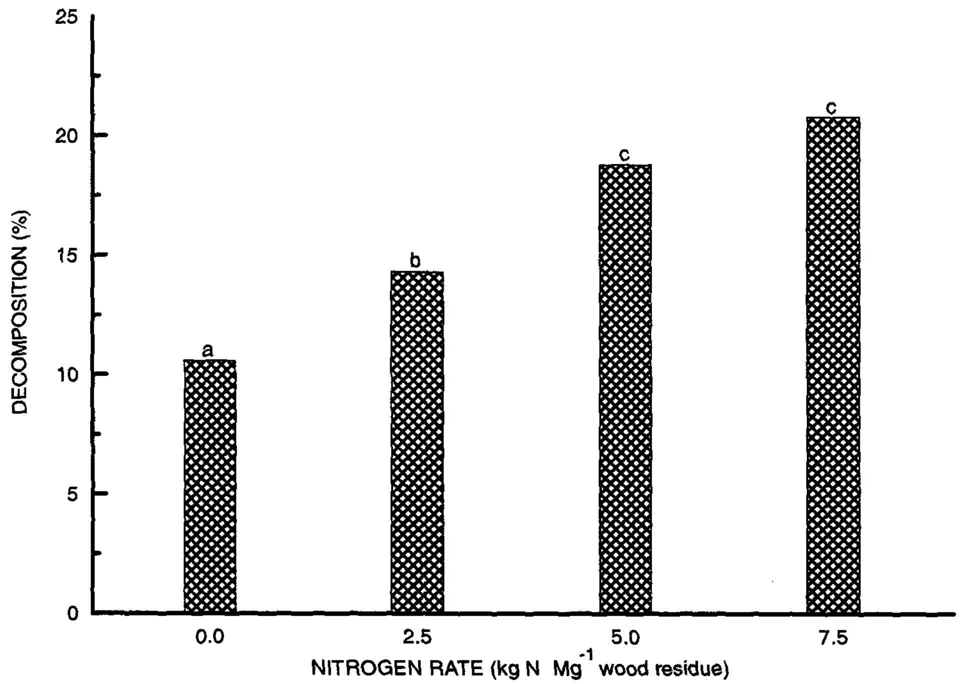

Figure 7. Decomposition of wood residues amended to bentonite spoils as a function of N fertilizer application rate (averaged across all sawmill residue rates and years). Means with the same letter are not significantly different, $P \leq 0.05$ (Schuman and Belden, 1991).

Reclamation of Abandoned Bentonite Spoil

In 1984, results from this research were developed into a reclamation technology for abandoned bentonite mine spoils and a 16 hectare pilot project initiated to evaluate the recommendations resulting from the research and to determine costs for the various phases of the reclamation based on contractor prices and equipment. The pilot project included spoil amendments of 65 Mg sawmill residue per hectare, 325 kg N ha^{-1} and 45 kg P ha^{-1}. Spoils were regraded, amendments applied and incorporated to 30 cm by ripping and disking, and the area drill seeded (HKM, 1985). The pilot project was a success in that it demonstrated that this reclamation technology was feasible on a large-scale basis and cost estimates were determined. In 1985, the Abandoned Mine Land Program of the Wyoming Department of Environmental Quality, Land Quality Division initiated a request for contract proposals for the reclamation of several hundred hectares of abandoned bentonite mine spoils in northeastern Wyoming. Between 1985 and 1995, over 4000 hectares of these lands were reclaimed with this technology under the Abandoned Mine Land Program at a total cost $47 million (Richmond, 1991). The amendment prescription for these spoils varied between project based upon the clay content and sodicity of the spoil material. In some instances where the spoil was composed of Newcastle sandstone materials limited or no sawmill wastes were applied but a calcium amendment and fertilizer (nitrogen and phosphorus) were applied. The form of calcium amendment varied between gypsum, calcium chloride, and phosphogypsum, but gypsum was the most frequent used calcium amendment because of its availability and ease of handling. In general, revegetation of these lands was successful.

Long-Term Assessment

In 1997, the Wyoming Abandoned Mine Land Division, requested that we initiate an assessment of some of the sites reclaimed under the Abandoned Mine Land program between 1985 and 1995. This request stemmed from their observation that small (<0.2 ha) areas on some of the reclamation sites exhibited vegetation failure or signs of stress. An experiment was designed to determine if spoil characteristics were contributing to the observed vegetation responses or failure and, if so, prescribe corrective treatment options.

Three study sites were selected at both Upton and Colony in northeastern Wyoming (Edinger, 1998; Edinger et al., 1999). Each study site selected exhibited a trend of decreasing vegetation cover leading to an area where the vegetation was dead. To evaluate these phenomena, three vegetation "conditions" were delineated: "good," "moderate," and "dead." A sampling scheme was designed that enabled statistical analysis of the spoil and vegetation parameters assessed (Figure 8). Soil cores were taken along the transects established at each site and separated into depth increments of 0-15, 15-30 and 30-60 cm. Spoil samples were analyzed for pH, EC, soluble salt concentrations, cation-exchange-capacity (CEC), and ESP. Aerial and basal plant cover were estimated adjacent to each spoil sampling site along the transects using a 10-pin point frame.

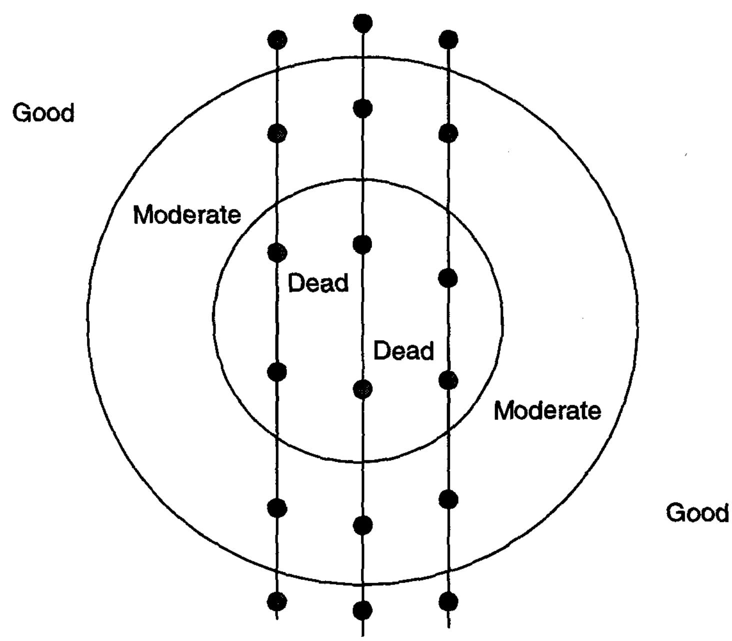

Figure 8. Field soil sampling design for assessment of abandoned bentonite reclamation sites (Edinger, 1998).

In general, spoil analyses indicated that the "dead" vegetation zones had high levels of exchangeable-sodium and ESP in excessive of 30-40%, while the "good" vegetation zones had ESP of <10%. The spoil conditions found in the "dead" zones suggest that insufficient calcium amendment was applied to ameliorate the sodic conditions of the spoil. Figures 9 and 10 demonstrate the level of sodicity found in the surface 15 cm of the spoil at the three vegetation conditions and the effect of ESP on canopy cover, respectively, on one of the Colony sites. The data clearly demonstrate that the sodicity of the "dead" areas

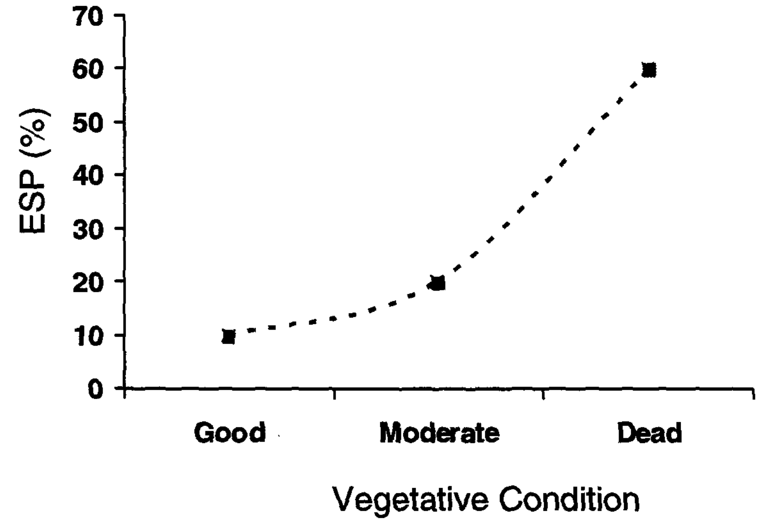

Figure 9. Exchangeable-sodium-percentage levels observed for the various vegetation conditions, Colony Site 107 (Edinger, 1998).

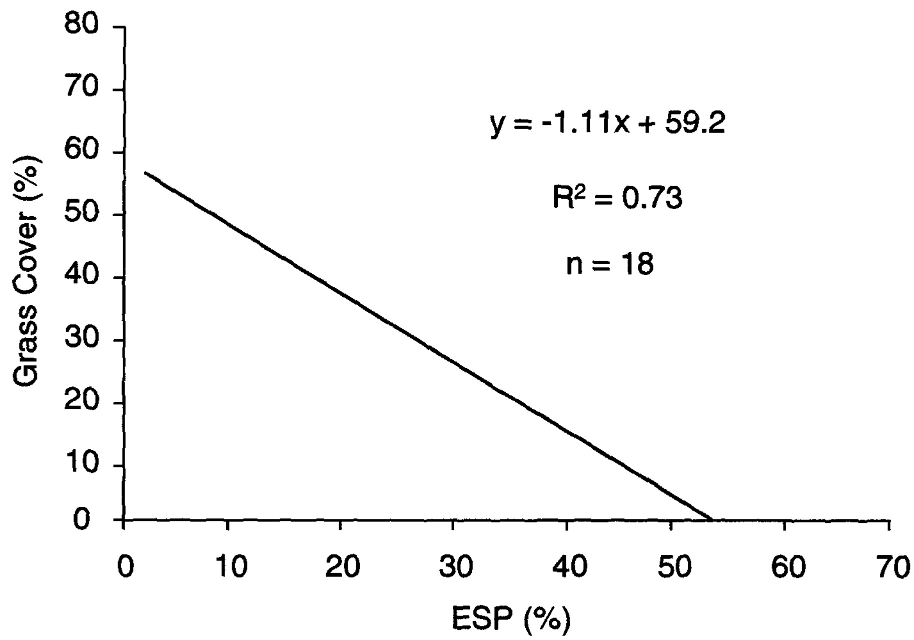

Figure 10. Effects of spoil ESP on grass canopy cover, Colony Site 107 (Edinger, 1998).

and to some extent the "moderate" areas was not effectively corrected by the amendments. Based on the spoil data and visual observations of these sites, we believe the calcium amendment requirement was either underestimated based upon the sampling method or the individual AML project quality control was not adequate to ensure uniform application of the amendment. The sampling design to determine the calcium amendment requirement was based upon 5 spoil cores being taken from each 0.8 ha area and the 5 cores combined for EC and ESP analyses. In an area of great heterogeneity the compositing process could result in an underestimation of calcium amendment needed for a small percentage of the 0.8 ha area; the dead or affected areas observed on the AML sites were generally <0.2 ha. Based upon our findings, it was recommended that further monitoring of some of the affected sites be done to determine if the sites continue to degrade or get larger. If the affected areas are relatively stable it was the consensus of the research people and the AML personnel that because of the size of these sites they did not warrant further remediation efforts because this pattern in native, undisturbed landscapes is not uncommon. We also recommended that future AML project design modifications include taking only 4 spoil cores per 1 hectare and that each of these cores be analyzed separately for ESP for determination of calcium amendment rates and that greater emphasis be placed on on-site supervision/oversight during the amendment application phase of the project (G.E. Schuman, personal communication to AML Director).

SUMMARY

Research addressing the reclamation of abandoned bentonite mined lands has been an example of how asking some basic research questions can lead to the development and evaluation of a reclamation technology. Our research and assessment of the reclamation technology spans a period of nearly 20 years. To be involved in a specific research project like this enables one many opportunities to assess various aspects of reclamation and to assess long-term edaphic and plant community changes and development. The technology developed by this research has been successfully used to reclaim and restore productivity to several thousand hectares of land in Wyoming. Hopefully, in the future this technology will be utilized in the reclamation of the even a larger total area of abandoned bentonite mine lands in Montana and South Dakota. The AML program that was responsible for the reclamation of these bentonite mined lands has been a success and has received praise by the industry, environmental groups, livestock producers, wildlife biologists, land owners, and the general public. Prior to revegetation these lands produced significant off-site environmental concerns, air and water quality, and were generally referred to as "moonscapes."

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LONG-TERM PLANT COMMUNITY DEVELOPMENT ON TOPSOIL TREATMENTS OVERLYING A PHYTOTOXIC GROWTH MEDIUM

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ABSTRACT

The application of topsoil over phytotoxic mine waste materials is often the most effective method of establishing and maintaining plant communities during reclamation. However, long-term data on the effectiveness of topsoil cover treatments, as well as on treatments used to enhance vegetation establishment on soil covers, are lacking. Therefore, we evaluated long-term plant community development on study plots in which 60 cm of Paraho retorted oil shale was covered by various depths of topsoil. Each plot was drill seeded with one of three seed mixtures (native, introduced, and combination of native and introduced species), and fertilized with one of three rates of nitrogen (N) and phosphorus (P) fertilizer following plot construction in 1977. Data collected in 1997 showed that native species were as productive as introduced species on deeper topsoil depths and on the control. Also, relative plant species composition and plant species richness continued to be greatly influenced by seed mixture treatments. Plots seeded with a particular seed mixture were still dominated by those species originally seeded, and native seed mixture plots were more species rich than introduced seed mixture plots. Finally, the one-time application of N and P was no longer influencing aboveground biomass.

INTRODUCTION

Mining activities that produce phytotoxic waste materials occur throughout the western USA. Elevated concentrations of certain salts and trace elements in mine waste materials, and the movement of these elements via capillary rise, leaching, diffusion, and plant uptake and cycling (biocycling), may hinder reclamation efforts by inhibiting the satisfactory establishment of vegetation (Stark and Redente, 1990). In order to protect establishing plant communities from the upward movement of salts and trace elements, several researchers have advocated the placement of topsoil over such phytotoxic waste materials as retorted oil shale (Harbert and Berg, 1978; Harbert *et al.*, 1979; Redente *et al.*, 1982; Redente *et al.*, 2000; Sydnor and Redente, 2000), trona tailings (Barth and Martin, 1981), molybdenum mill tailings (Trlica *et al.*, 1994), and alumina refinery wastes (Bell and Meecham, 1978). In addition, many mining reclamation laws throughout the western USA require salvage and replacement of topsoil and the establishment of diverse, self-sustaining plant communities following reclamation. To date, much of the research that has focused on topsoil coverings over phytotoxic mine waste materials, and the cultural methods used to enhance vegetation establishment, productivity, and diversity, has studied treatment effects over short time scales (i.e., less than five years). Long-term reclamation research does exist but has mostly been conducted on topsoil treatments overlying non-phytotoxic mine spoils (Chambers *et al.*, 1994; Redente *et al.*, 1997) and on intensively disturbed soils associated with mining activity (Newman and Redente, 2001). As a consequence, long-term plant community development on topsoil treatments overlying phytotoxic mine waste materials is poorly understood. Thus, it is difficult to make recommendations on the reclamation of phytotoxic waste materials that will promote diverse and self-regenerating plant communities over longer time scales.

These deficiencies in research led us to revisit the Retorted Shale Successional Study (RSSS), which was established in 1977 and described by Redente *et al.* (1982). The objectives of the current study were 1) to evaluate the effects of topsoil, seed mixture, and fertilization treatments on plant community development after 20 growing seasons, and 2) to determine if soluble salts and trace elements have migrated from retorted oil shale layers into overlying topsoil. Results pertaining to Objective 1 are presented in this paper, whereas results relating to Objective 2 have been reported previously (Sydnor and Redente, 2000). Results of this study should prove useful in the reclamation of phytotoxic materials that may require soil covers for successful reclamation.

MATERIALS AND METHODS

This study was conducted in the Piceance Creek Basin of northwestern Colorado in Rio Blanco county (39° 54' 13" N, 108° 24' 02" W) approximately 65 km northwest of Rifle, CO. The study plots are situated on level ground at an average elevation of 2020 m. The climate of the area is semi-arid. Mean annual precipitation (MAP) is 282 mm; winter and spring (November-April) precipitation contributes roughly half of MAP, and is received mainly as snow. Mean annual temperature (MAT) is approximately 6.8° C. Temperatures can often reach a maximum of 38° C in the summer and a minimum of -40° C during winter months.

The study area was classified within the Mid-Elevation Big Sagebrush/ Moderately Deep Loams Phyto-edaphic Unit as described by Tiedeman and Terwilliger (1978). Big sagebrush (*Artemisia tridentata* var. *tridentata* Nutt.) is the dominant species in undisturbed plant communities. Common understory species include: prairie junegrass (*Koeleria macrantha* (Ledeb.) J.A. Schultes), needle-and-thread (*Stipa comata* Trin. & Rupr.), carpet phlox (*Phlox hoodii* Richards.), scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.), and prickly pear cactus (*Opuntia polycantha* Haw.). Native reference plots adjacent to the study were found to support approximately 150 g m^{-2} of aboveground biomass averaged over a four year period (McLendon and Redente, *unpublished data*). Loamy soils of the Yamac series (mixed Borollic Camborthids) are common in the vicinity of the study site (Mount, 1985). Depth to bedrock is highly variable on these soils and averages approximately 50 cm (Redente *et al.*, 1982).

The RSSS was initiated in the summer of 1977 to examine three main treatments common in the reclamation of retorted oil shale with respect to their effects on plant establishment and succession, and to determine the movement of trace elements and salts contained in soil-covered retorted oil shale. The study was established as a split-split plot design with 5 topsoil treatments (whole plot treatment), 3 seed mixtures (subplot treatment), 3 fertilizer treatments (sub-subplot treatment), and 3 replications. A total of 135 study plots (experimental units) were established with each measuring 7 x 11.5 m. It should be noted that the three seed mixtures and three fertilizer treatments were truly replicated throughout the study;

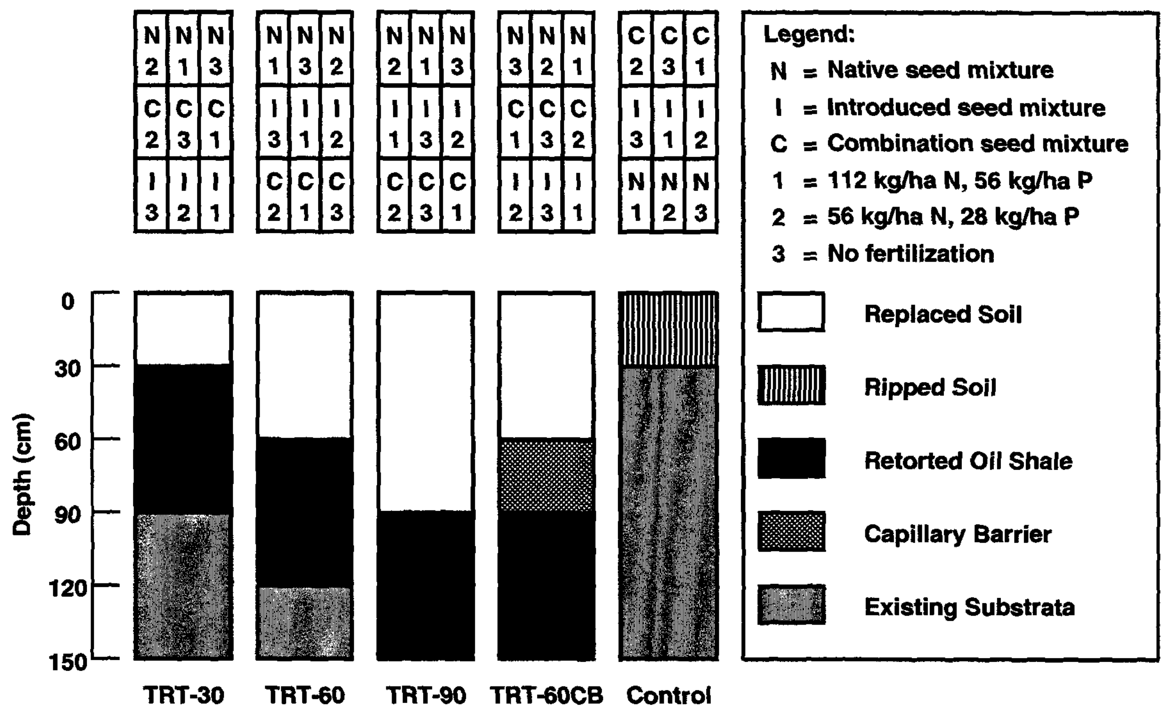

Figure 1. Overhead view of the experimental layout of study plots (top) and side view of topsoil treatments (bottom). Only one replication is shown for study plot layout.

however, since logistics required long, continuous pits in the construction of the topsoil treatments, these treatments were pseudoreplicated.

Topsoil used in this study was obtained on-site during the construction of the experiment, and the retorted oil shale (produced by the Paraho method) originated from the Anvil Points retorting facility near Rifle, CO. In all topsoil treatments except the control, a 60 cm layer of retorted oil shale was placed at an appropriate depth such that the surface of the various topsoil treatments would be level with the existing soil grade. Also, the lower 15 cm of the 60 cm layer of retorted shale was compacted to limit the percolation of soil water through the shale. The five topsoil treatments included:

1. 30 cm of topsoil over retorted shale (TRT-30).
2. 60 cm of topsoil over retorted shale (TRT-60).
3. 90 cm of topsoil over retorted shale (TRT-90).
4. 60 cm of topsoil over 30 cm rock capillary barrier over retorted shale (TRT-60CB).
5. Soil control without retorted shale which involved mechanically removing vegetation and ripping remaining soil to a depth of 30 cm (Control).

A visual representation of topsoil treatments and the experimental layout of study plots is presented (Figure 1).

Each topsoil treatment was then drill seeded with three different seed mixtures in November of 1977. The seed mixtures consisted of a diverse mixture of either all native, all introduced, or a combination of native and introduced grasses, forbs, and shrubs (Sydnor and Redente, 2000). In addition, three fertilizer treatments were applied: 1) 112 kg N/ha, 56 kg P/ha, 2) 56 kg N/ha, 28 kg P/ha, and 3) a control consisting of no fertilization. Phosphorus was applied as triple superphosphate (0-46-0) prior to seeding and was incorporated into the soil using a tractor-mounted rototiller to a depth of 30 cm. The application of N, in the form of ammonium nitrate (33-0-0), did not occur until the end of the first growing season (1978) in an attempt to limit the invasion of weedy annual plant species (Mount, 1985).

During June and July of 1997, we sampled each of the 135 study plots for aboveground biomass by harvesting vegetation within randomly placed 0.5 m^2 quadrats. Six quadrats were sampled within each study plot. Plants within the quadrat volume were clipped at ground level and separated by species. Plant samples were oven-dried at 55° C for 48 hours and then weighed to determine aboveground biomass.

Vegetation data were analyzed using a three-way analysis of variance (SAS Institute, 1998). The dependent variable was aboveground biomass (g m^{-2}), whereas independent variables included topsoil depth, seed mixture, and fertilization rate. The three main treatment effects, as well as any interactions, were tested for significance within grass, forb, shrub, and total aboveground biomass at the α=0.05 level. Means separation tests were performed using LSD at the α=0.05 level. The most important independent variables included topsoil and seed mixture treatments, as well as the interaction between these two variables. Fertilization rate, represented by the one-time application of N and P in 1978, was no longer significant; therefore, this treatment will not be discussed in further sections of this paper.

RESULTS AND DISCUSSION

Effect of topsoil depth

After 20 years of plant community development, variations in topsoil depth (when averaged over seed mixture treatments) continued to influence total aboveground biomass. Overall, deeper topsoil depths supported greater aboveground biomass, being greatest on TRT-60CB (139 g m^{-2}) and TRT-90 (131 g m^{-2}), and lowest on TRT-30 (116 g m^{-2}), TRT-60 (116 g m^{-2}), and the control (102 g m^{-2}) (Figure 2). Increased productivity of grasses, especially on TRT-60CB, was mostly responsible for greater total aboveground biomass on deeper topsoil depths (Figure 2). Forb and shrub biomass did not respond as consistently to variations in topsoil depth, but both were generally lowest on TRT-60CB and the control (Figure 2).

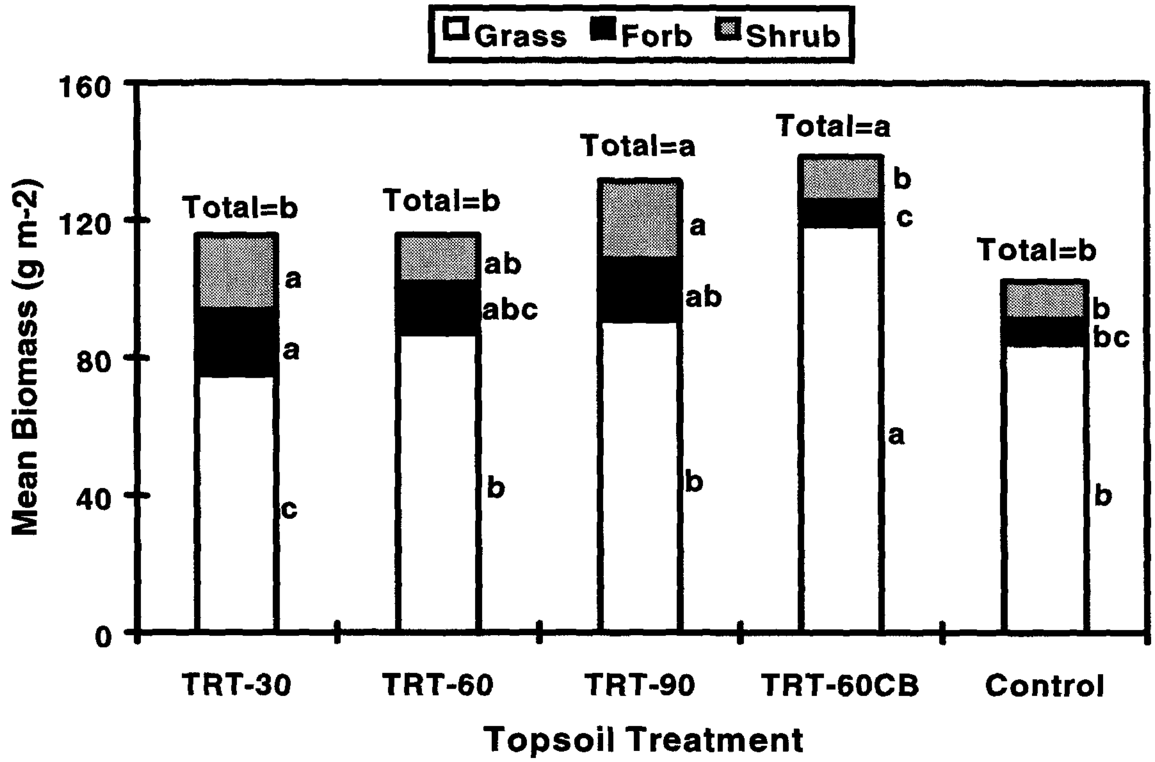

Figure 2. Mean aboveground biomass (g m^{-2}) by topsoil treatment. Each mean for a given life form or total value within a topsoil treatment represents data taken from 27 plots (n=27). Comparisons are made within each life form or the total of all three life forms across topsoil treatments. Means with the same letter within life forms or the total of all three life forms are not significantly different ($\alpha = 0.05$).

The depth of topsoil needed to maximize aboveground biomass on reclaimed mined land has been widely studied (Harbert and Berg, 1978; Bell and Meecham, 1978; Power *et al.*, 1981; Redente *et al.*, 1982; Barth, 1983; Schuman *et al.*, 1985; Trlica *et al.*, 1994; Redente *et al.*, 1997). In general, these authors reported that productivity increased, especially with respect to grass biomass, as topsoil depth increased. The topsoil depth at which aboveground biomass is maximized is site-specific (Schuman and Power, 1981), and depends greatly upon (in order of importance) the characteristics of the underlying mine waste material, regional climatic conditions, and topsoil quality (Hargis and Redente, 1984). With respect to the characteristics of the waste material to be covered, Hargis and Redente (1984) recommended that deeper depths of topsoil are necessary when underlying mine waste or spoil material is phytotoxic, as compared to non-phytotoxic materials. In support of this statement, Barth (1983) found that the productivity of perennial grasses was maximized on the following topsoil depths over mine spoils (with chemical characteristics of spoil in parentheses): 50 cm (slightly saline), 71 cm (sodic), and more than 100 cm (acidic). In contrast, Schuman *et al.* (1985) reported that 40 cm of topsoil overlying non-toxic spoil from a uranium mine supported equal amounts of aboveground biomass as did 60 cm of topsoil. Likewise, Redente *et al.* (1997) reported that 15 cm of topsoil overlying non-phytotoxic coal spoil supported as much total aboveground biomass as 60 cm of topsoil. Deeper depths of topsoil overlying phytotoxic waste materials apparently benefit plant communities by isolating plant roots from the inimical properties of mine waste materials and limiting the upward movement of salts and trace elements (Barth, 1988).

Despite supporting equal amounts of aboveground biomass, relative production of grasses on TRT-60CB plots was approximately 25% greater than on TRT-90 plots. Furthermore, the relative production of forbs and shrubs on TRT-90 plots was nearly twice as great when compared to TRT-60CB plots (Sydnor, 1999). Relative production of grasses, forbs, and shrubs on TRT-60CB plots may have been influenced by the physical presence of the capillary barrier. Redente and Cook (1984) hypothesized that the abrupt textural change at the topsoil/capillary barrier interface disrupted the downward movement of soil water on TRT-60CB plots during the first six growing seasons (1978-1983), leading to greater soil moisture in topsoil overlying the barrier and more favorable growth conditions, especially for grasses. Upon examination of the capillary barrier in 1997, we observed that the large pore spaces that once existed in the rock barrier have filled with soil since the 1983 growing season. However, Barth (1988) suggested that large rocks present in capillary barriers, even when void areas within these barriers are filled with soil particles, may continue to disrupt the movement of soil water by interrupting pore continuity of soil present in the capillary barrier. Thus, the downward movement of soil water through the capillary barrier may still be obstructed, leading to greater soil moisture in overlying topsoil, and helping to explain the continued dominance of grass species on TRT-60CB plots relative to the other topsoil treatments (Figure 2).

Effect of seed mixtures

Barth (1986) stated that many of the plant species used to revegetate disturbed areas should be transitory and that their use should not compromise secondary successional processes by preventing or hindering the establishment of colonizing, non-seeded species. However, our long-term data revealed that study plots seeded with a given seed mixture in 1977 have tended to remain dominated by those species originally seeded (Sydnor and Redente, 2000). Other long-term studies have reported similar findings 14 to 23 years after seeding (Jordan and Dewar, 1985; Chambers *et al.*, 1994; Walker *et al.*, 1995; Newman and Redente, 2001). Furthermore, in support of our study, these same authors reported that the colonization of native, non-seeded species (especially shrubs) was slow in the presence of introduced species, possibly due to competition with introduced grasses. For example, colonizing, non-seeded native shrubs contributed 1% of total production in the introduced seed mixture in 1983 (Redente and Cook, 1984), and by 1997 were contributing only 3% (Sydnor, 1999); conversely, colonizing, non-seeded native shrubs only represented a trace amount of total production in 1983 on plots seeded with the native mixture (Redente and Cook, 1984), but contributed 8% of total production by 1997 on these same plots (Sydnor, 1999). Given that seeded species were initially favored by a well-prepared seedbed, we feel that the long-term dominance of seeded species has been maintained over time by interspecific competition among these species for limited resources, which has slowed the colonization of non-seeded species.

Our results also indicated that the choice of seed mixture may affect the long-term productivity of restored plant communities. In the current study, the introduced seed mixture (134 g m^{-2}) supported greater aboveground biomass than either the native (120 g m^{-2}) or combination (108 g m^{-2}) seed mixtures, when averaged over topsoil depth (Figure 3). This result contradicts Newman and Redente (2001) who found that a native seed mixture was more productive than an introduced seed mixture after 21 growing seasons; this response was partially due to the effects of an initial, two-year irrigation treatment. However, when we considered variations in topsoil depth, we found that the native seed mixture was as productive as the introduced seed mixture on deeper topsoil depths (TRT-60CB and TRT-90) and the control (Table 1); conversely, the introduced seed mixture was more productive than both the native and combination mixtures on shallow topsoil depths. This trend suggests that the use of a native seed mixture may result in a plant community as productive as one resulting from a seed mixture containing all introduced species, over longer time scales, when well isolated from a phytotoxic growth medium (i.e., with the use of deeper topsoil depths). Overall, the results of this study indicate that the selection of a seed mixture for reclamation projects may have long-lasting effects on the resulting plant community in terms of plant species composition and productivity.

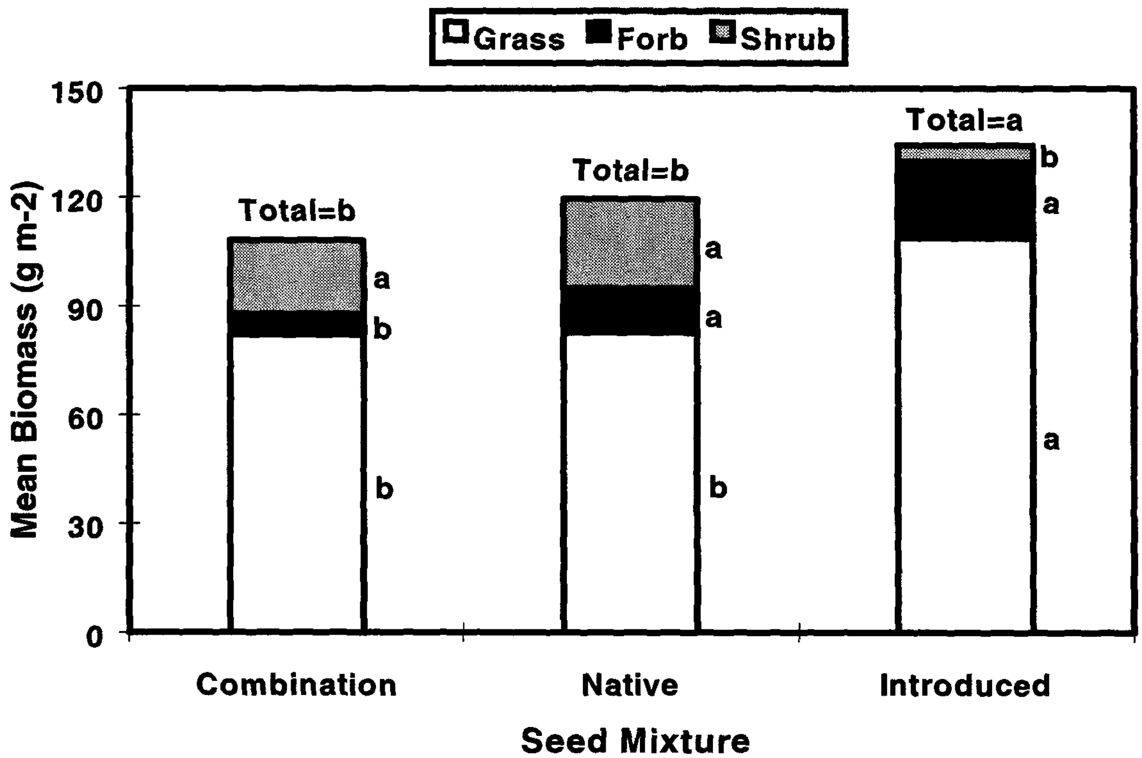

Figure 3. Mean aboveground biomass (g m^{-2}) by seed mixture. Each mean for a given life form or total value within a seed mixture represents data taken from 27 plots (n=27). Comparisons are made within each life form or the total of all three life forms across topsoil treatments. Means with the same letter within life forms or the total of all three life forms are not significantly different ($\alpha = 0.05$).

Effect of treatments on plant species richness

Overall, changes in topsoil depth did not affect plant species richness. This result contradicts Huston's (1979) hypothesis concerning the relationship between diversity (which included the concepts of species richness and evenness) and productivity: "[d]iversity is determined not so much by the relative competitive abilities of the competing species as by the influence of the environment on the net outcome of their interactions." Put another way, conditions that enhance the rate at which certain plant species' competitive abilities are expressed will tend to lower diversity (or richness) as less competitive species are excluded. However, on deeper topsoil treatments, the increased productivity of grasses did not appear to heighten competitive exclusion of other species or limit colonization of species from the neighboring species pool.

Despite the fact that the introduced seed mixture was generally the most productive in the current study, this mixture had the lowest species richness. Overall, plots seeded with the introduced mixture contained

Table 1. Mean aboveground biomass (g m^{-2}) by life form within a given seed mixture and topsoil treatment. Each mean represents data taken from nine plots (n = 9). Comparisons are made within each life form (and the total of all three life forms) and are among seed mixtures. Values followed by the same letter within a column are not significantly different ($\alpha = 0.05$).

	Topsoil Treatment				
Life form within seed mixture	**TRT-30**	**TRT-60**	**TRT-90**	**TRT-60CB**	**Control**
	g m^-2	*g m^-2*	*g m^-2*	*g m^-2*	*g m^-2*
Native					
Grass	**61b**	**67c**	**78b**	**113b**	**94a**
Forb	**13a**	**17a**	**13ab**	**11a**	**7a**
Shrub	**28a**	**21a**	**38a**	**22a**	**15ab**
TOTAL	**102b**	**105b**	**129a**	**145a**	**116a**
Introduced					
Grass	**102a**	**110a**	**109a**	**132a**	**90a**
Forb	**32a**	**25a**	**31a**	**10ab**	**7a**
Shrub	**11b**	**2b**	**7b**	**0b**	**4b**
TOTAL	**145a**	**137a**	**147a**	**142a**	**101ab**
Combination					
Grass	**62b**	**84b**	**86b**	**111b**	**68b**
Forb	**11a**	**2b**	**8b**	**1c**	**7a**
Shrub	**26a**	**19a**	**24a**	**17a**	**15a**
TOTAL	**99b**	**105b**	**118a**	**128a**	**90b**

an average of 2.7 species m^{-2}, whereas native and combination seed mixture plots supported an average of 4.3 and 3.7 species m^{-2}, respectively (Sydnor, 1999); as a comparison, undisturbed reference plots adjacent to the study site were found to contain 5.6 species m^{-2}, on average (McLendon and Redente, *unpublished data*). In support of the current study, Redente *et al.* (1984) reported that seed mixtures containing all introduced species were generally less diverse than native seed mixtures, based on the Shannon-Weiner index. There may be several reasons why species richness or diversity is generally lower on sites seeded with introduced species mixtures. The most plausible explanation for this phenomenon in the current study may be attributed to the lack of introduced shrub establishment during the initial phases of this study (Redente *et al.*, 1982). Thus, competition between introduced shrubs and grasses for resources on introduced seed mixture plots was non-existent during early plant community development. This lack of competition, coupled with favorable growing conditions for several of the introduced grasses, probably enhanced the growth rates and competitive abilities of introduced grasses, thus allowing them to dominate the introduced mixture, exclude other less competitive species, and lower species richness (Huston, 1979).

The reclamation of mined lands in the western USA must achieve specific goals in terms of total production and plant species diversity; however, research has shown that productive, yet diverse plant communities are difficult to re-create (DePuit, 1984; Stark and Redente, 1985; Biondini and Redente, 1986). Some authors have successfully obtained both by increasing the number of species in an all-native seed mixture (DePuit and Coenenberg, 1979), or by using irrigation to manipulate composition of the seeded community (Redente and DePuit, 1988). Other authors (DePuit, 1984; Stark and Redente, 1985) have suggested the application of various depths of topsoil across the landscape as a potential strategy for obtaining productive and diverse plant communities. The results of the current study indicate that productive and relatively species-rich native plant communities can be established and maintained over phytotoxic mine waste materials with the use of at least 30 cm of topsoil, a diverse seed mixture of native species, and no initial fertilization. In addition, deeper topsoil coverings may be used to increase the productivity of a native seed mix without compromising plant species richness.

CONCLUSIONS

The lack of long-term data on the effectiveness of treatments used in the reclamation of phytotoxic waste materials is apparent in the literature. In an attempt to fill this void of knowledge, the current study shows that initial treatments may have long-lasting effects on the productivity, species composition, and plant species richness of plant communities 20 years after establishment. For example, the use of topsoil overlying retorted oil shale has resulted in plant communities that are as or more productive than the control, depending on the depth of topsoil used. Also, the long-term maintenance of native, species-rich plant communities may be achieved on topsoil treatments by initially seeding with a diverse mixture of native species. Thus, productive and species-rich native plant communities may be supported over longer time scales with the use of a topsoil covering over a phytotoxic mine waste material, a native seed mixture, and no initial fertilization. However, if greater productivity or increased isolation of plant roots from waste materials is a goal of reclamation, then deeper depths of topsoil or the use of a capillary barrier in conjunction with a topsoil covering may be used without compromising plant species richness.

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DESIGN AND PERFORMANCE CRITERIA FOR SOIL COVERS AND CAPS

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DEVELOPMENT OF REGULATIONS

Early regulation of solid waste was driven, probably even in ancient times, by odor and common sense. By the late 1800's some control was provided by law by the 1899 Rivers and Harbors Act. This legislation, however, was primarily to prevent refuse from interfering with shipping in navigable waters. Common law could protect property interests, but on the whole, actions of this kind were reactive in nature. As late as the 1960's landfills in rural areas were generally low-lying unregulated dumps.

Before 1965 there were only a handful of waste management laws. Over the next two decades over 20 laws would be passed dealing directly with solid or hazardous waste. The 1965 Clean Air Act Amendments (Solid Waste Disposal Act of 1965) focused on solid waste management primarily to improve air quality by reducing open burning and low tech incineration.

By the early 70's solid waste management was chaotic, and totally unregulated in some areas of the country. Overall federal management was in the hands of the U.S. Public Health Service in the era before the Environmental Protection Agency (EPA). It was becoming clear to many that hazardous waste management was an emerging concern.

The 1976 Resource Conservation and Recovery Act (RCRA) separated hazardous and non-hazardous waste. The 1980 Comprehensive Environmental Response and Liability Act (CERCLA) addressed cleanup by passing the cost back to the owners or "potentially responsible parties." The 1984 RCRA amendments tightened landfill design requirements and addressed the need to protect groundwater.

PRESCRIPTIVE COVERS UNDER RCRA

Soil covers for municipal, other non-hazardous waste, and hazardous waste landfills are regulated under RCRA. The primary component has been a low permeability cover consisting of hydraulic barriers (or resistive covers). These have been designed with:

- Compacted clays;
- Soil amended with bentonite;
- Geocomposite liners (GCLs); or
- Geomembranes (e.g., HDPE).

In general these designs are intended to function by creating a barrier of low saturated hydraulic conductivity. The key concept in this type of application is that the hydraulic barrier will resist or retard the downward infiltration of water and direct the flow laterally. Additional layers in the cover system have been addressed in common practice as well as by EPA guidance, including:

- Gravel or sand drainage layers;
- Biota barriers of rock or concrete; and
- Surface vegetation.

Interestingly, vegetation has been considered primarily as an erosion control element of the design, not as a barrier to infiltration of water through the cover system and down into the waste layers (percolation). Evapotranspiration, for example, has not until the last five or so years been seriously considered as a key design element.

RCRA Categories for Solid and Hazardous Waste

RCRA addresses solid waste under Subtitle D and hazardous waste under Subtitle C. The regulations and guidance are relatively prescriptive, although Subtitle D does provide greater flexibility for alternative covers. Solid waste landfill covers (Subtitle D) must, in the most simplistic sense, simply achieve a cover permeability less than the permeability of any underlying liner, or if no liner has been constructed, less than the permeability of the underlying unit beneath the disposed waste. The logic behind the design cover permeability being less than the lower confining layer was to prevent a "bath-tub" effect, which tend to place waste in contact with groundwater, thus generating leachate. Subtitle D guidance also allow waivers based on depth to groundwater.

Hazardous (Subtitle C) landfills are by far the most prescriptive with respect to design, requiring "composite liners" such as clay in contact with a geomembrane, such as high density polyethylene (HDPE). (clay/synthetic liners and covers)

Prescriptive or Traditional Cover Advantages

Regulatory acceptance has been high for soil covers that use hydraulic barriers, as opposed to designs incorporating more of a natural water balance approach (e.g., evapotranspiration). This is in part because of the clear regulatory requirements and criteria, which prescribe the saturated hydraulic conductivity (K_{sat}). The latter parameter can be measured for the design barrier material, and monitored during construction. EPA has also established excellent guidance to assure that standards are met during construction. In general these covers can be engineered as barriers with gravel drainage controls and vegetation to control erosion.

Challenges Associated with Prescriptive Barriers

In arid and semi-arid areas special care required to avoid cracking and root penetration. Clay begins desiccating during hot weather, and in general, geomembranes are often needed simply to assure that water does not evaporated from clays which are usually placed slightly wet of optimum with respect to compaction.

GCLs are also a concern in some applications, and should be carefully evaluated with respect to calcium carbonate content in adjacent soils (e.g., bentonite GCLs can be attacked by calcium substitution for sodium ions, greatly increasing hydraulic conductivity).

In general, the barrier designs can function well, but environmental impacts particularly in arid areas, should not be overlooked. Very importantly, a high level of assurance can be provided with effective Quality Control/Quality Assurance during construction and during the pre-borrow investigation.

CURRENT DEVELOPMENTS IN ALTERNATIVE COVERS, COMPACTED BARRIERS VS. EVAPOTRANSPIRATION COVERS

Evolution of ET-type non-barrier designs

Investigators have drawn attention to natural systems illustrating that deep percolation can be controlled by soil water retention and evapotranspiration. Numerous long-term studies suggest that soils of proper texture inhibit moisture moving into the groundwater table.

Rocky Mountain Arsenal

The selected remedy outlined in the On-Post Operable Unit Record of Decision (ROD) for the Rocky Mountain Arsenal (RMA) near Denver, Colorado, included constructing RCRA-equivalent covers over three remediation projects that would cover approximately 250 acres. Agreements have recently been reached with the regulatory agencies to construct RCRA-equivalent covers on three more remediation projects, bringing the total area covered by RCRA-equivalent covers to approximately 500 acres. These remediation projects include former manufacturing, disposal basin, and disposal trench areas, and contain contaminated soils, manufacturing wastes, and munitions debris.

RMA is unique in that the alternative cover standard for this site is Subtitle C. The ROD therefore required a comparative analysis using a suitable design model, as well as field demonstration. The model UNSAT-H, a physically based unsaturated flow model was selected for the initial evaluation of alternative covers. Field verification was achieved with a test plot study that lasted for four years following construction of four test plots and seeding with native vegetation. The percolation criterion was established at 1.3 mm/year, which was considered to be comparable to the expected performance of a composite clay/synthetic cover system.

Design for Monitoring and Testing

The basic design concept was intended for use on containment of waste in-place. As shown on Figure 1, the alternative RCRA-equivalent design uses a 42-inch minimum cover, with appropriate native vegetation to achieve the expected performance target percolation. In general, a cover of this type is expected to perform well in the semi-arid Denver area, at a significant cost savings over construction of a composite Subtitle C landfill-type cover.

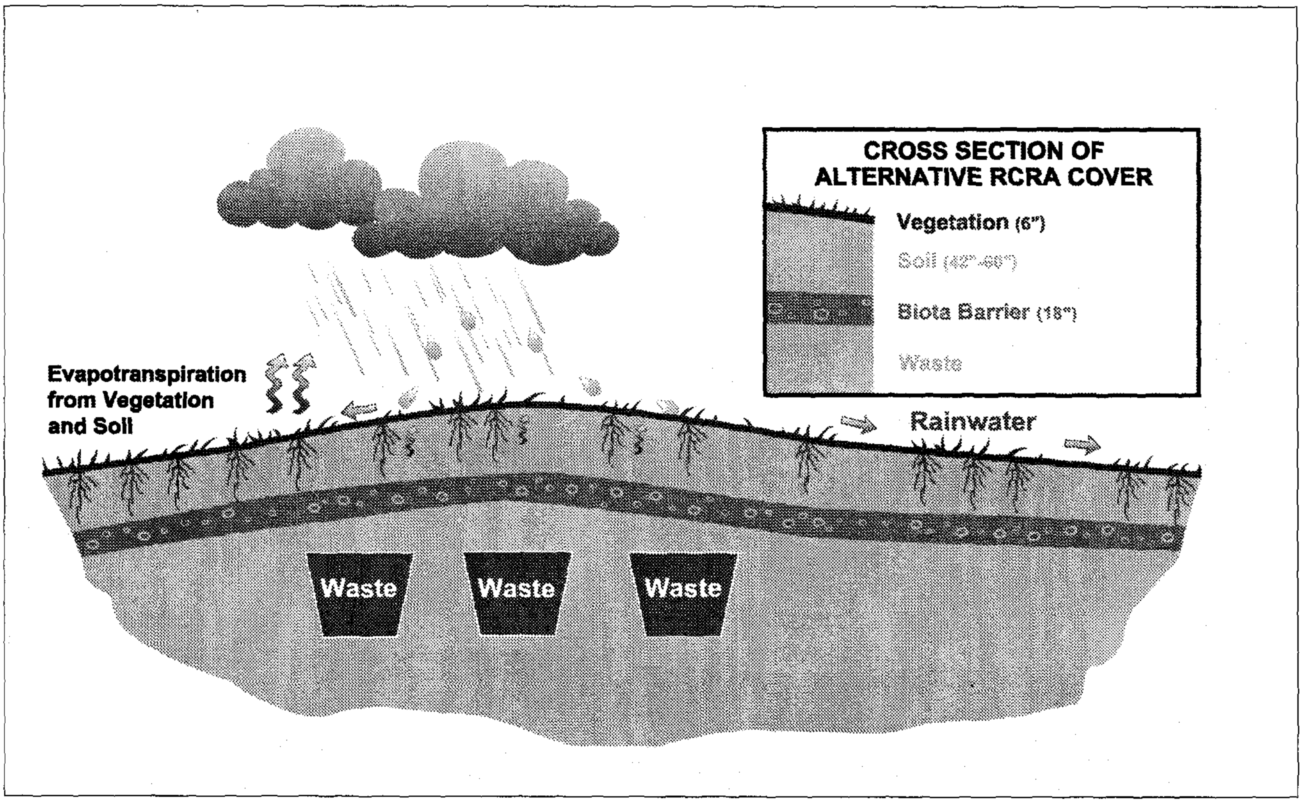

Figure 1. Alternative Cover Design at RMA

Soils Specification

The soil cover engineering specifications must identify a suitable soil texture that also provides acceptable unsaturated flow characteristics. Secondly, the soils specification must address agronomic requirements that will encourage a strong development of native grasses. The key engineering specification was a minimum percent fines passing the no. 200 sieve of 35 percent or greater, including an acceptable clay content (as yet undetermined). The compaction specification will strive towards are natural density, generally thought to be 80 to 85 percent of Standard Proctor. These characteristics will be monitored during construction to avoid over compaction, or placement of overly granular soils.

Long-Term Performance Monitoring

Long-term monitoring will include yearly vegetation cover sampling to ensure ongoing compliance with an empirical vegetation cover requirement. This requirement was developed in consideration of long-term erosion control and reduction of percolation by evapotranspiration. Erosion impacts will also be monitored, although the maximum allowable slope is only 3 percent for these cover systems.

The ultimate performance criterion, however, will be percolation, which will be monitored via a number of strategically placed large pan lysimeters.

CONCLUSIONS

Containment is still heavily relied upon for solid/hazardous waste management. Cost considerations, as well as the high cost of treatment will place increasing demand on containment as the ultimate remedy. Cover systems utilizing barriers, when properly constructed, offer demonstrated effectiveness for long-term isolation for protection of human health and the environment. Additional research and full-scale demonstrations are needed to determine if the evapotranspiration covers are indeed effective containment alternatives in lieu of barrier designs. The expectation is that these cover systems will perform well, and act as natural systems.

LONG-TERM EFFECTS OF TORDON CONTROL OF DIFFUSE KNAPWEED ON PLANT COMMUNITY CHARACTERISTICS AND THE DYNAMICS OF KNAPWEED

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ABSTRACT

Native rangeland comprised of mid-grass and shortgrass plant communities in the southern portion of Boulder County on pediment scarps and lower slopes had become infested with diffuse knapweed (*Acosta diffusa*) and in April 1996 was treated with the herbicide known commercially as Tordon®. Long-term observations of the plant communities sprayed as well as unsprayed control areas has been undertaken twice each year since (June and Late August/early September). Initial fears of devastation of native broadleaf plants (forbs) were allayed by subsequent quantitative observations. In general, total late season native perennial forb cover rose in all spray transects until the drought of 2000. Some early season species such as *Viola nuttallii* and *Lesquerella montana* showed declines as they did in control transects. However, their declines in sprayed transects were of greater magnitude. Other early season species such as *Senecio integerrimus* and *Castilleja sessiliflora* showed increases in the years after the 1996. Knapweed cover in sprayed areas stayed well below pre-spray levels and followed general vegetation cover in decline in 1999 and especially in 2000 in response to drier/much drier conditions. However, in 2001, with the return of more nearly average precipitation conditions, knapweed has rebounded in the spray transects to levels comparable to pre-spray conditions, far exceeding the increase in cover by native vegetation.

INTRODUCTION

Studies reported here are based on work undertaken in 1996, 1997, 1998, 1999, 2000, and 2001 with the intent of documenting effects of a May 1996 application of Tordon herbicide on approximately 800 acres of City of Boulder Open Space and Boulder County Open Space land infested by diffuse knapweed (*Acosta diffusa*). Objectives have been to continuously assess of the impacts of the herbicide on the target plant (knapweed) as well as other broadleaf plant species, especially the native species. Early season observations were made in April 1996 (prior to spraying), June 1997, 1998, 1999, 2000, and 2001. Late season observations were made in late August of 1996 and 1997, early September of 1998 and 1999, late September of 2000, and late August of 2001. Early and late season observations allowed assessment of partially different sets of plant species that comprise the vegetational cover of these grasslands during these different times of year.

METHODS

Project Location

The areas studied were located in T1S, R70W, Secs. 25 and 35, approximately 1.25 miles southeast of Coal Creek on the upper surface and side slopes of a Rocky Flats-age pediment.

Sample Locations

Permanent sample locations were established in 1996 and were placed subjectively to incorporate the variability of the treatment area. At each sample location, the end points of the sample transect were marked with a rebar stake driven flush with the ground and with a Carsonite flat fiberglass post. The rebar stakes can be located with a metal detector. The Carsonite posts were labeled to indicate the origin and endpoint. Samples with an "S" prefix were located within the sprayed area and samples with a "C" prefix were placed in unsprayed areas. Sites S-1 and S-2 were located within the sprayed area on the wind-exposed upland just west of Coalton Road ("terrace escarpment" soils; see Map 1). Site S-3 was located on a mid-slope area (Kutch series; moderately deep) and site S-4 was placed in a swale area on deep soils (McClave series). Control sample C-2 was placed on a wind-exposed upland site with shallow ("terrace escarpment") soils similar to spray sites S-1 and S-2. Control sample C-1 (Valmont series deep soils) was more comparable to the less wind-exposed sites with deeper soils of spray samples S-3 and S-4. Sample S-2 was located in an area transitional between "terrace escarpment" soils and valmont series soils, and thus is transitional between deep and shallow soils. All soils in the study area are very fine in the fine earth (< 2mm) fraction – varying from loam to clay in the surface layers, but mostly in the clay loam USDA textural class.

Cover

Cover data were collected using a point intercept method in which data were recorded as interceptions of a point with plant species, litter, standing dead plant material, soil or rock. Plant material produced during 2001 and still standing was tallied by species. Litter was considered to be any organic material that had fallen, or had substantially fallen to the soil surface. Standing dead was any dead plant material that was produced in previous years but which was still standing and had not lodged or broken off to become litter. Inorganic materials greater than 1 cm in diameter were considered rock. The cover sampling points were optically projected using a Cover-Point Optical Point Projection Device. Two hundred points were collected at each transect and distributed evenly along the 50 meter transect with a pair of points collected at each 0.5 meter mark. The pair of points were sampled on opposite sides, 0.5 m from the transect.

The point intercept method of cover assessment was chosen because it provides superior objectivity and repeatability. Because more abundant species are more likely to be "hit", this method collects more information about abundant species than about rare species. This inherent tendency has been countered in two ways. First, all vascular plant species present within one meter to either side of the sample transect were tallied. Besides pure documentation of their presence, this tally gives a measure of species "density" that is useful in itself. In addition, frequency plot data have been collected to provide further details of the abundance of less common species (see Frequency, below).

Frequency

Frequency data were collected in ten subplots located along each 50 m transect. All subplots measured 1 m X 5 m and were placed to the right of the transect as viewed from the origin. In each plot, all species present were tallied. For each species, the number of plots in which the plant was observed was divided by ten (the number of plots observed). Thus, for example, if Species A occurred in seven plots, its frequency for the transect is 7/10, or 70 percent. In addition, as described above, all species present within 1 meter to either side of the 50 meter sample transect were tallied and a value of species density expressed as the number of species per 100 square meters calculated.

Knapweed Density

In the course of early and late season sampling, the sample plots along the transects were assessed for knapweed density. The density knapweed within each of the ten 1 m X 1 m frequency plots was determined by direct count. Rosette-stage and bolted plants were tallied separately.

RESULTS

Data collected in 1996, 1997, 1998, 1999, 2000, and 2001 (ESCO 1997, 1998, 1999a, 2000a, 2001, 2002) are too voluminous to present in this document. Summary knapweed cover results for 1996, 1997, 1998, 1999, 2000, and 2001 are graphically illustrated in Figure 1. Knapweed frequency results for the same period are illustrated in Figure 2; knapweed density results are illustrated in Figure 3. Relative cover by lifeform and species density by lifeform data from 2001 are depicted in Figures 4 and 5, respectively. Relative cover by lifeform for all early season sample dates (1996-2001) is presented in Figures 6a and 6b. The same for all late season sample dates (1996-2001) is presented in Figures 7a and 7b. Species density by lifeform is similarly depicted for early season data in Figures 8a and 8b and for late season dates in Figures 9a and 9b. A compilation of total vegetation cover for all sample dates is presented in Figure 10. Species present in the entire sampling area are shown in Table 27.

When this study was initiated in 1996, one of the objectives was to compare the extent of fully developed plant cover before spraying to observations made later in the year and in subsequent years. Therefore, the April 1996 sampling separately assessed the extent of both knapweed and other plants living at the time of sampling and the extent of standing dead material apparently produced in 1995. These two measures were combined to provide a "total" value that approximates the plant species cover that might have been expected in late season of 1995 and would be at least roughly comparable to late season observations in subsequent years.

DISCUSSION

Study Sample Locations Along a Soils Gradient

The following depicts a conceptual arrangement of samples along a gradient of soil texture and exposure:

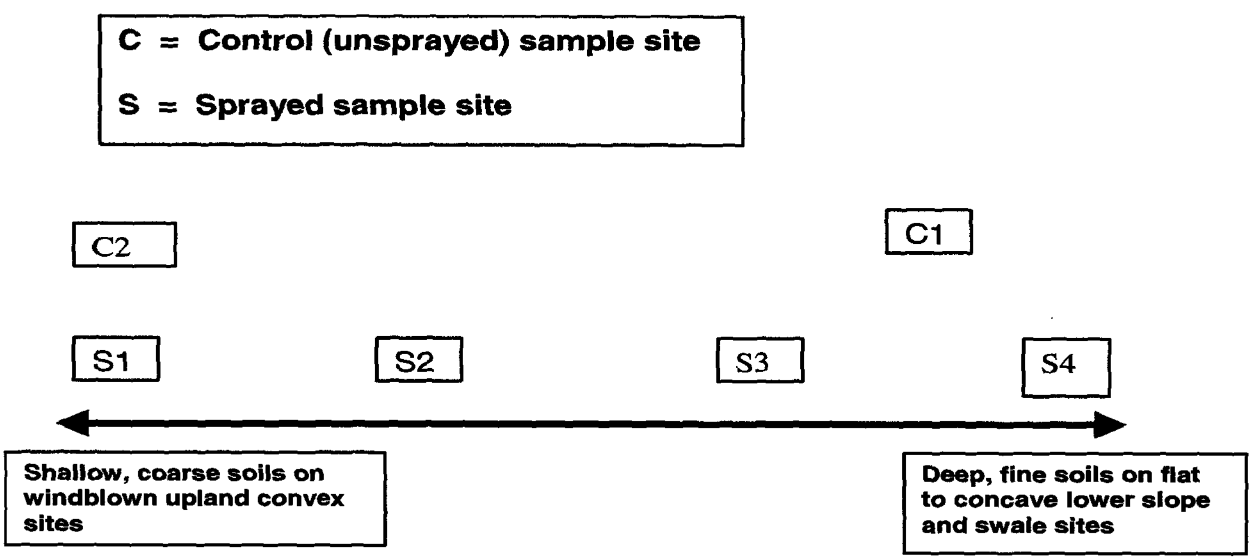


Figure 1. Foliar cover by Diffuse Knapweed - Early Season Sample Dates

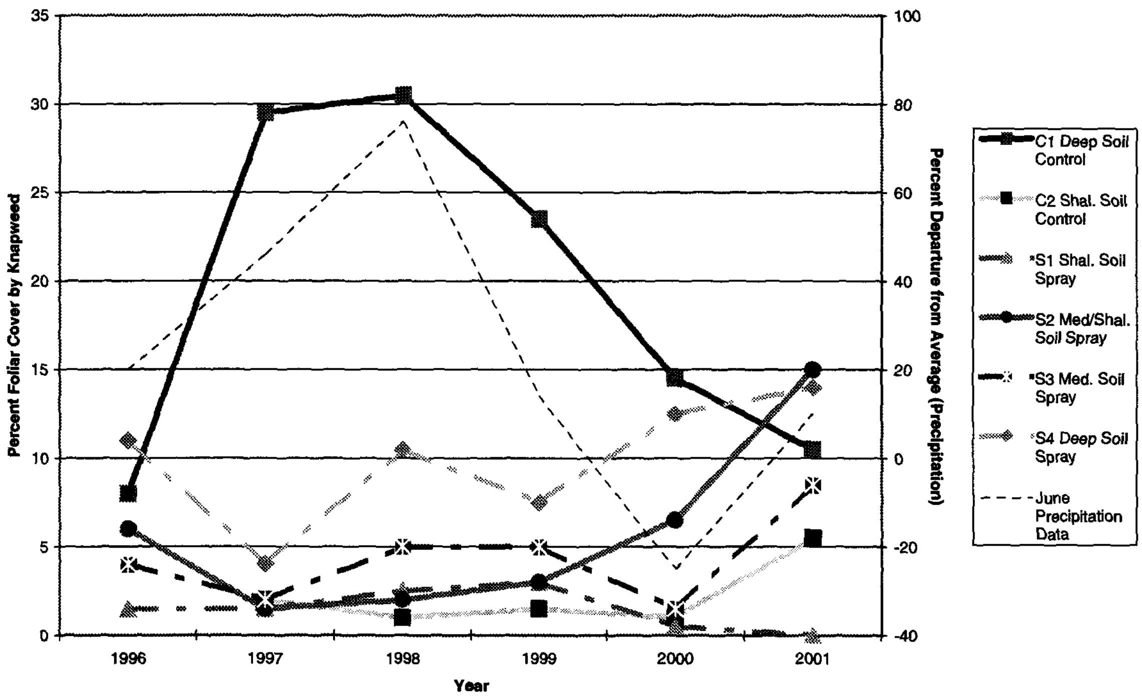
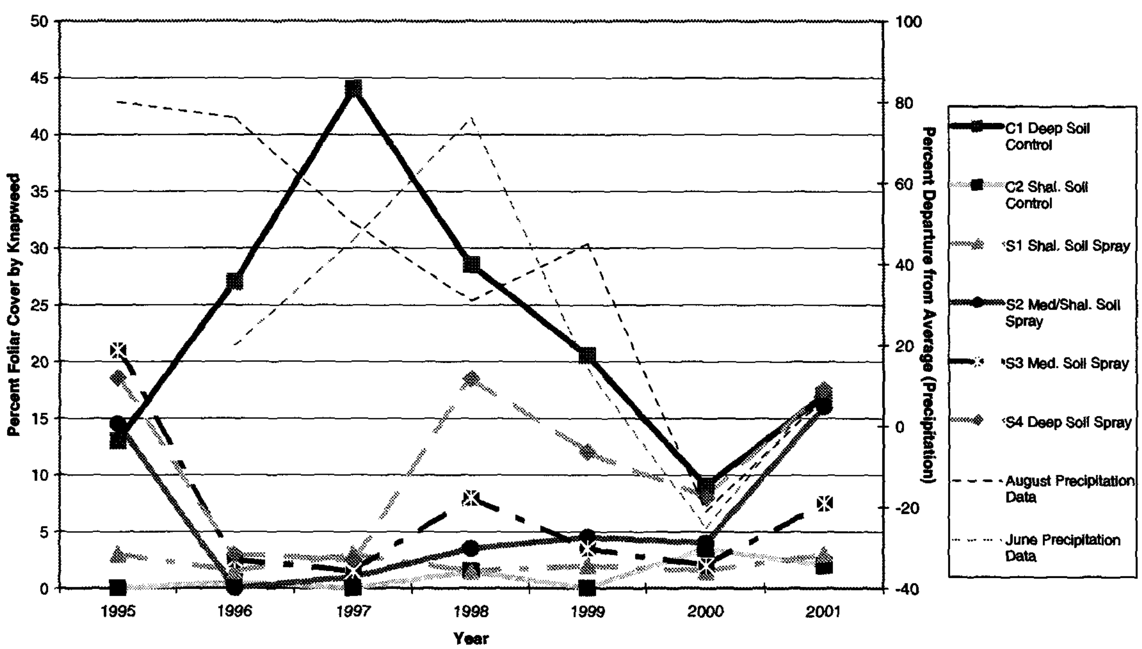
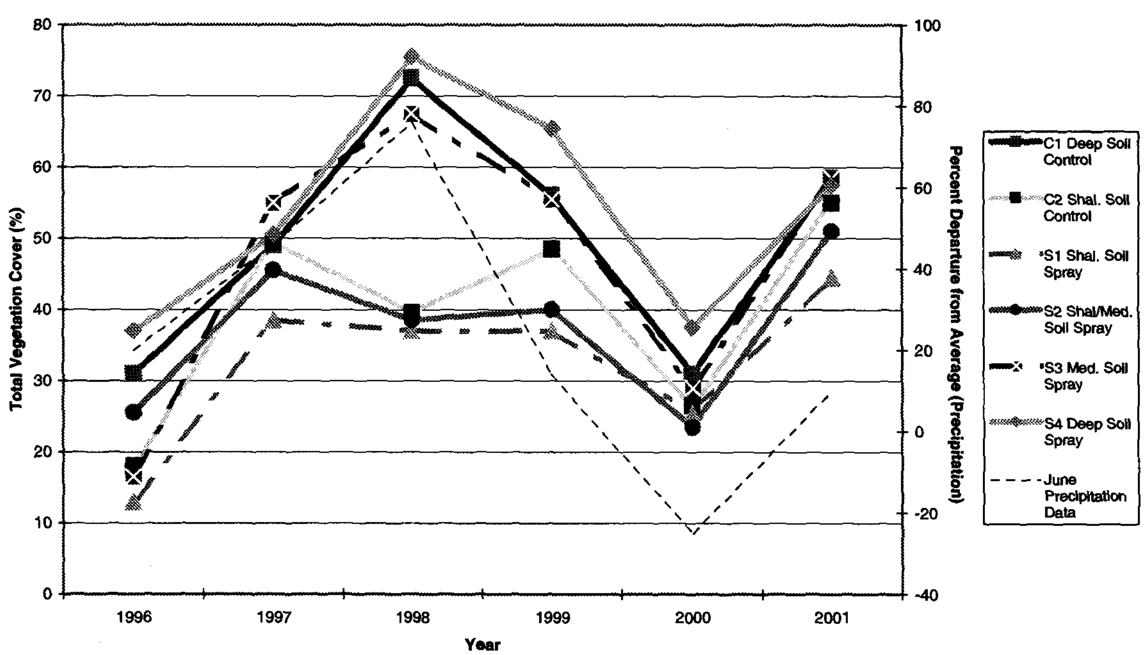


Figure 2. Foliar Cover by Diffuse Knapweed - Late Season Sample Dates



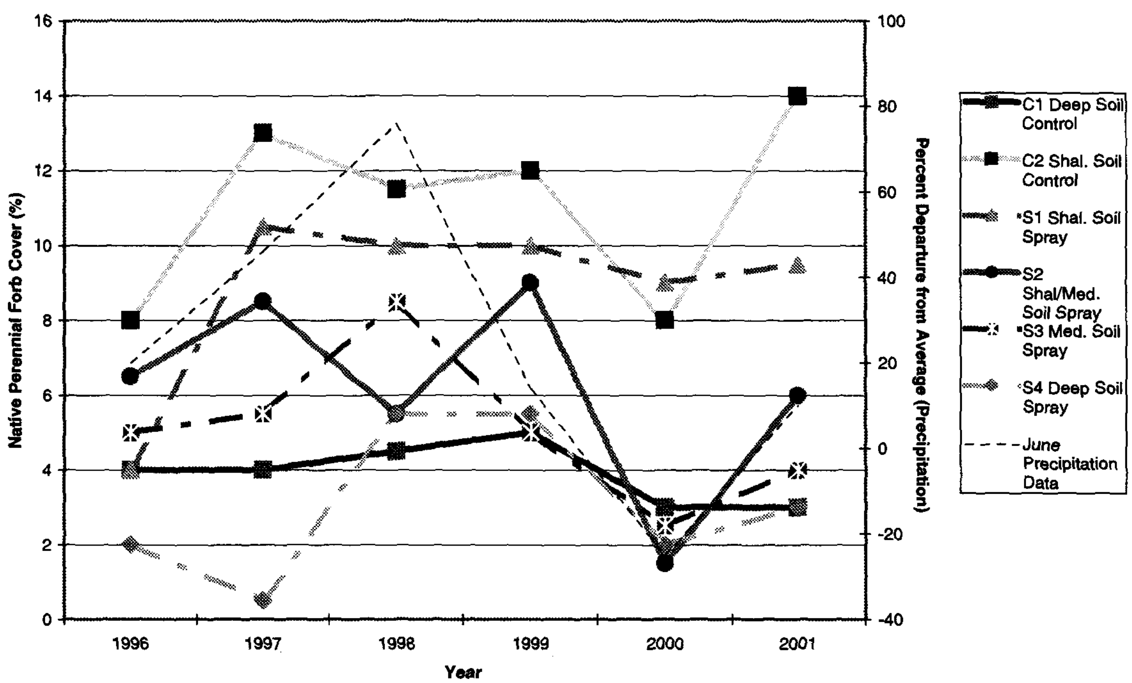
As can be seen in Figure 1, early season knapweed cover in the C1 control has followed the precipitation pattern rather closely. The precipitation data shown in Figures 1 and 2 are calendar year totals as they depart from long-term average. 1997 through 1999 were all years with above average precipitation through June and unsprayed knapweed cover in the followed the general pattern of moisture fairly closely. The C2 control has low suitability for knapweed and it has remained low there throughout the study until 2001 when it reached its highest level of the period of observation. Note that prespray data for knapweed (1995 – Figure 2) showed that the knapweed abundance in spray transects S2, S3, and S4 (the moderate to deeper end of the soil spectrum) was as great as or greater than C1. After spray, (April 1996) knapweed cover in sprayed areas remained far below the C1 control level until 2000 and 2001. Knapweed cover in sprayed areas was unable to respond to favorable moisture conditions as did the knapweed cover in the C1 control. Knapweed cover in sprayed areas stayed well below pre-spray levels and followed general vegetation cover in decline in 1999 and especially in 2000 in response to drier/much drier conditions. However, in 2001, with the return of more nearly average precipitation conditions, knapweed has rebounded in the spray transects to levels comparable to pre-spray conditions, far exceeding the increase in cover by native vegetation.

Figure 3. Total Vegetation Cover - Early Season Sample Dates

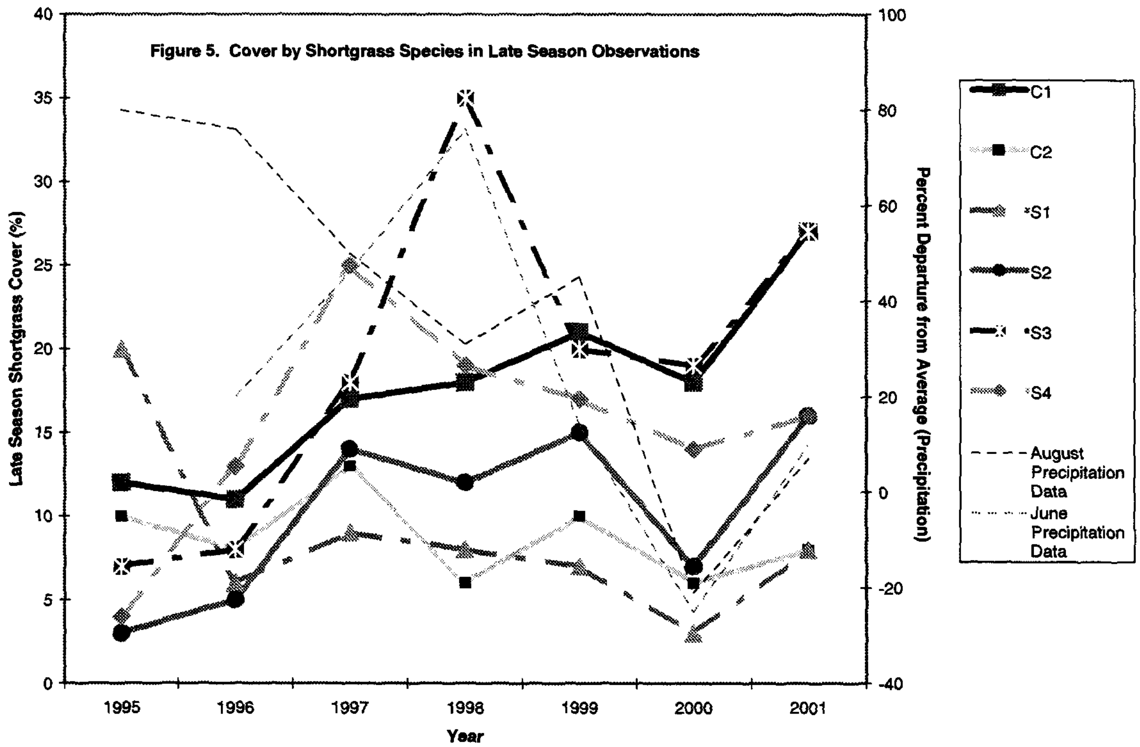


As can be seen in Figure 3, total vegetation cover in the moderate and deep soil sites was very responsive to moisture availability while the shallower soil sites were synchronized when the January through June precipitation was less than 40 percent above average. However with higher precipitation, only the deep soil sites could take advantage.

Figure 4. Native Perennial Forb Cover - Early Season Sample Dates



Native perennial forb cover (Figure 4) is by its nature higher on the shallow soils of this area than on the deep soils. Hence, the C2 control native perennial forb cover has been 2x to 3x that of the C1 control through the six years of observation. The effects of spraying on native perennial forb cover have been small. Note that the shallow soil spray transect (S1) has stayed at a high level in parallel with the C2 control through the six years. In the period after the April 1996 spraying, the only apparent possible decline in response to the herbicide was on S4 the deep soil spray transect. However after 1997, even its native perennial forb cover was in the middle of the range of the other transects. Note that the biggest apparent event affecting native perennial forb cover during the six years was the drought of 2000 in which the native perennial forb cover of the shallow to medium and deeper sites all fell to about 2 to 3 percent in synchrony. The shallow soil sites' (C2 and S1) cover also got together, but at the considerably higher level of 8 to 9 percent. Note that the modest effect this one-pint per acre application of Tordon on native perennial forb cover may have related to extenuating circumstances in the form of dilution by rain in the days immediately after application. Applications at the same rate on the nearby Rocky Flats Environmental Technology Site resulted in much larger declines of native perennial forbs for at least the first two years (ESCO 1999b, 2000b).



Another effect of the introduction of the herbicide in early 1996 may be the spikes of shortgrass cover on the deep soil spray site (S4) in 1997 and the medium soil site (S3) in 1998 (Figure 5). Shortgrass species involved were buffalograss (*Buchloe dactyloides*), blue grama (*Chondrosum gracile*), and hairy grama (*Chondrosum hirsutum*). These spikes were not seen in the other transects including the controls until the stress of the drought of 2000 elicited shortgrass increases on all transects in 2001. It is speculated that these spikes represent "wound responses" to the perturbation represented by the herbicide application.

Reactions of Individual Forb Species

Some early season species such as *Viola nuttallii* and *Lesquerella montana* showed declines both in control and spray transects. However, their declines in sprayed transects were of greater magnitude. Other early season species such as *Senecio integerrimus* (lambstongue groundsel) and *Psoralidium tenuiflorum* (small-flower scurfpea) showed increases in the years after the 1996. The *Senecio* varied moderately in all transects except the deep soil spray transect (S1) where it showed some fairly large fluctuations in frequency. The *Psoralidium* showed greater abundance on all spray transects until year 2000 when the dry conditions substantially decreased its frequency on all transects except the deep soil spray and the shallow soil spray transects.

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ENVIRONMENTAL FACTORS INFLUENCING YELLOW TOADFLAX (*Linaria vulgaris* Mill.) DISTRIBUTION IN THE FLAT TOPS WILDERNESS AREA OF COLORADO

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and

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ABSTRACT

Yellow toadflax (*Linaria vulgaris* Mill.) is a common weed that has become a serious problem in the Flat Tops Wilderness of Colorado. Using GPS technology, yellow toadflax infestations were mapped in the Ripple Creek and Marvine Creek drainages of the Flat Tops Wilderness during the summers of 1999 and 2000, respectively. Characteristics of plots containing yellow toadflax were recorded and compared to non-infested control plots surveyed during the same season. Statistical design was a case control study in two locations. Plot characteristics were analyzed using logistic regression with forward selection. Yellow toadflax was positively correlated with parks, trail sides, and higher number of species per plot ($p<0.05$). Individual species correlations were determined by chi-square comparison of a species' presence in a plot to yellow toadflax presence. Yellow toadflax was positively correlated with several species including western yarrow (*Achillea lanulosa*), and negatively correlated to gymnosperms ($p<0.05$). Percent bare ground and litter were analyzed using one-way analysis of variance (ANOVA). Yellow toadflax plots had a higher percentage of bare ground than non-infested plots ($p=0.0547$). Results of this study will direct future research on the ecological and environmental requirements of yellow toadflax, as well as assist in the development of inventory and monitoring protocols for yellow toadflax.

MANAGING INVASIVE SPECIES IN AN ECOLOGICAL CONTEXT

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ABSTRACT

Integrated Pest Management (IPM) has been a foundation of pest management for more than thirty years. IPM is defined as "a sustainable approach combining biological, cultural, physical, and chemical tools to regulate pest populations while minimizing economic, environmental, and human health risks." Application of this concept to weeds resulted in Integrated Weed Management (IWM) and a refinement of the IPM definition to "the application of many kinds of technologies in a mutually supportive manner to manage weeds". Under this approach, managing weeds is the selection of one or more treatment options where effectiveness is optimized by the integration of the various techniques, timing of applications and through varying the intensity of treatment. Even though application of this prescriptive approach has lead to many successful weed treatments, it often fails to sustain native plant communities. A long-term sustainable weed management program can only be achieved through understanding and incorporating ecological processes.

Natural resource management is based on an understanding of ecological principles. Managing exotic plant invasions relies upon incorporating many of these same ecological principles. Prior to selecting any treatment method, the ecological setting, both biotic and abiotic must be described. Understanding the potential and existing plant communities is essential in determining if a given control method will be effective and if the native plant community can reassert itself. Chemical control on sites where the native seed banks have been depleted will only result in temporary weed removal. Environmental keys give us insight into the susceptibility of a site to invasion and the prevention techniques that will be useful. A new definition of IWM may be, "an integration of ecological considerations with biological, cultural, physical and chemical tools in a way that minimizes economic, health, and environmental risks."

HISTORICAL SUMMARY: OLDEST WATERSHED STUDY IN AMERICA, WASATCH PLATEAU, UTAH, GREAT BASIN EXPERIMENT STATION

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ABSTRACT

Historical perspective in the establishment of Watershed A and B study. Starting in 1912 Watersheds A and B, two adjoining depleted subalpine watersheds at the head of Ephraim Canyon, UT, have been under continuous study. Since 1920 Watershed A has been protected from grazing. This protection resulted in a rapid increase in plant cover, especially forbs, on all but the more depleted areas. Increase in plant cover has resulted in substantial reduction in runoff and sedimentation. On Watershed B, heavy grazing reduced ground cover and changed a fairly stable watershed to a serious flood-source area. Immediate control of summer runoff and sedimentation was achieved with disking, contour trenching, and seeding of grasses and leguminous forbs in 1952. Watershed stabilization can be much more rapidly accomplished using restoration techniques than long periods of nonuse.

INTRODUCTION

Settlement of the Sanpete Valley began in 1848. Extensive livestock grazing did not occur on the Wasatch Plateau prior to the ending of the Blackhawk Indian War in 1872. In the early 1880's sheep numbers began to increase, and reached a peak after the turn of the century. Extensive and excellent summer range was available on the mountains and was free. Sheep were profitable for anyone who could obtain enough summer range for them. This resulted in extensive uncontrolled use. Old timers have stated that by 1900 one could count the number of sheep herds on the mountaintop by the number of dust clouds on the horizon. Reynolds (1911) graphically reported the outcome of this grazing:

"The result was that, between 1888 and 1905, the Wasatch Range, from Thistle to Salina, was a vast dust bed, grazed, trampled and burned to the utmost. The timber cover was reduced, the brush thinned, the weeds and grass cropped to the roots, and such sod as existed was broken and worn. The basins at the head of the canyons suffered most, relatively, because they contained the best feed for sheep and were less broken in topography and more easily accessible. Their scanty timber cover, however, made them particularly liable to removal of the soil by wind action wherever the surface cover was broken through and the dry powdered earth exposed."

These high mountain pastures, received not only the most abuse, but have been proportionately longer in recovering from its effects. The mountain ranges suffered from two types of serious damage; valuable forage species had been killed out, and considerable topsoil had been washed or blown away; this left an erosion pavement of comparatively unproductive soil and rock, and a significant decrease in the retention and detention of surface moisture. A decade of extensive sheep use resulted in the mountain ranges being damaged so seriously that summer-time floods began. Serious floods occurred in Ephraim Canyon and other canyons in the area in nine seasons between 1888 and 1910.

By the end of 1901, the situation in Sanpete County was becoming desperate. On May 29, 1903, President Roosevelt created the Manti Forest Reserve. Five months later, the Commissioner of the Land Office ordered all sheep removed from the western slope of the mountains before the start of the following grazing season. Temporary exclusion of stock from mountain rangelands was all very well as an emergency measure, but the Utah livestock industry could not tolerate the locking up of high elevation summer range as a permanent arrangement. Summer grazing was subsequently allowed with some control. In 1911 the Washington Office of the Forest Service sent Dr. A.W. Sampson to the Great Basin to determine what was causing extensive flooding that was occurring throughout the west, and how to stop it. A location in Ephraim canyon was selected for the establishment of an experiment station to look into the flooding, and associated range problems. Dr. Sampson could see that flooding most likely originated at higher elevations from high intensity late summer storms. In order to determine the relationship of grazing and vegetal cover to erosion, he selected two complete erosion-bearing watersheds to study. He called these, Watershed A and Watershed B. The two watersheds were fenced in 1912. Area A covers 11 acres and Area B nine acres. The two watersheds are about 900 feet apart at an elevation of 10,000 feet on a generally west-facing slope at the crest of the Wasatch Plateau. They are typical small watersheds in the Subalpine zone and were strategically established in as area where thousands of sheep had been grazed and trailed summer after summer.

Watershed A bas been closed to grazing since 1920, and no restoration techniques have been used to enhance cover. Watershed B was exposed to grazing and cove loss before 1952 when it was disked, trenched, and seeded and livestock being permanently excluded.

LOCATION

The two watersheds are located about 900 ft apart in a subalpine vegetative zone at 10,000-ft elevation on the crest of the Wasatch Plateau. Both watersheds are complete, separate, and isolated. Neither has a permanent stream. Watershed A with a west facing exposure, average slope is 18.5 percent and occupies 11acres. Watershed B average slope is 16.3 percent and covers 9 acres (Meeuwig 1960).

Ellison (1954) stated that heavy grazing and accelerated erosion have changed the characteristics of surface soil in much of the Wasatch Plateau subalpine zone. Forsling (1931) estimated that a few inches to as much as 3 ft of soil had been removed from Watersheds A and B prior to 1912. Soils are residual clay and clay looms derived from limestone and bituminous shales.

Precipitation varies considerably, averaging 36 inches annually, with the majority coming as snow (Price and Evans 1937). In 1983, 53 inches of precipitation occurred on the area. An average of 6 inches of rain falls during the summer growing season. During July and August high-intensity localized storms occur. The highest-intensity storm occurred in 1953 at a rate of 2.2 inches per hour over a 20 minute period.

Prior to introduction of livestock in the 1880's Ellison (1954) characterized the subalpine community on the Wasatch Plateau. Seventy to 80 percent of the vegetation consisted of the following broadleaf species: small-leaf angelica (*Angelica pinnata*), Colorado columbine (*Aquilegia caerulea*), rhexia-leaved paintbrush (*Castilleja leonardii*), sulphur painted-cup (*C. sulphurea*), Oregon fleabane (*Erigeron speciosus*), wallflower (*Erysimum elatum)*, oneflower helianthella (*Helianthella uniflora*), Utah peavine (*Lathyrus utahensis*), Porter ligusticum (*Ligusticum porteri*), tall bluebell (*Mertensia leonardii)*, sweetanise (*Osmorhiza occidentalis)*, leafy polemonium (*Polemonium foliosissimum)*, low goldenrod (*Solidago ciliosa*), edible valerian (*Valeriana edulis*), and western valerian (*V. occidentalis*). The remaining vegetation consisted of slender wheatgrass (*Agropyron trachycaulum*), nodding brome (*Bromus anomalus*), mountain brome (*B. carinatus*), oniongrass (*Melica bulbosa*), and mutton bluegrass (*Poa fendleriana*), with only a few shrubs, trees, and annuals. Ellison (1954) also listed the following species that characterized depleted areas on the plateau: Louisiana sage (*Artemisia ludoviciana*), Richardson geranium (*Geranium richardsonii*), tarweed (*Madia glomerata*), Rydberg penstemon (*Penstemon rydbergii*), Letterman needlegrass (*Stipa lettermanii*), and common dandelion (*Taraxacum officinale*).

METHODS

Vegetative cover of Watersheds A and B has been manipulated with sheep since 1912 (Forsling 1931; Keck 1972; Meeuwig 1960, 1970 Sampson and Weyl 1918; Stevens and others 1992; Stewart and Forsling 1931. In 1912, Watershed A live cover had been depleted to 16 percent. This was mostly broadleaf herbs. Watershed B, live cover was reduced to about 40 percent, consisting of a mixture of broadleaf herbs and perennial grasses. Both watersheds were maintained at these levels of live vegetative cover with controlled grazing, using sheep, through eight seasons to 1919. In 1920, livestock were excluded permanently from Watershed A and the range has been allowed to recover naturally since then. From 1920 to 1930 Watershed B was maintained at about 40 percent cover by controlled grazing. By 1924, Watershed A had recovered to an average of about 40 percent cover, similar to that of Watershed B. Between 1924 and 1930 Watershed A cover remained at 40 percent and Watershed B was held to 40 percent. Starting in 1931 Watershed B was exposed to heavy grazing in an effort to reduce cover to the 1912 Watershed A level of 16 percent. This effect was accomplished by 1950. Late in the fall of 1952 Watershed B was disked, some contour furrows were installed on the steeper slopes and the area was seeded. The seed mixture included smooth brome (*Bromus inermis*), meadow foxtail (*Alopecurus pratensis*), orchardgrass (*Dactylis glomerata),* mountain brome (*B. carinatus*), meadow brome (*B. erectus*), 'Nomad' alfalfa *(Medicago sativa*), mountain lupine (*Lupinus alpestris*), and cicer milkvetch (*Astragalus cicer*). Livestock have not grazed Watrshed B since it was seeded.

Sediment catchment basins were constructed in 1914 at the lower end of each watershed to measure surface runoff and sedimentation. These catchment basin were however to small to accommodate the large amount of sedimentation and runoff. Dr. A. W. Sampson made the following statement in 1919. "Seeing, of course is believing, but if anyone had told me that as much as a car load, or approximately 50,000 pounds of air dry dirt and rock would be deposited from a ten acre area from a single storm I would probably be inclined to ask permission to examine the figures for myself. Nevertheless air dried sediment of from 20,000 to 50,000 pounds has been deposited several times during the six tears from a single rainstorm" (Keck 1972). Larger basins were subsequently built to accommodate the larger volumes of soil that were being delivered.

Vegetative surveys have been made periodically since 1912. Surveys prior to 1951 only estimated or measured live cover. The importance of litter in soil stabilization was not understood, especially on these Watersheds, as very little litter was produced or accumulated in the early years. In the early years, the reconnaissance method was employed (Sampson and Weyl 1918). Forsling (1931) used the point method (Levy and Madden 1933) on permanently established transects. Sampling was done along six 98.5-ft transects per watershed in 1983 (Stevens and others 1992).

RESULTS

1912 to 1920

Using sheep, Watershed A vegetative cover was maintained at about 16 percent and Watershed B cover at about 40 percent. During this period, Watershed A produced six times as much runoff, and five times as much sediment as Watershed B (Table 1). This period of study was summarized by Sampson and Weyl (1918).

Table 1. Summary of Watershed "A" and Watershed "B", 1912-2001

Year	Watershed A (11 acres, 18.5% Slope)			Watershed B (9 acres, 16.3% Slope)		
	Live Cover (%)	Sediment*	Runoff**	Live Cover (%)	Sediment*	Runoff**
1912-1920	16-sheep	134	913	40 - sheep	25	153
1921-1923	16 to 30	105	922	40 – sheep	37	260
1924-1930	30 to 40	24	362	40 – sheep	10	171
1931-1945	40	20	445	40 to 14 – sheep**	29	556
1946-1950	40	3	64	14 – sheep	36	288
1951	40	3	63	14 – sheep	102	396
1952	40	16	291	Disked, trenched, seeded	100	1,376
1953***	40	60	1,662	30	6	553
1954-1957	37	T	2	30	0	0
1958-1983	37 to 53	T	1	40	0	0
1984-2001	-	0	0	—	0	0

* ft3/ac/yr
** No use 1942-1945
***Highest recorded storm, 2.2 inches/hr. in 20 min.

1921 to 1923

Sheep were used to maintain Watershed B at 40 percent cover. Sheep were excluded from Watershed A, and its herbaceous cover recovered from 16 percent to about 30 percent by 1923 and up to 40 percent by 1924. Vegetative recovery on most of Watershed A was fairly rapid, resulting in considerably less runoff and sediment. The more severely depleted steep area, however, showed little improvement. Even with vegetative improvement, Watershed A produced almost three times as much surface runoff and sediment as Watershed B Table 1).

1924 to 1930

Watershed A was ungrazed and cover persisted at 40 percent. Watershed B was grazed to maintain 40 percent cover. Vegetative composition on the two watersheds was somewhat different; B had considerably more perennial forbs and bunchgrasses than A. Watershed A also had steeper areas that were fairly bare and subject to erosion. Forsling (1931) and Stewart and Forsling (1931) summarized work up to 1931.

1931 to 1952

Because the study failed to employ replication, which was not important in 1912, the study received considerable criticism. An answer to their criticism resulted in reversing treatments on the watersheds. It was felt that the influence of herbaceous cover on surface runoff and erosion could be determined more conclusively if plant cover on Watershed B was reduced to Watershed A's percent cover of 1912 (Meeuwig 1960). During this period Watershed A was ungrazed, and cover remained at 40 percent. Watershed B was heavily grazed by sheep (no grazing during World War II, 1942-45) to reduce plant cover to about 16 percent. This reduction in plant cover resulted in Watershed B producing an average 25 percent more runoff and 40 percent more sediment than Watershed A in 1951. Runoff and sedimentation on A decreased during these years (Table 1). Reduction in plant cover and resulting increase in erosion and runoff on Watershed B substantiates the importance herbaceous cover has on watershed stabilization.

1953 to 1957

No grazing occurred on Watershed A. Vegetative cover remained at about 40 percent; most plants were broadleaf herbs. Very little sedimentation has come off A during this period (Table 1). To determine how effective revegetation efforts are in reducing erosion and runoff Watershed B was disked, furrowed on the steeper slopes, and seeded during the fall of 1952. The 1952 treatment on Watershed B produced three major results: (1) no summer runoff or sedimentation after 1953, (2) vegetative community changed from basically a broadleaf herb to a strong grass stand, and (3) gully systems that were prominent were broken up by disking, trenching, and seedling establishment. Prior to the 1952 restoration treatment on Watershed B, broadleaf herbs accounted for two-thirds of the total vegetative cover. Six years following treatment only 6 percent of the vegetative cover consisted of broadleaf herbs, with Louisiana sage being the major forb species. Seeded species made up 90 percent of the vegetation. Meeuwig (1960) summarized data from 1912 to 1958.

1958 to 1983

No grazing occurred on either watershed. Vegetative cover on Watershed A remained nearly the same until 1983 when it increased due to considerable high precipitation (53 inches). There was a difference in percent vegetative cover between Watersheds A and B in 1958 but no difference between watersheds in 1961 and 1983. The five most abundant species, in order of abundance as determined by percent cover, changed more on Watershed A than on Watershed B. Watershed A had more species than did Watershed b in all years. Watershed A had considerably more forbs and fewer grass species than did Watershed B (Table 2). Little runoff or sediment was measured off Watershed A from 1958 to 2001, or Watershed B between 1958 and 1983. Stevens and others (1992) summarized work for this period.

Table 2. Number of Species encountered on Watershed A and Watershed B in 1958, 1961, and 1983

	Watershed A			**Watershed B**		
	Year			**Year**		
	1958	1961	1983	1958	1961	1983
Total number of species	43	46	43	32	32	34
Grasses	7(16)[1]	8(17)	7(16)	12(38)	10(31)	9(26)
Forbs	34(79)	36(80)	36(84)	19(59)	21(66)	25(74)
Shrubs	2(5)	2(4)	0(0)	1(3)	1(3)	0(0)

[1]number in parentheses is percent of total cover

1984 to 2001

No grazing occurred on either watershed. No runoff or sediment came off of either watershed during this period. Total ground cover, live and litter on Watershed B approached 80%, except on exposed rocky area. Being a forb community, Watershed A shows about 43% bare ground, and very little litter accumulation. Vegetative cover was closely associated with amount of precipitation on Watersheds A and B. Average water year precipitation on the watersheds over 56 years (1927 through 1983) is 35.95 inches. Precipitation in 1958 (37.79 inches) and 1961 (37.70 inches) was close to average and considerably lower than 1983 (51.72 inches) precipitation. Vegetative cover was significantly higher on A and B in 1983 than in either 1958 or 1961. Photos from 1915 to 1992 are available in Niebergall (1993) and Stevens and others (1992).

CONCLUSIONS

Uncontrolled grazing in the 1880's and 90's and early part of the new century resulted in extensive loss of vegetation, species, and soil resulting in erosion, gutting of stream channels, and flooding of communities and farms in the valley. Watershed A and B study was established in 1912 to evaluate the relationship of grazing and vegetal cover to erosion. It was determined that runoff and sedimentation on Watersheds A and B are closely associated with vegetative and litter cover. Early work on Watersheds A and B demonstrated that as cover increases runoff and sedimentation decreases. When cover decrease the reverse occurs. The forb community of Watershed A has not been grazed since 1920. It took at least 34 years for Watershed A to be stabilized to the point where vegetation and litter were sufficient to intercept and detain surface moisture with no runoff or sedimentation occurring. All runoff and sedimentation was stopped on Watershed B in 1 year with an artificial restoration treatment that included seeding with stabilizing perennial grasses and forbs. The highest intensity storm ever recorded on the Watersheds occurred the summer (1953) following disking, trenching, and seeding of Watershed B. Even with 34 years of protection from grazing, Watershed A produced 60 ft3/acre of sediment and 1,662 ft3/acre of runoff water from the storm. The freshly disturbed and seeded Watershed B produced only 6 ft3/acre of sediment and 553 ft3/acre of runoff water from the same storm. In 1953 there was considerable difference in vegetative community composition; Watershed A consisted mainly of forbs that do not produce much in-place litter and Watershed B supported primarily grasses that produce much more in-place litter. With 53 inches of precipitation in 1983 no runoff or sedimentation came off Watershed B and only trace of sediment and 1 ft3/acers of runoff came off Watershed A. This long-term study has demonstrated that management practices can stabilize depleted subalpine range through long periods of nonuse or rapidly with restoration techniques.

ACKNOWLEDGEMENTS

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VEGETATION RESTORATION OF ALPINE SOCIAL TRAILS ON COLORADO'S 14,000-FOOT PEAKS

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ABSTRACT

Heavy and rapidly increasing recreation on Colorado's high peaks has created needs to restore closed alpine trails. Since 1998, we have tested several restoration techniques. Turf transplants from newly cut trails survived extremely well over 3 yr. Most species did not decrease in absolute or relative cover although overall vascular plant cover decreased somewhat. Species richness did not decline. Grasses increased in absolute and relative cover in transplants, while sedges and forbs decreased. Plugs (10-cm diameter and 15-cm deep) from undisturbed vegetation showed excellent survival of all species in a wet area after 1 yr. Seeding of two common graminoids under erosion matting produced 400 monocot seedlings/m^2 after both 1 and 2 yr, 5-6 times more than seeded areas without matting and 20-28 times more than untreated plots. Density of unseeded dicots also increased to 190 seedlings/m^2, 5 times greater than without matting. After 3 yr of a tiller transplant experiment, directly transplanted pieces *of Geum rossii* survived moderately well and were occasionally vigorous. *Carex scopulorum* rooted for 4 to 6 weeks had moderate survival, tillered vigorously, and frequently flowered. Rooted *G. rossii* and directly transplanted *Carex* survived poorly. Longer-term monitoring will reveal if promising initial restoration results will continue in the longer term.

INTRODUCTION

Recreational use of Colorado's "Fourteeners" (peaks >14,000 ft = 4270 m) is increasing dramatically. This heavy use has greatly impacted the alpine environment. Until very recently, the only trails to summits of almost all these peaks were unplanned social trails. These trails are often numerous, redundant, and ascend steep slopes. Coupled with the loss of vegetation cover due to trampling, this situation causes water channeling and erosion, which is severe in some places.

Recently, the Colorado Fourteeners Initiative and the Rocky Mountain Field Institute began building sustainable trails to the summit of these peaks and attempting to stabilize and restore eroded social trails (Hesse 2000). Restoring alpine communities is often difficult due to the limited number of species available as colonizers; short, cold growing seasons; episodic seedling establishment; and unpredictable diaspore production (Chambers 1997). In Colorado, most high peaks are 3 to 9 km (2 to 5 mi) from roads and in federal established wilderness areas, adding further logistical, financial, and physical limitations. In addition, volunteers will do much of future restoration work so unskilled workers must be able to easily use any proposed restoration techniques.

Previous research has shown natural seedling recruitment is slow, but occasionally a viable method of revegetation (Chambers et al. 1990). It can be encouraged where mature vegetation or erosion matting acts as a 'safe-site' trapping diaspores (Chambers et al. 1991), providing nutrients and insulation for seed germination and establishment, and protecting against environmental hazards (Urbanska and Schutz 1986). Creating these safe-sites increases natural colonization of local species (Urbanska and Schutz 1986; Chambers et al. 1990; Urbanska 1997b) as well as the success of planted seeds (Urbanska 1997c).

However, reliance on unassisted, natural recolonization is unlikely to work well on most social trails on these high peaks. These trails generally ascend steep slopes and the depressed trails channel water and are actively eroding. Many of these trails go through drier communities of the eastern half of Colorado's mountains where natural recolonization is very slow even on stable, small sites (Ebersole, in review). Recreationists often continue to use closed trails that are not revegetated, while most avoid trails that vegetated or obviously undergoing rehabilitation (personal observations).

As with restoration of any ecosystem, strategies for alpine restoration vary depending on the situation. Previously tested methods include seeding and transplanting of both single species and pieces of turf (Chambers 1997).

When severe disturbance eliminates the soil seed bank, as on machine graded ski runs in Switzerland, natural recruitment is not reliable (Urbanska 1997a), and seed or transplants must be used to assist revegetation. Seeding of native species has been found successful at high elevations in some situations (Bayfield 1980; Guillaume et al. 1986; Chambers 1997). Collecting seed is less damaging to the donor population than transplanting. However, seeds and seedlings are more susceptible to environmental hazards (Urbanska 1997a), so seeding can take longer to revegetate areas than transplanting.

Indirect single species transplants, where whole plants are removed, split into single rootstocks and propagated in a greenhouse before transplanting, have been used successfully on machine-graded ski runs in Switzerland (Urbanska et al. 1987; Urbanska 1994). Direct single species transplants were not successful in these trials, but May et al. (1982) found transplants of entire plants survived on Niwot Ridge, Colorado. Transplanting large turf pieces has worked well in the Rocky Mountains when evaluated after 1 yr (Marr et al. 1974; Buckner and Marr 1988), especially when using turf from construction to avoid damaging undisturbed vegetation. Benefits to this method include reduced shock to individuals, greater mix of transplanted species, immediate diaspore production, and potential safe sites for seedlings and vegetative propagule expansion (Urbanska 1997a; 1997b).

In this paper, we report on the effectiveness of several techniques for restoring closed social trails on three 14,000' peaks in Colorado. We evaluated the techniques on their demonstrated capability and potential to create plant cover that would resist erosion on steep slopes in the upper alpine and to create a species-rich community similar to the surrounding undisturbed vegetation.

STUDY SITES

Mount Belford

Mount Belford is located in the Sawatch Range in the Collegiate Peaks Wilderness Area of the San Isabel National Forest, Chaffee County, Colorado at 38°58' N, 106°21' W (Fig. 1). The Belford trail climbs south from Clear Creek, up Missouri Gulch, and then ascends a steep (15 – 35°), northwest-facing, broad ridge crest from 11,900 ft (3620 m) to the summit at 14,197 ft (4328 m) (Fig. 1). The study site (Fig. 1) was located between 12,000 and 12,200 ft (3660 to 3720 m) in an alpine meadow dominated by grasses, sedges and *Geum rossii* [Botanical nomenclature follows the Natural Resource Conservation Service PLANTS database (2000)]. *Dryas octapetala* dominated scattered areas on the northeast side of the ridge with a large cover *of Salix arctica* and *G. rossii*. We chose plots to avoid these *Dryas*-dominated areas because of the difference in species composition.

The bedrock at the site is Denny Creek granodiorite gneiss, a coarse-grained gneissic biotite granodiorite with some quartz material (Brock and Barker 1972). The coarse sandy soil averaged 28% gravel, 60% sand, 13% silt and 2% clay in the revegetated trail (n=9). Soil pH was slightly acidic to neutral, extractable nitrogen and nitrate levels were low, and organic carbon concentrations were moderate (Table 1).

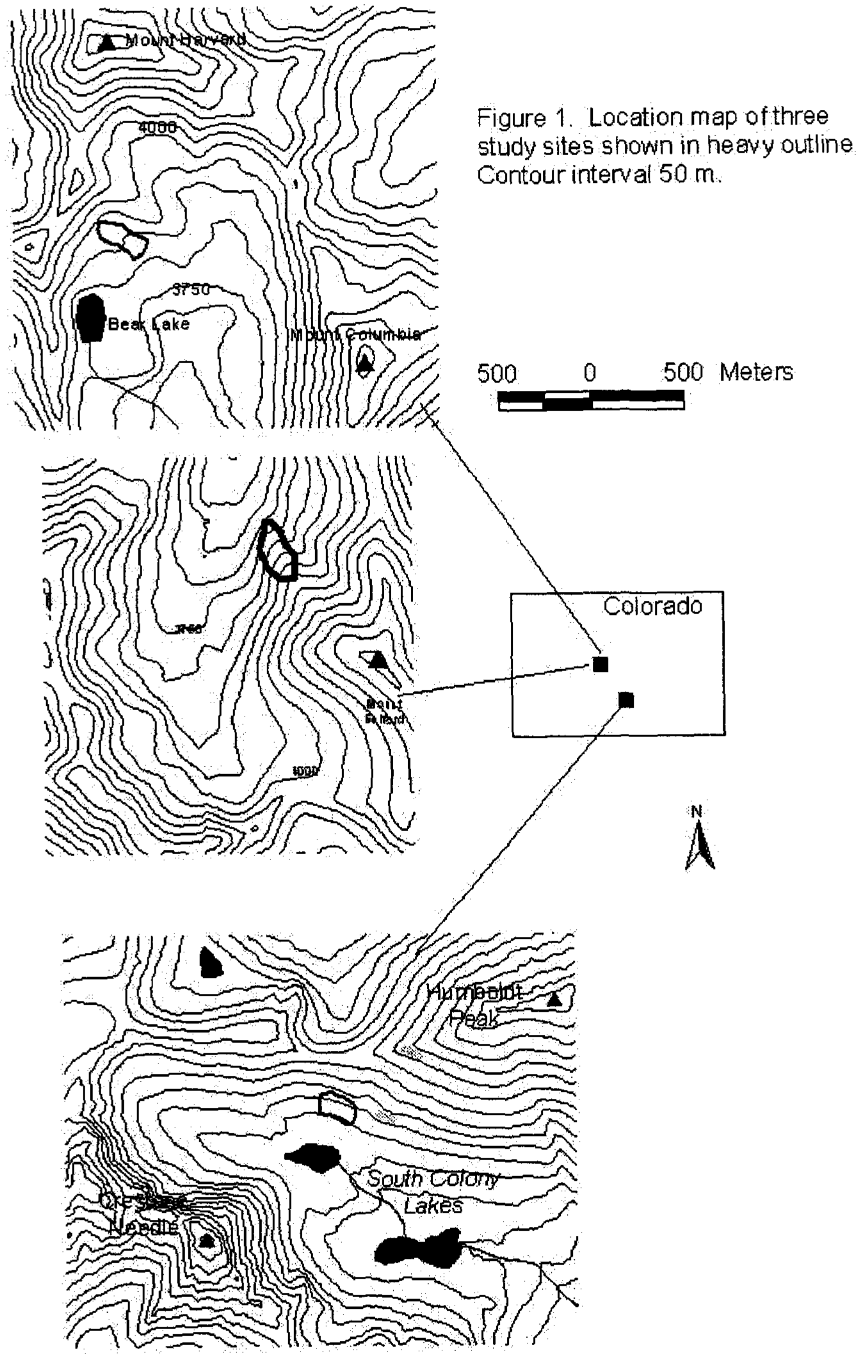

Figure 1. Location map of three study sites shown in heavy outline. Contour interval 50 m.

Table 1. Soil properties [0 ± SE, (n)] in top 10 cm of soil on Mount Belford and Humboldt Peak, Colorado. Data are from Conlin and Ebersole (2001) and Bay and Ebersole (in review).

	Soil pH	Extractable Nitrogen (NH_4^+) mg N/g dry soil	Nitrates/Nitrites ($N\text{-}NO_2^- + N\text{-}NO_3^-$) mg N/g dry soil	Organic Carbon g C/g dry soil
Mount Belford	5.9 - 7.5 (9)	2.65 ± 0.41 (9)	1.36 ± 0.20 (9)	4.12 ± 0.83 (5)
Humboldt Peak	5.95 (9)	0.095 (20)	0.107 (20)	1.95 ± 0.59 (3)

Mount Harvard

Mount Harvard (38°55' N, 106°19' W) is located in the Collegiate Range and Chaffee County, Colorado. The peak lies in the Collegiate Peaks Wilderness Area of San Isabel National Forest. Kroenke Granodiorite underlies the study site, and is composed of biotite granodiorite with local areas of quartz monzonite and quartz diorite (Brock and Barker 1972).

The new summit trail climbs north up Horn Fork Basin, past a trail spur to Bear Lake, across some dry slopes, up a talus slope, across a high alpine meadow and finally up a steep southeast-facing slope and along the south ridge to the summit at 14,420 ft (4396 m). In 1998 the Colorado Fourteeners Initiative (CFI) closed and rerouted the original social trail from the junction with the Bear Lake trail to the top of the talus slope in order to redirect hikers away from a sensitive snowbed area and a very loose section of talus.

The site of the seedling study was located at 12,600 ft (3840 m) just below the talus in a late-melting snowbed area dominated by *Deschampsia caespitosa*, *Carex scopulorum*, *Calamagrostis purpurascens*, and *Juncus drummondii*. Most of the trail lay in areas of 0° to 5°. In steeper sections (10° to 15°) there were fewer graminoids, more lichens and more *Sibbaldia procumbens,* and we chose plots to avoid these drier areas. The mineral soil surface of the closed trail was 30 to 35 cm wide and generally minimally depressed below the surrounding surface, except on steeper areas where erosion had lowered the surface up to 15 cm.

For the study of transplanted plugs, we used the old trail that went from the Bear Lake spur along a small stream to the base of the talus slope. This area is wet most of the growing season. Trail surfaces were mostly flush with adjacent areas. Some intact vegetation remained and the surface soils had large amounts of organic matter.

Humboldt Peak

Humboldt Peak is located in the Sangre de Cristo Mountains in the Sangre de Cristo Wilderness Area of the San Isabel National Forest, Custer County, Colorado at 37°58' N, 105°33' W (Fig. 1). The trail to Humboldt's summit climbs north from Upper South Colony Lake, up a south-facing slope to a saddle at 12,850 ft (3920 m) and then continues east on a ridge to the summit at 14,064 ft (4286 m). The study site for the turf transplant experiment lies between 12,100 to 12,400 ft (3700 and 3770 m) on a steep (20° - 30°) S-facing slope (Fig. 1). The seedling and single species transplant trials took place higher on the slope, ca. 12,800 ft (3900 m).

The vegetation was mesic alpine meadow dominated by *Geum rossii* and *Carex elynoides*. Other common species included *Polygonum bistortoides* and *Potentilla subjuga*. Soils are derived primarily from well-decomposed, undifferentiated units of the Sangre de Cristo Formation, including red arkosic sandstone, conglomeratic sandstone, siltstone, shale, and minor limestones (Lindsey et al. 1986). In the bare soil around the turf transplants, soil pH was slightly acidic, extractable nitrogen, nitrate, and organic carbon concentrations were much lower than on Belford (Table 1).

Climate

The nearest climate stations to the Belford and Harvard sites are the Colorado Climate Center Leadville station at 39°14' N, 106°18' W and 10,000 ft (3060 m), and Twin Lakes station at 39°05' N, 106°19' W and 9300 ft (2835 m). These stations are approximately 20 and 12 mi (32 and 19 km) from Mt. Belford and 2200 and 2900 ft (660 m and 885 m) lower in elevation respectively. In the three years (1997 - 1999) after the Mount Belford restoration, growing season (June - September) precipitation was equal to or greater than the 1948 -1999 average at both stations. The only exception was the Twin Lakes station in water year 1997 (October 1996 - September 1997, Colorado Climate Center 2001). Average growing season (June - September) temperatures at the Leadville station 1997 – 1999 were slightly higher than the historical average (Colorado Climate Center 2001).

At the Humboldt Peak trailhead, 1.4 mi (2.2 km) southeast of the study site, the National Resources Conservation Service South Colony SNOTEL station measures precipitation and temperature data in the forested valley bottom at 37°58' N, 105°32' W and 10,800 ft (3290 m). Averages for 1961 to 1990, show an annual precipitation of 111 cm, a snowpack beginning 15 October, a maximum snow water equivalent of 53 cm on 15 April, and meltout in early June (Natural Resources Conservation Service 1996). Total precipitation in South Colony Lakes Basin for water years 1997 - 2001 was very close to average except water year 2000, which was 25% below average (Western Regional Climate Center 2001). However, growing season precipitation was about the same in all four water years. Growing season temperatures over the years 1992-1998 averaged 8.4°C, with average minimums of 1.9°C and maximums of 17.3°C. The 1997 to 1999 growing seasons were slightly cooler than the historical average, but 2000 was much warmer (Western Regional Climate Center 2001).

Trail use

Many hikers climb Belford and Humboldt during the summer months since they are relatively easily accessible. Estimates of trail use are made using United States Forest Service registers located at trailheads plus a compliance factor, which takes into account people who do not sign the register. An estimated 3500 to 3600 people climbed Humboldt Peak in 1996 and 4000 in 1999 (M. Smith, U.S. Forest Service, pers. comm., 1999). Between 4000 and 5000 people hiked part or all of the Mount Belford Trail in 1999 (Desrosiers, Colorado Fourteeners Initiative, pers. comm., 1999).

Table 2. Increasing use of trailheads that access 14,000-peaks in the Leadville Ranger District (unpublished reports, U.S. Forest Service files, Leadville District Office). We calculated percent increase per year assuming exponential growth between the two years for which data are available.

Trailhead	Peak	Time Period	% increase / yr	Doubling Time, yr
North Elbert	Mt. Elbert	1990-1996	10	7
North Halfmoon	Mt. Elbert	1990-1996	10	7
		1995-2001	14	5
Missouri Gulch	Mt. Belford and 2 others	1991-1996	12	6
		1995-2001	11	6
South Fork Clear Creek	Mt. Huron	1991-1996	25	3

Use of trailheads that provide access to 14,000-ft peaks in the Leadville Ranger District of the Pike-San Isabelle National Forest has soared in the last decade (Table 2, unpublished reports, U.S. Forest Service files, Leadville District Office). These trailheads show a 10% or greater increase in use per year. At this rate, numbers of people using these hiking routes will double every 7 years. Use on some peaks is increasing even faster (Table 2). Given what we know about the popularity of hiking the high peaks in

Colorado, it seems reasonable to assume that similar increases are occurring on other 14,000-ft peaks. The high number of users will have tremendous impact on already degraded routes.

TURF TRANSPLANTS

Turf transplants could serve as an important restoration technique in alpine areas where establishment of cover by other means is slow (e.g. Chambers 1997) and where remoteness and wilderness regulations limit access and materials used. Transplanting turf blocks compared to transplanting individuals likely reduces shock to plants. Compared to seeding, it avoids the germination and seedling stages when plants are more susceptible to environmental trauma (Urbanska 1997a). Transplanting turf also produce a more complete mix of native species, enhance production and entrapment of diaspores, and include potential for vegetative expansion into surrounding bare areas (Urbanska 1994, Urbanska 1997a, Urbanska 1997b).

Turf transplants in non-alpine areas are used primarily when development or mining will destroy areas with high ecological value (Anderson 1995, Baines 1989). Since transplanting turf is expensive and logistically complicated, it is not commonly used. Because social trails cover relatively modest areas compared to most non-alpine sites needing restoration and since remoteness and wilderness regulations limit restoration approaches, turf transplants may be an important alpine technique. In one previous alpine study, Buckner and Marr (1988) found turf transplants to be successful 18 yr after transplanting on a pipeline disturbance in the Front Range of Colorado. However, their study site was in a moister environment with more winter snow cover than our study sites (Conlin and Ebersole 2001). The results of our turf transplant trials will add to the understanding of this technique a restoration tool in alpine environments like those on many hiking routes on Colorado's 14,000-ft peaks.

Methods

Crews closed old social trails and revegetated them with turf cut from newly constructed trails on two peaks. Results 1 yr after transplanting on Humboldt Peak were reported in Conlin and Ebersole (2001), and 3-yr results from Humboldt Peak and Mount Belford are in Bay and Ebersole (in review). Results are summarized here.

On Mount Belford in 1996, the American Mountain Foundation (AMF, now the Rocky Mountain Field Institute) closed the old, eroded trail that went straight up the ridge, and cut a new trail with switchbacks. As they cut blocks of tundra turf from the new trail, they immediately placed them into the old trail and packed soil and rocks around them to stabilize them. The rocks also discouraged hikers from using the old trail. Turf blocks were placed close together so very little bare ground was visible between them.

On Humboldt Peak in 1997, AMF closed and restored the standard ascent trail (Hesse 2000). Channeled water and hikers have severely eroded steeper sections of this trail into a gully 0.5 to 1.5 m deep and 1 to 3 m wide). Rock walls (0.3 to 0.1 m high) were built across the gully to stabilize it and maximize chances of successful restoration. These terraces were backfilled with rock from talus slope topped with raw soil from under talus. As the new trail was cut, AMF removed pieces of tundra turf approximately 25-35 x 35-50 cm in length and width and 15 cm thick from the new trail and immediately transplanted them onto the terraced areas. Volunteers dug turf blocks into centers of terraces, and turf generally covered 50% to 90% of the bare area.

On each peak, we did point-intercept sampling in late July to early August 3 yr after transplanting. Control plots were randomly chosen in areas from which the turf had been cut. Sample size in both control and transplant plots was ten on Mount Belford and 17 on Humboldt Peak. At each plot 100 points were used to sample vegetation. Rock and bare ground were recorded when hit and, in transplant plots, intact vegetation from the surrounding area was recorded separately from transplant vegetation. We recorded multiple hits at each point by moving aside the first plant structure and extending the line to the next structure below to record every individual below the point. We also recorded any species present in the plot but not under a sample point.

We determined absolute cover (percentage of points not rock) for each species. From this, we calculated relative cover, proportion of each species relative to the sum of all species' absolute covers. We compared mean absolute and relative covers of each species for transplant and control plots using oneway ANOVA or Kruskal-Wallis test when parametric assumptions were not met. After correcting for differences in plot size between transplant and control plots (see Conlin and Ebersole 2001, Bay and Ebersole, in review), we compared differences in species richness.

Results

On Mt. Belford, transplanting caused a modest decrease in the sum of absolute covers of vascular plants (Fig. 2). The sum of covers decreased 17 percentage points (P=0.056), or 12% from the 142% cover in control plots. On Humboldt Peak, the decrease due to transplanting was substantial, 59 percentage points ($P < 0.001$). This is a 31% decrease from the 188% cover in control plots.

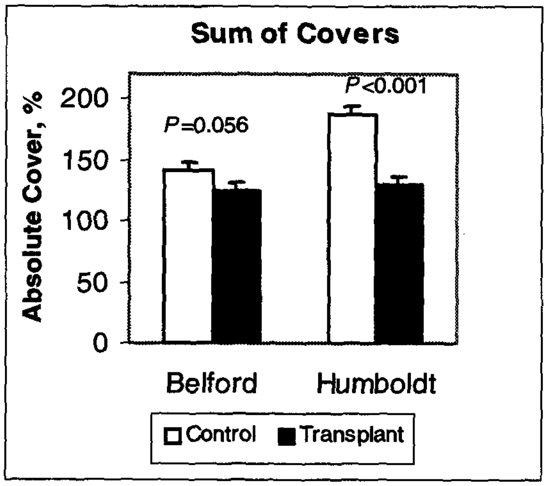

Figure 2. Sums of absolute covers of vascular plants (0 ± SE) in control and transplant plots on Mt. Belford (n=10) and Humboldt Peak (n=17).

Grasses increased in absolute cover at both sites while forb cover decreased on both peaks. On Mt. Belford total forb absolute cover decreased by 28 percentage points while absolute cover of grasses increased 25 points (Fig. 3). Relative cover results (Bay and Ebersole, in review) show that forbs dominate undisturbed areas (62%) while graminoids make up the remaining 38% with grasses comprising 16%. The increase in grasses due to transplanting makes forbs (48%) and graminoids (51%) about equal in relative cover. On Humboldt Peak absolute cover of grasses increased 14 percentage points (Fig. 3), while absolute cover of sedges decreased by the same amount; thus there was no differences in total graminoid cover between treatments (P = 0.940). Total forb absolute cover decreased by 59 percentage points. Relative cover results (Bay and Ebersole, in review) show that forbs dominate undisturbed areas (74%) on Humboldt Peak. Graminoids comprise the remaining 26% with grasses making up 12%. Increases in grasses in transplant plots On Humboldt Peak makes forbs (60%) and graminoids (40%) closer in relative cover with grass relative cover 29%.

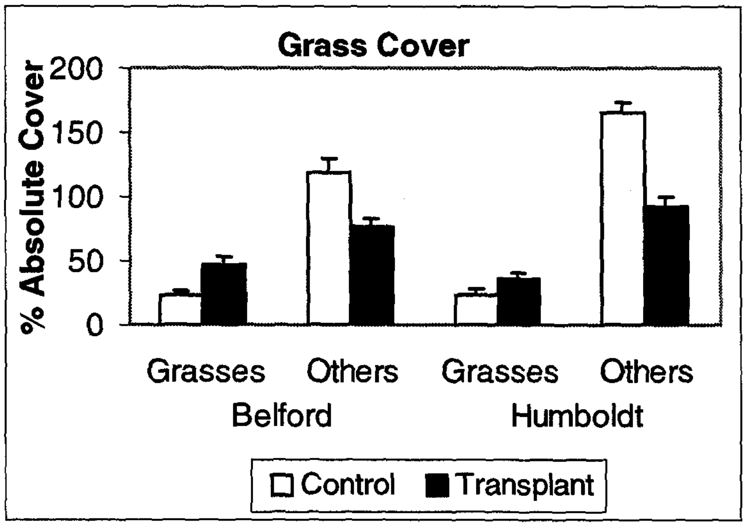

Figure 3. Sum of absolute covers of grasses and all other growth forms combined (0 ± SE) in control and transplant plots on Mt. Belford (n=10) and Humboldt Peak (n=17).

Only a few species caused the differences in cover after 3 yr. Most species tolerated transplanting well and did not increase in either absolute or relative cover (Table 3). On Mt. Belford, of the 49 species with recorded cover (Appendix 1 in Bay and Ebersole, in review), 38 showed no differences ($P < 0.05$) in either absolute or relative cover between transplant and control plots. Consistent with the greater overall grass cover, most grass species increased in cover (Table 3). Of 37 forb species, 31 showed no effects of transplanting in either absolute or relative cover. All three forbs that increased in transplant plots are small, short-lived species. Two of three forbs showing decreases in cover had small (< 3 % points) changes in absolute cover. However, *Geum rossii*, one of the community dominants decreased greatly, from 17% to 3%. Another notable decrease was the common sedge *Carex elynoides,* from 14% to 5% absolute cover.

On Humboldt Peak, of the 52 species with recorded cover (Appendix 2 in Bay and Ebersole, in review), 36 showed no differences 3 yr after transplanting ($P < 0.05$) in either absolute or relative cover. All but one of seven grass species, *Poa alpina*, and 27 of 39 forb species showed no effects of transplanting in absolute cover. Nine of 11 forbs showing decreases in cover had small (< 5% points) changes in absolute cover. However, *Thalictrum alpinum* decreased from 14% to 7% and *Geum rossii* again decreased greatly, from 52% to 17%. *Carex elynoides* also decreased dramatically from 20% to 9% absolute cover.

After correction for differences in plot size (Conlin and Ebersole, 2001; Bay and Ebersole, in review) species richness was greater in transplant plots than in control plots on Mount Belford. On Humboldt Peak species richness was slightly less in transplant plots than in control plots (Fig. 4).

Discussion

Vegetation communities on Mount Belford and Humboldt have several dominants in common, including *Geum rossii* and *Carex elynoides.* Both communities are species-rich and had similar disturbances. On both peaks, it appears that turf transplants can survive for at least three years and maintain high species richness.

Table 3. Numbers of species by growth form with covers affected and unaffected 3 yr after transplanting ($P \leq 0.05$) on Mount Belford and Humboldt Peak, Colorado. For covers by species, results of statistical tests, and powers of statistical tests, see Bay and Ebersole (in review). For transplant and control, entries are numbers of species with significantly greater cover in that treatment.

	Absolute Cover			Relative Cover			
	Transplant	Control	No Difference	Transplant	Control	No Difference	Total
Mount Belford	8	3	38	8	3	38	49
Forbs	3	3	31	3	3	31	37
Graminoids[1]	5	0	7	5	0	7	12
Cyperaceae	0	0	4	0	0	4	4
Poaceae	4	0	3	4	0	3	7
Humboldt Peak	2	14	36	7	9	36	52
Forbs	1	11	27	4	7	28	39
Graminoids[1]	1	3	9	3	2	8	13
Cyperaceae	0	3	2	0	2	3	5
Poaceae	1	0	6	3	0	4	7

[1]Both peaks had one Juncaceae species, so numbers of Cyperaceae plus Poaceae species will not equal number of graminoids species in all cases.

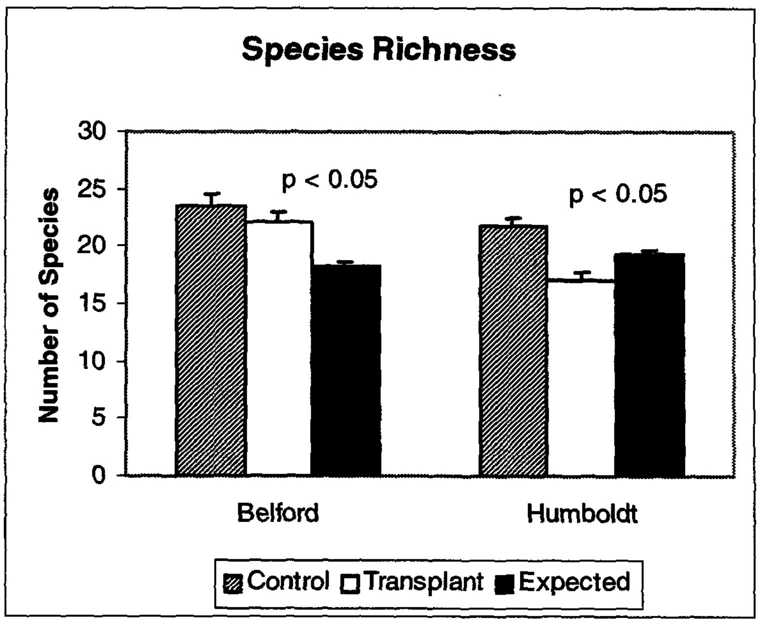

Figure 4. Differences in species richness (0 ± SE) in control and transplant plots on Mt. Belford (n=10) and Humboldt Peak (n=17). Statistical tests compare actual transplant plot values with richness expected for plots of that size if transplanting did not affect richness. See Conlin and Ebersole (2001) and Bay and Ebersole (in review) for details of plot size correction.

While turf transplants were very successful on both peaks after three years, it seems they were more successful on Belford than Humboldt. Total absolute cover decreased moderately due to transplanting on Mount Belford while it decreased substantially on Humboldt Peak. Similarly, fewer individual species decreased in cover due to transplanting on Mount Belford, and species richness was greater in transplant plots on Belford, but decreased after transplanting on Humboldt.

The more favorable soils and moisture regime on Belford likely account for the somewhat greater success of turf transplants there (Bay and Ebersole, in review). The Humboldt site is south-facing, which would presumably cause drier soils due to solar radiation than the northwest-facing Belford site. Additionally, the common summer afternoon cloud cover would decrease evapotranspiration at the Belford site during the time of day when radiation is most intense. Most plots on Humboldt were located at the base of the rock terrace above them. The walls might increase soil surface and plant temperatures and further increase evapotranspiration. While both study sites have similarly coarse soils, soils around turf blocks on Belford had twice as much organic carbon and about 20 times as much extractable nitrogen.

While most species tolerated transplanting well, several dominant and common species did not. *Geum rossii* and *Polemonium viscosum* showed significantly lower absolute cover in transplant plots at both sites and in the study by Marr et al. (1974). These two species account for most of the decline in forb cover. However, while *G. rossii* cover decreased in transplants from 1998 to 2000 on Humboldt, *P. viscosum* cover actually increased slightly. Conlin and Ebersole (2001) attributed the decrease in *G. rossii* cover to tap root damage when the turf was cut, because May et al. (1982) had success with *G. rossii* when the roots were excavated individually. *G. rossii* is one of the most common alpine plants in several alpine communities, and it occurs in several others. To retain it in substantial amounts as part of restored vegetation, deeper turf blocks, individual transplants, or other techniques may be necessary.

The significantly higher relative cover of Poaceae in transplant plots supports the conclusions of Marr et al. (1974) and Urbanska et al. (1987) that grasses do well when transplanted. While graminoids in general have been found to be highly successful in transplants (e.g., Guillaume et al. 1986), we found lower absolute cover of Cyperaceae in transplant plots on both Humboldt and Belford.

The success of alpine turf transplants we observed is consistent with results of Buckner and Marr (1988). They examined success of turf 18 years after transplanting during to pipeline burial in the Colorado Front Range. They found that although the site had not completely recovered to pre-disturbance conditions, no visually noticeable difference remained between the transplants and the surrounding vegetation. On Mount Belford and Humboldt Peak, more differences exist between transplant and control plots although overall transplants were very successful. Buckner and Marr's (1988) study site had high covers of *Deschampsia caespitosa* and *Sibbaldia procumbens* indicating a moister environment with more winter snow cover than our study sites. Their results and our studies indicate that turf transplants have potential to be successful in several different alpine environments.

NATURAL SEEDLINGS

Turf blocks cut from new trails rarely can cover all of a disturbed area. Vegetative expansion of turf blocks or colonization of seedlings could eventually cover bare areas between turf blocks. We studied natural seedling colonization around transplanted turf blocks on Humboldt Peak and Mount Belford at the same sites as studied in the turf transplant section of this paper.

Methods

We counted seedlings near transplanted turf blocks in four locations on Mount Belford: 1) 0 cm from trail edge, 2) 0 cm from turf block edge, 3) 5 cm from either trail edge or turf block edge, and 4) 10 cm from either trail or turf. No differences between groups 1 and 2 were found so these were combined. On Humboldt Peak, we established plots at 0, 5, and 10 cm from turf blocks. Plots 3 x 10 cm made from plastic-coated wire were anchored into position using galvanized deck nails with a long edge of the plot parallel to the turf/trail edge. Distances were measured from the closer long edge of the plot. We placed all plots at least 15 cm from other vegetation.

We identified seedlings in each plot to species or genus when possible or listed them as monocot or dicot if too small to identify. On Mount Belford, we recorded their position and identity onto a map 1.5 times larger than the actual plot so that survival can be determined. On Mount Belford, where turf blocks were transplanted in 1996, we examined plots in 1999, 2000, and 2001. On Humboldt Peak, restored in 1997, we counted seedlings in 2001. Here we present total seedling density after 4 yr, i.e. 2000 data for Mount Belford and 2001 data for Humboldt Peak.

Results

Mount Belford had many more seedlings near turf blocks than Humboldt Peak (Fig. 5). On Humboldt Peak, mean densities of the three distances ranged from 18 to 120 seedlings/m^2 with no significant differences among the three distances. Seedlings were abundant on Mount Belford and declined from densities of 3100 seedlings/m^2 in the plots adjacent to turf edges to 1000 seedlings/m^2 in plots 10 cm from turf edges (Fig. 5).

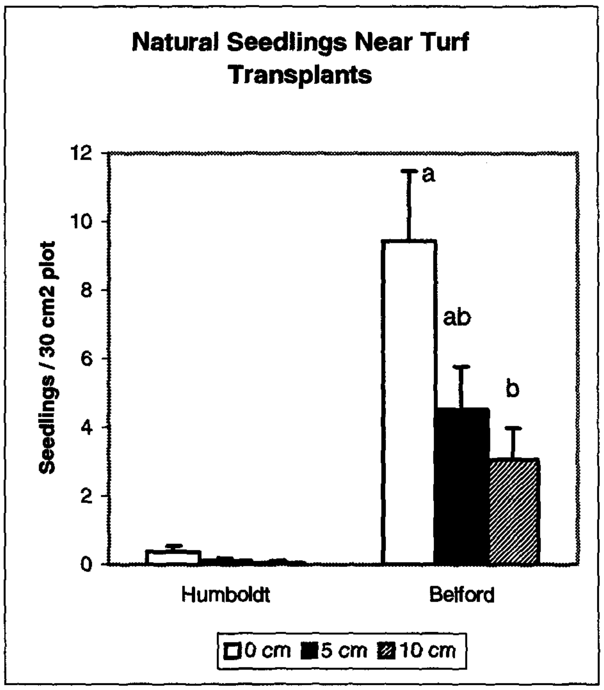

Figure 5. Density of natural seedlings (0 $\pm$ SE) adjacent to, 5 cm away and 10 cm away from turf transplants or trail edge. Lower case letters indicate homogeneous subsets within peaks (Tukey's test of all pairwise comparisons, family error rate = 0.05; done after oneway anova). Densities of the three distances were not different on Humboldt Peak (Kruskal-Wallis test). Humboldt Peak had 20 plots at each distance, and sample size on Mount Belford ranged from 16 to 30 in the three groups.

Most common seedlings on Mount Belford, from most abundant to less abundant, were *Cerastium beeringianum*, *Draba* sp., unknown monocots, unknown dicots, *Poa* sp., *Bistorta* sp., *Potentilla* sp., and *Artemisia* sp.

Discussion

As described in the turf transplant section, soils between turf transplants had more organic matter and extractable N on Mount Belford than on Humboldt Peak. The greater organic matter on Mount Belford likely indicates that the soil came from close to the surface. Surface soils at other Rocky Mountain alpine communities contain moderate numbers of seeds (Archibold 1984; Chambers 1993, Humphries 1993). This importance of the buried seed bank and the more favorable mesotopographic and microclimate of the Belford site likely explains the better success of seedlings near turf transplants there.

Our results underscore the importance of maximizing the benefits of surface soils. Workers should carefully preserve topsoil during construction of new trails and use in to improve facilitate restoration of closed social trails. If amount of topsoil is limited, it should be spread over the top several cm of restored areas with soils obtained from talus slopes and similar sites used below the topsoil.

If amount of turf cut from new trails cannot completely cover areas needing restoration, turf blocks can be placed 20 to perhaps 30 cm apart. At this distance, they can still increase seedling establishment of the bare soil between them.

Based on observations of many disturbed sites, we have not seen effective natural seedling establishment on sites that had any soil movement (i.e., had more than very gentle slopes). We believe natural seedling establishment will produce effective plant cover only on very small bare areas partially protected from needle ice, desiccation, and other environmental extremes.

PLUG TRANSPLANTS

When turf blocks are not available, transplanting small plugs of vegetation from adjacent intact vegetation might retain the benefits of transplanting mature vegetation without significantly damaging previously undisturbed vegetation. Using plugs avoids the susceptible seedling stage, and plants in the plugs might provide seeds and protection of seedlings in adjacent bare areas. We have not found previous reports of this technique in the literature. We present preliminary data from one trial 1 yr after transplanting plugs.

We chose a relatively wet area dominated by graminoids since research in the arctic shows small, wet areas recover relatively quickly due to vegetative expansion of sedges (Ebersole 1987; Forbes et al. 2001). Arctic and alpine areas show substantial differences (Billings 1979; Korner 1995), and one often should not extrapolate patterns and results from one region to the other region. However, similar species of rhizomatous *Carex* dominate wet areas of both regions, and wet areas of both regions have similar soils. Thus, we began trials of plugs in communities where we believed they would work best.

Methods

In late July 2000, we cut more-or-less cylindrical plugs ca. 10-cm in diameter and 15-cm deep from undisturbed vegetation near the closed social trail. We placed these in holes dug in the social trail so that the plug surface was flush with the surrounding soil. We used soil from the holes in the trail to fill donor holes. We assume impact on the previously undisturbed vegetation will be minimal given the rapid vegetative expansion observed in wet areas of the arctic.

Results

Species richness in the plugs ranged from 3 to 9 with a mean of 5.1. Of the 55 plugs, 71% lost no species after 1 yr, and only 7% lost two species (Table 4). The remaining plugs lost one species. Plants in plugs appeared vigorous after one year, i.e., fully turgid, dark green, and with new growth.

Table 4. Maintenance of species richness in plug transplants after 1 yr on Mount Harvard.

Number of Species Lost	Number of plugs
0	39
1	12
2	4

Discussion

Based on results of one trial 1 yr after transplanting, plugs seem to have the same advantages as turf transplants, but can be used when turf is not available. We will monitor these plugs in the future as well as evaluating plugs transplanted in 2001 into drier areas.

SINGLE SPECIES TRANSPLANTS

Urbanska and colleagues have successfully transplanted parts of plants onto machine-graded ski runs after rooting them in a greenhouse. The transplants have created species-rich areas with good cover in these high alpine sites in the Swiss Alps. Direct transplanting of individual plant parts has not worked well (Urbanska et al. 1988, Urbanska 1994, Urbanska 1997b). Plants rooted in the greenhouse can serve as safe sites for colonization by other plants. This transplanting of single species avoids the susceptible stages of seedlings (Urbanska and Schutz 1986, Urbanska et al. 1988, Urbanska 1994, Urbanska 1997b, Chambers et al. 1990).

We tested this technique of harvesting plant parts and rooting them in favorable growing conditions on Humboldt Peak. In addition, we tried direct transplanting of graminoid tillers and dicot stems so that, if possible, we could eliminate the rooting procedure in the future.

Methods

In early to mid-summer 1998 we removed ca. 5-cm plugs of five species (Table 5) from undisturbed vegetation adjacent to the social trail which we revegetated. For two species of *Carex,* we separated these plugs into single tillers for planting. For *Carex elynoides,* we used a small group of tillers about 0.5 cm in diameter, and for the two dicots, we used a single stem with attached underground parts. The same day as harvesting we planted these into Root-Trainers ca. 1.5 cm square in sterile potting soil. We put these under shade cloth at 12,050 ft and watered them regularly with a solution containing indole acetic acid to promote rooting. Temperatures on hot, sunny days rose to 30 to 35 °C under the shade cloth.

Plant parts remained in Root Trainers 4.5 to 6 weeks, depending on time of harvest. In late August, we planted the healthiest individuals 10 cm apart into 17 plots along the social trail. We used 17 additional plots to plant similarly harvested and separated parts of four of the same species (Fig. 6). We immediately planted these into the social trail under Curlex II® excelsior erosion matting (Table 5). We randomized order of planting species so that position within plots did not bias results.

Results

Stabilization and drainage restoration of the closed trail in which we made single species transplants was poor. The trail continued to channel water, which eroded some areas and deposited soil on others. Wind removed erosion matting from some plots. These problems likely reduced survival of transplants. Because of these problems, we did not statistically analyze the data since probability values would imply more definite conclusions than these data warrant. The data do show several important trends however, and point out possibilities for further research.

Survival of *Trifolium dasyphyllum* during rooting was poor (Table 5) and it was not planted. Survival of *Carex haydeniana* was somewhat less than 1/2 and that of the other species 2/3 to 3/4.

Table 5. Survival of plant parts during rooting.

Species	Initial Number	Number Surviving	Percent Surviving
Carex elynoides	480	368	77
Carex haydeniana	288	124	43
Carex scopulorum	192	123	64
Geum rossii	480	355	74
Trifolium dasyphyllum	480	84	18

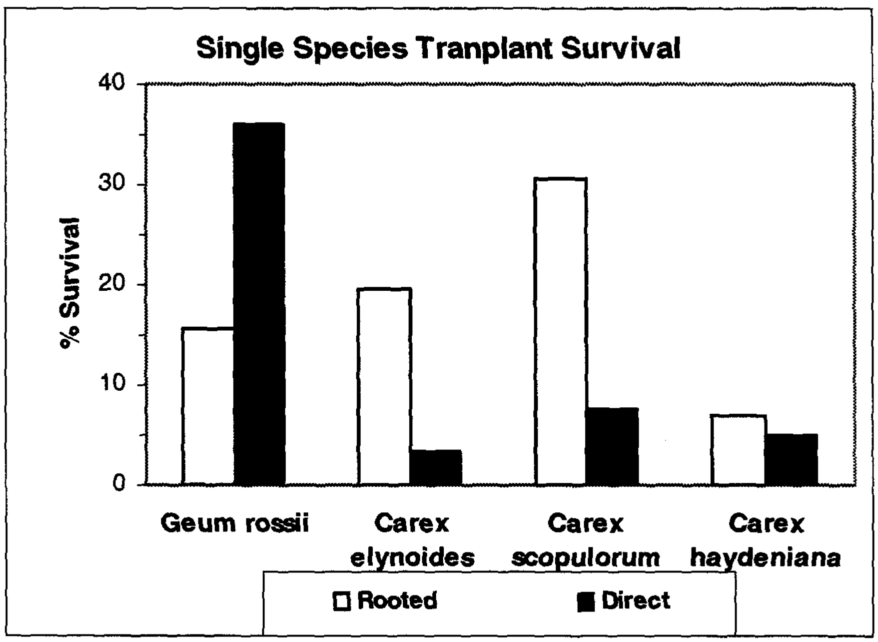

Figure 6. Three-year survival (percent) of plant parts transplanting directly or after rooting. *G. rossii* and *C. elynoides* had 294 individuals of each treatment planted, *Carex haydeniana* 98 of each, and *Carex scopulorum* had 84 rooted and 98 direct transplants.

Survival of single species transplants differed among species and by whether or not plants were rooted before planting. Despite an extremely dry late summer and fall 1998 and the problems described in the methods, there was modest success of two species. After 3 yr, directly transplanted pieces of *Geum rossii* survived moderately well and were occasionally vigorous. Rooted *Carex scopulorum* had moderate survival, tillered vigorously, and almost one-third flowered. Rooted *G. rossii* and directly transplanted *Carex* survived poorly although rooting appeared to increase survival of *Carex elynoides*.

Discussion

Some species of *Carex* have done well in transplants (May et al. 1982, Urbanska 1994) and as disturbance colonizers (Chambers et al. 1984, Rikhari et al. 1993). However, other *Carex* spp. did not colonize disturbances at alpine mine sites in Wyoming and Montana (Chambers et al. 1984). Based on our results, *Carex scopulorum* may survive vigorously with prior rooting, perhaps especially without over-heating problems during rooting. *Carex elynoides* and *C. haydeniana* show poorer potential although over-heating and stabilization problems complicate interpreting survival of plants in the rooting treatment.

Geum rossii transplants survived poorly after rooting treatment, but had modest survival (ca. one-third) when directly transplanted. Since direct transplants avoid the labor-intensive and logistically difficult rooting treatment, direct transplants might work to add *Geum rossii* to turf transplants, in which it survives poorly (this paper).

SEEDING

On some sites, seeding can produce reasonable results in the alpine (e.g., Chambers 1997). With seeding, one can select the desired species, easily move the seed to restoration sites, and potentially quickly restore an area. Our seeding trials tested whether seed collected from the surrounding area and immediately sown into closed social trails could effectively generate reasonable densities of seedlings.

Methods

In a preliminary seeding trial on Humboldt Peak, we collected seeds of four monocot and four dicot species in mid-September 1998. We immediately sowed them into a closed social trail under Curlex II® excelsior erosion matting at the rate of 40 g wet material / m^2. We followed success in the thirteen 70 x 70 cm plots with erosion matting. In 1999, we counted seedlings and in 2001, we recorded cover, since seedlings were too numerous to count.

In a second trial on a closed social trail on Mount Harvard, we established and marked ten 30 cm x 100 cm plots in each of three treatments in early September 1999. The treatments were always in the same order: seeded without erosion matting; control (with no seed and no erosion matting); and seeded with erosion matting (downhill to uphill). There were at least 25-cm spaces between plots. We chose plots to avoid areas with >25% rock cover or intact root systems. Volunteers raked plots to loosen the soil, then planted each plot with 12 g (40 g/m^2) of a mixture of *Deschampsia caespitosa* and *Carex scopulorum* (Table 6), the most common species in the area. They then covered all plots with Curlex II® excelsior erosion matting secured with 6 in steel staples.

Table 6. Species and quantities seeded into a closed social trail on Mount Harvard. The first two columns give the amount of seed spread on each 30 x 100 cm plot. Seeding rate is total seeds, not germinable seeds.

Species	Field Weight, g[1]	Dry Weight, g[1]	Number of Seeds / dry g[2]	Seeding Rate, no. / m^2
Deschampsia caespitosa	6.0 g	1.6g	3700 ± 420	12,000 ± 140
Carex scopulorum	6.0 g	3.0 g	2700 ± 240	9,000 ± 70
Total	12.0 g	4.6 g	-	21,000 ± 160

[1]Weights include some inflorescence material as well as seed.

[2]Mean ± SE from three random samples of dry seed plus other inflorescence material.

In August 2000, we returned to these plots to evaluate seeding success. Although we were not able to differentiate between *C. scopulorum*, *D. caespitosa*, and other first year graminoid seedlings, we counted total monocot and dicot seedlings and identified non-seedling individuals. In September 2001 we sampled plots again; this time counting all monocot and dicot seedlings present in a centrally placed 20 cm x 50 cm frame as well as identifying non-seedling individuals present. After adjusting seedling densities for percentage of rock cover in each plot, we compared mean seedling densities of monocots, dicots, and total seedlings among treatments.

Results

On Humboldt Peak after 1 yr, we conclusively identified seedlings for seven of the eight seeded species (Table 7). Seedlings of *Deschampsia caespitosa* were likely present, but are difficult to definitively separate from other graminoid seedlings. After 4 yr six of the eight seeded species were present and seedlings of an additional 20 species had germinated. Mean cover after 4 yr was 5.5%, but ranged as high as 18%.

Poa alpina and *Trisetum spicatum*, both seeded species, provided the most cover. Two seeded dicots, *Trifolium dasyphyllum* and *Silene acaulis*, provided significant cover. The third seeded dicot, *Castilleja occidentalis*, was not present after 4 yr; its strategy as a hemi-parasite may limit its establishment in these situations. Of non-seeded species, *Arenaria fendleri*, *Festuca brachyphylla*, *Luzula spicata*, and *Potentilla* sp. were the most frequent; *Cerastium beeringianum* and *Cirsium scopulorum* are not as frequent, but provide significant cover in a few plots.

On Mount Harvard, seeding under matting produced many more seedlings after two years than either seeding alone or the no-action control (Fig. 7). Monocot seedlings were 6 times more abundant in the seed-plus-mat treatment than in seeding alone and 20 times more abundant than in controls. At least one non-seeded monocot germinated (Table 8). Although no dicots were seeded, dicot seedlings (Table 8) were 5 times more abundant in the seed-plus-mat treatment than in both the other treatments (Fig. 7).

Discussion

Despite the problems with the Humboldt site (described under Single Species Transplants), seeding is establishing reasonable cover with high species richness. Success of many alpine species in establishing from seed on Humboldt Peak and Mount Harvard indicates that re-establishing the high species diversity of undisturbed alpine vegetation is possible. Future studies should experiment with additional species, and managers can use a variety of species and growth forms rather than limiting themselves to grasses.

Minimal densities of seedlings are present without seeding. Without assistance, restoration of social trails, even those like this trail on which erosion is not a significant problem, will be unacceptably slow. Seeding without matting is only marginally better than no action at all and is unlikely to create erosion-resistant and aesthetically acceptable vegetation conditions after a reasonable time.

Seeding under matting dramatically increases seedling density of graminoids, presumably mostly those seeded, compared to either seeding alone or no action. The matting also provides safe sites (Chambers et al. 1991; Urbanska and Schutz 1986)), which greatly increase densities of unseeded dicots. This effect will hasten restoration of vegetation cover and create higher species richness more comparable to the surrounding undisturbed vegetation.

Table 7. Results of seeding eight species into a closed social trail on Humboldt Peak at 12,900 ft. Frequency: A=present in all/almost all plots, M=in most plots, S=some plots, F=few plots. Cover are in percent; "+" = <1% cover but abundant; "-" = <1% cover and few. Y=yes.

Species	% Seeded, by weight	1-Yr Density no. / m2	4-Yr Frequency	4-Yr Cover	Some Flowering?
Seeded species					
Castilleja occidentalis	4.0	6.4	zero	zero	
Deschampsia caespitosa	20.0	0.0	zero[1]	zero[1]	
Elymus scribneri	4.4	1.6	M	r to 2	Y
Poa alpine	27.8	30.0	A	+ to 10	Y
Polygonum bistorta	18.9	158.9	A	+	
Silene acaulis	11.1	34.4	M	- to 1	
Trifolium dasyphyllum	8.9	6.3	M	- to +	
Trisetum spicatum	4.9	33.2	M	- to 6	
Non-seeded species					
Arenaria fendleri			M	- to +	Y
Acomastylis rossii			F	-	
Artemisia scopulorum		1.0	F	-	
Cerastium beeringianum			S	- to 1	Y
Cirsium scopulorum			F	- to 2	
Draba sp.			S	-	Y
Erigeron pinnatisectus			F	-	
Erigeron simplex			F	-	Y
Festuca brachyphylla			A	- to +	Y
Lloydia serotina		0.1			
Luzula spicata		0.4	M	- to 1	Y
Minuartia obtusiloba			F	+	
Oreoxis sp.		0.6	F	-	
Pedicularis parryi			F	-	
Phacelia sericea			F	-	
Poa arctica			F	-	
Potentilla sp.			M	- to +	
Sedum lanceolatum		0.3			
Sibbaldia procumbens			F	-	
Solidago sp.			F	-	Y
Tetraneuris brandegeei			F	-	
Thlaspi montanum			F	-	
Total monocots		293.9			
Total dicots		257.7			
Grand total		539.8			
Cover, %				+ to 18	

[1]Seedlings of *Deschampsia caespitosa* likely are present but unidentifiable.

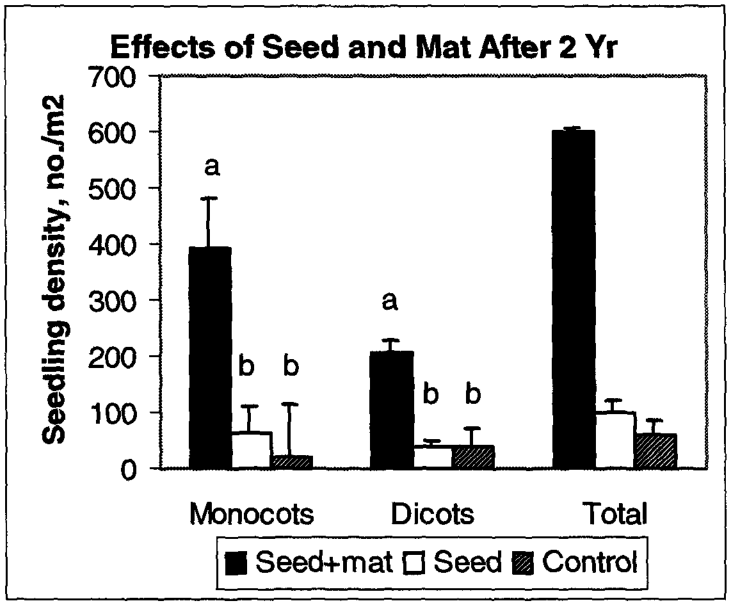

Figure 7. Effects of seeding and matting, seeding only, and no treatment (control) on density of seedlings 2 yr after seeding a closed social trail on Mount Harvard (0 $\pm$ SE). Lower case letters indicate homogeneous subsets within growth forms (Tukey's test of all pairwise comparisons, family error rate = 0.05). We did not test for differences among treatments in total seedlings since this test is not independent of the other two tests.

Table 8. Species of seedlings with definite identities 2 yr after seeding *Deschampsia caespitosa* and *Carex scopulorum* into a social trail on Mount Harvard. Numerous graminoid and dicot seedlings were too small to definitively identify to species. R=rare, M=moderately abundant, C=common[1].

Species	Abundance
Androsace septentrionalis	R
Arenaria fendleri	M
Artemisia scopulorum	M
Bistorta sp.	R
Castilleja occidentalis	C
Deschampsia caespitosa	C
Draba sp.	R
Festuca brachyphylla	C
Geum rossii	R
Oreoxis sp.	R
Potentilla sp.	M
Sibbaldia procumbens	C
Tonestus pygmaeus	R
Trifolium dasyphyllum	R

[1]On another Harvard site at about 12,900 ft (3930 m) that was seeded with graminoids under matting *Bistorta* sp. and *Silene acaulis* seedlings were abundant.

RECOMMENDATIONS FOR RESTORING ALPINE SOCIAL TRAILS

Given the slow rates of recovery of many Colorado alpine communities (Ebersole, in review) and because hikers usually continue to use social trails that are not revegetated, essentially all social trails on Colorado's 14,000-ft peaks will require active restoration. After 4 yr of research we have these recommendations for restoring social trails and comparable small disturbances in alpine sites of Colorado and similar areas:

1) Stabilizing the soil and restoring the original drainage regime are essential before restoration can be successful. Even slightly eroded trails usually channel water, and the effect of the water and the erosion it causes will prevent re-establishment of a vegetation cover. Normally, this means that the depressed or eroded trail must be filled with rocks and soils to restore the original surface. Stabilization is often time-consuming and difficult on steep slopes, especially without motorized equipment, but must be done thoroughly and solidly for vegetation to grow. Hesse (2000) describes techniques for preventing erosion problems on steep, eroded, difficult sites.

2) Based on our results and those of Buckner and Marr (1988), turf transplants are very successful for revegetating alpine social trails. Turf transplants survive well in several communities and presumably would survive even better if attempted in moister sites. They maintain high species richness and enhance natural seedling colonization near them in some cases. Whenever turf is available, it should be considered extremely valuable. We recommend crews carefully excavate new trails to maximize amount of turf available for restoration. They need to place turf blocks into areas with very similar original vegetation. Immediate transplanting is best although turf blocks might survive for a limited time with watering before transplanting. Edges of turf blocks need to be flush with the surrounding surface as blocks placed on the surface or whose edges are partially exposed have poor survival (personal observations).

Even if disturbance cannot be completely covered with turf transplants, turf blocks can serve as sources of seeds and safe sites for other colonizers (Urbanska 1997c). In favorable sites turf blocks can be 20 cm to perhaps 30 cm apart and still strongly enhance colonization of natural seedlings. Seeding areas between turf blocks is also likely to be effective.

3) When turf blocks are not available, seeding seems to be the most time-efficient, logistically reasonable, and effective approach for restoring social trails. Erosion matting increases seedling density dramatically, and seeding is unlikely to be successful without it. Matting should be used whenever permitted and logistically feasible. Drastically greater seedling density will likely revegetate the area much more quickly, reduce erosion, and restore long-term aesthetic values far more quickly than seeding without matting or no action.

Seed can be collected on site when it matures in late summer to early fall and immediately seeded into the disturbed site. This eliminates transporting it to and from the site, cleaning, and storage. Disadvantages include time constraints of collecting sufficient seed and poor seed production and viability in some years (Chambers 1989). Many species have germinated from seed collected on site so that maintaining species richness using this technique seems likely. Seed collected on site could be grown out and increased in a native plant center, but we have not yet explored this option.

4) Harvesting plant parts, rooting then, and then planting them into bare areas has effectively produced good cover and high species richness in other sites. Poor stabilization, subsequent erosion and deposition, and problems with erosion matting complicate interpreting our results of this technique. Future trials need to eliminate high temperatures during rooting and use longer rooting times if possible. Some dominant dicots may tolerate direct transplanting. This may allow establishment of *Geum rossii* within areas of turf transplants, where its survival is poor.

Although restoring large areas with rooted plant parts seems time-consuming and difficult logistically, it could be useful in certain situations. It could be combined with seeding for those species that do not establish from seed well or it could be used to create strips of fairly well-established plants across the fall line to slow water and trap small amounts of sediment.

Long-term monitoring and further trials of these various techniques or combinations will reveal if our promising short-term results will continue over longer periods.

ACKNOWLEDGEMENTS

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NEW PLANT MATERIALS FOR HIGH ALTITUDE

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ABSTRACT

Although there are numerous plant varieties used in present revegetation projects, there are only a few tested and adapted plant material varieties available for the revegetation of high elevation sites. Fewer products are available for reclamation used in the alpine, subalpine and montane biomes combined than for any other single biome in the Central Rocky Mountains. However, in the development stage are a number of new products with release potential. Each of these products is well suited to high altitude revegetation projects. One of these materials, 'Garnet' germplasm mountain brome, was recently released for commercial production. Two selections each of Columbia needlegrass and bottlebrush squirreltail have been tested in several locations and field produced for more than eight years at the Upper Colorado Environmental Plant Center. Four products collected from sites near 11,000 feet, alpine timothy, bigelow groundsel, spike trisetum and slender wheatgrass, have also been field produced the last two years at the Plant Center, and show promise for commercial production. Additional testing and production will be necessary on these and other experimental materials, but present information indicates they will add to the short list of plant materials suitable for revegetating high altitude surface disturbances.

NATIVE SHRUB ESTABLISHMENT IN COLORADO

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ABSTRACT

The Colorado Division of Minerals and Geology is sponsoring a study to evaluate native shrub establishment on reclaimed lands. The goal of the study is provide enhanced wildlife habitat after mining. Dr. Ed Redente and Dr. Mark Paschke from Colorado State University are conducting the research. The first phase of the study included a comprehensive literature review. The literature review covered the biology, ecology, and propagation of seven species that are of primary importance for wildlife habitat in Colorado.

Two main limitations to shrub establishment at the Colorado reclaimed mines are browsing and competition from aggressive herbaceous species. The second phase of the project involves a field study to evaluate reclamation techniques to overcome these obstacles. The experimental design uses large-scale demonstration plots that were constructed with standard reclamation equipment to test shrub establishment techniques that have commercial practicality. Plots were established at three coal mines in northwestern Colorado. Several treatments are being tested to evaluate shrub establishment on spoil material, 6 inches of topsoil, and 18 inches of topsoil. Plots were strip seeded with native seed mixes, alternating rows of herbaceous species and shrub species. Native shrub transplants were planted at one mine. Half of each treatment was fenced to prevent browsing. Plots were installed in 2000. Soil samples at all plots were collected in April 2001. The first year's data was collected in July 2001. Results of the study to date are presented.

INTRODUCTION

Colorado coal mines are located in prime wildlife habitat. Sagebrush grasslands provide winter range, breeding and nesting habitat for sage grouse and Columbian sharp-tailed grouse. Mixed mountain shrub communities provide winter range and fawning and calving grounds for deer and elk. Big game is concentrated in mountain shrublands during winter periods and the quality of the mountain shrub habitat is the key determinant of the carrying capacity for big game population in Colorado (Wallmo et al. 1976). Despite the wide diversity of mountain shrub habitat types, there are relatively few dominant shrub species found in this vegetation type. Notable among these common shrubs are big sagebrush, antelope bitterbrush, mountain mahogany, Gambel oak, Saskatoon serviceberry, black chokecherry, snowberry, rabbitbrush (*Chrysothamnus* sp.), rose (*Rosa* sp.), willow (*Salix* sp.), and saltbush (*Atriplex* sp.)

(Terwilliger 1978, Tiedeman and Terwilliger 1978, Hoffmann 1979, Hoffman and Alexander 1980, Hess 1982, Hoffman and Alexander 1983, Alexander 1985, Hess and Alexander 1986, Alexander 1987, Banner 1992, Colorado Natural Areas Program 1998).

In the majority of the Colorado coal mine permits, wildlife habitat is either the primary or secondary post mining land use. Reclamation plans are designed to restore habitat for wildlife species. The Colorado Division of Minerals and Geology (DMG), in cooperation with the Division of Wildlife (DOW) and coal mine operators, has and continues to evaluate reclamation techniques that will promote wildlife habitat.

Over the years many attempts have been made to reestablish the native shrubs that dominate a majority of the mined lands in western Colorado. These techniques included transplanting native shrub islands, planting shrub seeds with the standard reclamation mix, transplanting small shrub tubelings, and strip seeding rows of shrub seed between the reclamation mix. The results of these attempts were inconsistent and variable. Additionally, there was a lack of technical information regarding the cost-effective methods for establishing shrubs on disturbed lands (Blaisdell 1971).

PHASE I STUDY

In an attempt to better understand native shrub establishment on reclaimed lands, the DMG requested funding to evaluate shrub establishment techniques. Funds were appropriated from the State Severance tax fund. DMG signed an agreement with Colorado State University (CSU) to conduct the research with Dr. Ed Redente and Dr. Mark Paschke as the lead researchers. The project was divided into two phases. Phase I included a comprehensive literature review on the shrub species of interest and development of a field study design. Phase II is the implementation of the field study using demonstration plots.

The literature review in Phase I covered the biology, ecology, and propagation of seven species that are of primary importance for wildlife habitat in Colorado. These are: Antelope bitterbrush, Big sagebrush, Chokecherry, Mountain mahogany, Serviceberry, Snowberry, and Gambel's oak. Four general conclusions were derived from the literature review. They were that successful establishment of these species has most often involved: 1) utilization of local shrub ecotypes, varieties or subspecies in reclamation efforts, 2) protection from browsing during the establishment phase, 3) providing a source of mutualistic soil organisms and 4) strategies for avoiding herbaceous competitors.

During Phase I representatives of the DMG, the Colorado Division of Wildlife (DOW), CSU and interested mine representatives toured mines to observe different shrub techniques that had been attempted at several mines. Based on the results of the literature review, the field visits and several meetings amongst all parties, a field study was developed.

PHASE II

The mines that volunteered to participate in the field study are all large surface mines in northwestern Colorado: the Colowyo Mine, the Seneca Mine, and the Trapper Mine. All three mines are in dense mountain shrublands that provide valuable wildlife habitat. The mines collectively have made many attempts at shrub establishment on their reclaimed lands and they all are interested in developing a technique that will have higher levels of success. Permit areas at these mines range from 3500 acres at Seneca to 10,400 acres at Trapper. Elevations range from 6500 at Colowyo and Trapper to 8100 feet at Seneca No. 2. Geology is characterized by interbedded shales, sandstones, sandy shales and coals. Ephemeral and intermittent streams drain the permit areas. Northwestern Colorado has a highland continental climate characterized by low precipitation, large fluctuations in diurnal temperatures, low humidity, moderate wind and high levels of insolation (exposure to sunlight). Local climate is characteristic of semi-arid steppe regions with average precipitation averaging 18 inches. Soils are typical of soils found in cold, semi-arid regions of the western United States. They are moderately deep (20 to 40 inches) to shallow (10-20 inches). Soils were developed in weathered, interbedded fine sandstone, siltstone and shale, and in local slopewash and colluvium. The dominant vegetation types are sagebrush grasslands and mountain shrublands. Sagebrush is common on the colluvial toe-slopes. The north facing hillslopes and higher elevations are dominated by well-developed mountain shrub communities. Current and historic land uses in the vicinity of these operations has been grazing for livestock, and wildlife habitat. Herds of mule deer and elk are common, especially on reclaimed areas during the winter. Known elk calving areas are scattered throughout these permit areas. Common raptors are the Golden Eagle, Red-tailed hawk, Great horned owl, Marsh hawk and American kestrel. Blue grouse, sharptail grouse and sage grouse are all residents or occasional residents in this area.

The treatments used in the field study were designed to overcome the two primary obstacles to shrub establishment - competition from aggressive herbaceous species and browsing. The herbaceous competition is primarily from introduced cool season grass species. These species are reliable and serve as quick erosion control. They thrive where topsoil is uniformly replaced and become well established, often at the expense of other desirable species. Seed mixes for the field plots were carefully evaluated to eliminate the competitive introduced species and include native species. Strip seeding was used to isolate the shrub species to further reduce competition from the herbaceous species. Topsoil depths were varied and included seeding directly on spoil. This was done for a couple of reasons, to reduce the competition from herbaceous species that thrive where topsoil has been replaced and to better represent the natural rocky substrate for several of the shrub species. Young shrub plants are highly desirable browse for deer and elk. Since the reclaimed lands are located in heavily used wildlife habitat, the deer and elk are drawn to the wide open fields of reclamation. To determine the impact of wildlife browsing, half of each treatment is fenced. Heavy-duty elk proof fence is necessary to isolate the plots.

With the reduced seeding rate and the lack of aggressive species that establish quickly it was necessary to consider erosion control on the treatment plots. Surface roughening using a dozer to create depressions was included on several of the treatments. Not only will this help with erosion control, but the depressions create a microhabitat that may enhance shrub establishment.

The demonstration plots are large-scale plots constructed with standard reclamation equipment to test shrub establishment techniques that will have commercial practicality. Plots were established at three coal mines in northwestern Colorado: the Colowyo Mine, the Seneca No. 2 Mine and the Trapper Mine. At each mine five to six treatments are being evaluated as shown on Figures 1-3. The treatments vary slightly between mines to accommodate the reclamation techniques and material availability at each mine. Test plots for each treatment range in size from 100 x 100 feet at the Seneca Mine to 60 x 1000 feet at the Colowyo Mine.

All plots were constructed in the fall of 2000. Colowyo and Seneca seeded their plots in the fall. At Trapper winter weather arrived before they could get the plots seeded and they initially seeded their plots in April, 2001.

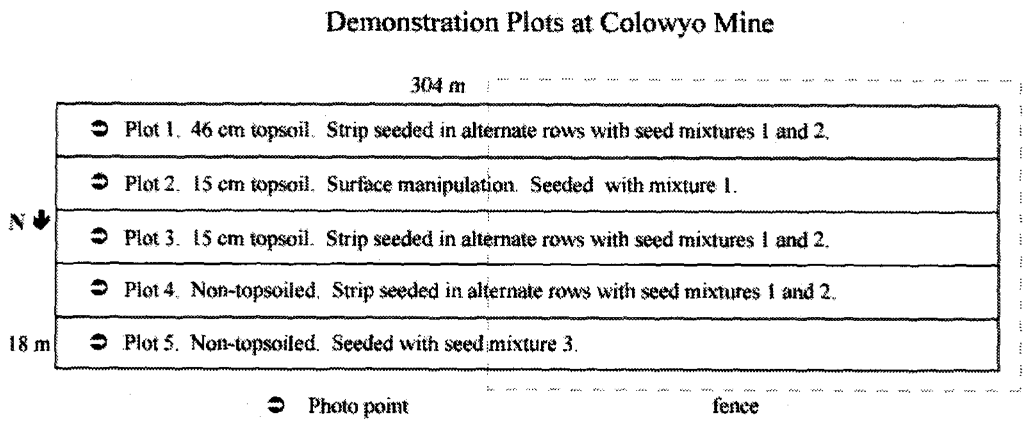

Figure 1. Shrub establishment demonstration plots at Colowyo mine.

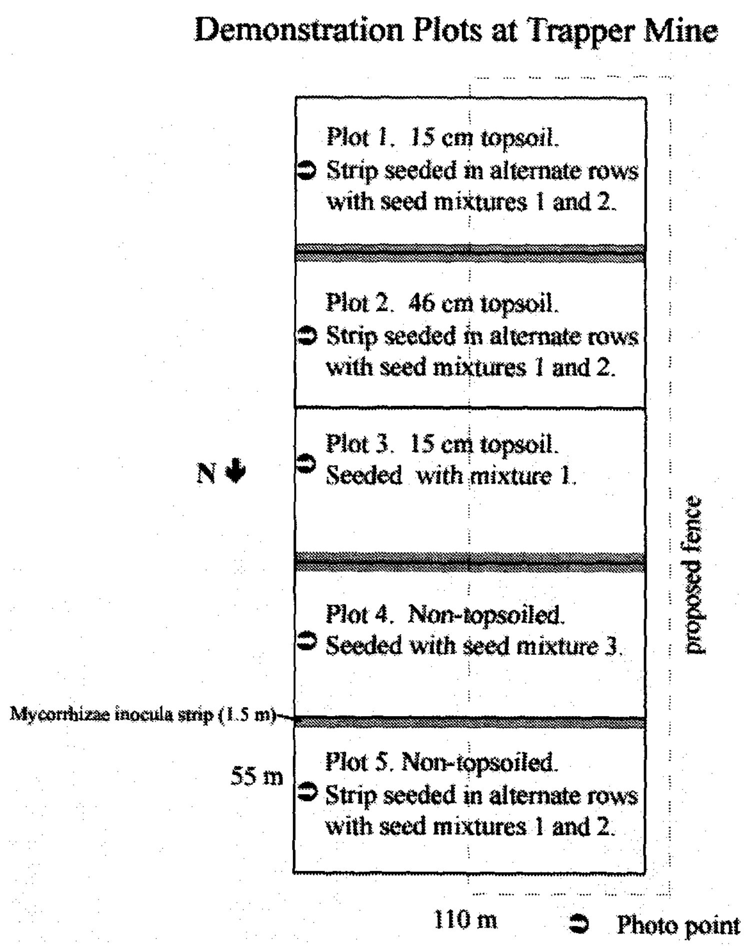

Figure 2. Shrub establishment demonstration plots at Trapper mine. Refer to Tables 1-3 for seed mixes used in the demonstration plots.

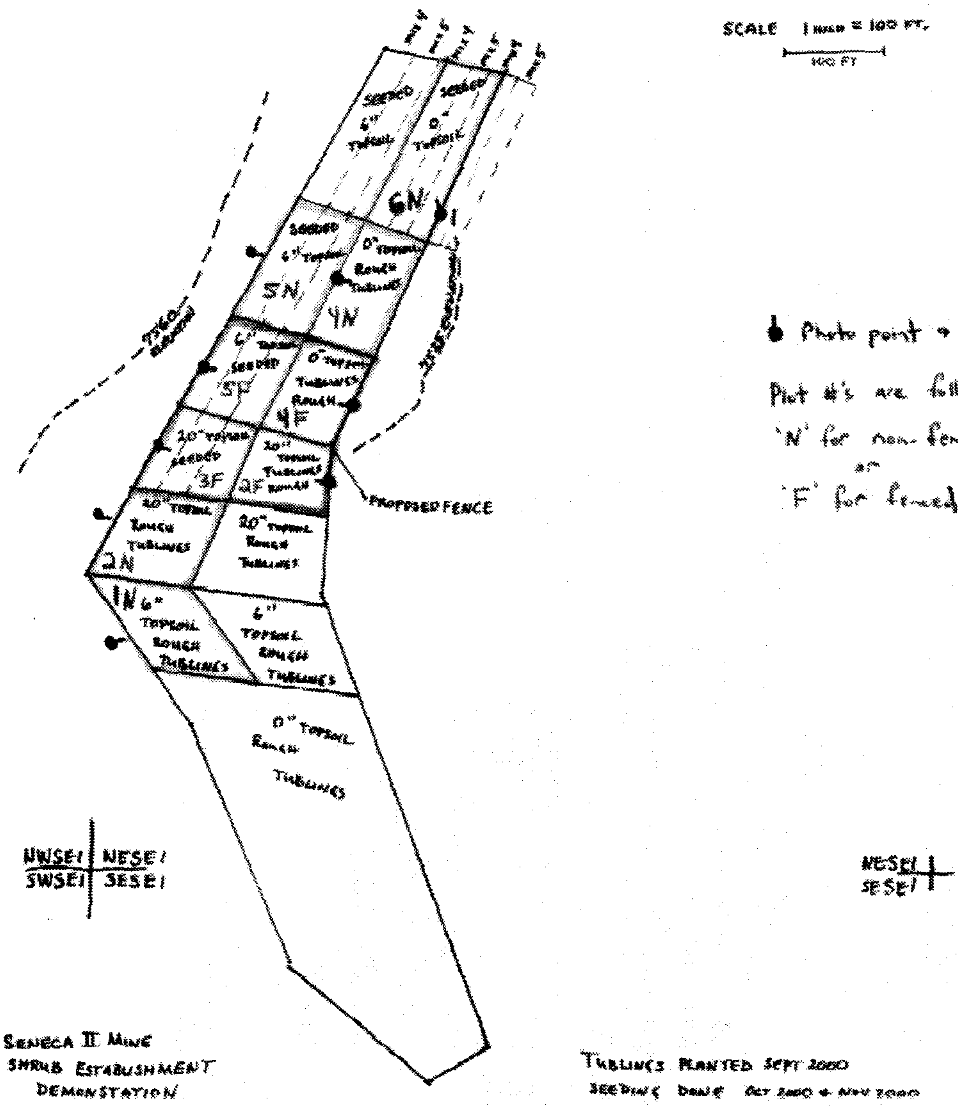

Figure 3. Shrub establishment demonstration plots at Seneca II mine. Refer to Tables 4-5 for seed mixes used in the demonstration plots.

RESULTS TO DATE

In April of 2001, a composite soil sample was taken from each treatment at each mine. Overall, the soils (topsoil and spoil) at all three mine sites have good physical and chemical properties. Soil pH ranges from 6.9 to 7.8, macronutrients appear to be adequate for sustained plant growth, organic matter contents are relatively high (3.7% to 6.3%), salt levels are low (EC ranges from 0.6 to 1.6 mmhos/cm and SAR ranges from 0.3 to 1.8), cation exchange capacity (CEC) is in a normal range, and textures are clay loam and sandy clay loam. A potential deficiency was apparent at Trapper and Seneca where phosphorus levels range from 0.2 to 4.3 mg/kg, below the 7mg/kg level considered to be adequate for plant growth.

Little variation was observed between topsoil and spoil materials with a few exceptions. At Colowyo potassium levels were substantially lower in the spoil. At Trapper, pH is slightly higher in the spoil and NO_3-N levels are higher in the topsoil. Phosphorus and potassium levels are both substantially lower in the spoil. At Seneca, phosphorus levels and pH are lower in the spoil.

Overall, topsoil and spoil at all mine sites have favorable characteristics for plant growth, with the possible exception of phosphorus at Trapper and Seneca. However, plant growth from previous reclamation efforts has not shown evidence of phosphorus deficiencies and we can assume at this time that phosphorus levels are adequate. As a precaution, however, inspections for visual symptoms of phosphorus deficiency (purple leaf coloration) will be made during future vegetation monitoring.

In July of 2001, vegetation sampling was conducted at all three mines. Each treatment was sampled using a point intercept method. Shrub data was collected in quadrants along each transect. The number and height of each shrub species in the quadrat was recorded.

Preliminary results from Colowyo mine indicate that the autumn 2000 seeding operation was successful as most of the seeded species were present on the plots. Lewis flax and mountain brome are two seeded species that were showing relatively high cover during the first growing season, especially in topsoiled plots. Early successional weedy annual species such as field pennycress were also well established, especially in the plot with 20 inches topsoil. The non-topsoiled plots at Colowyo had much lower vegetative cover and fewer plant taxa than the topsoiled plots. This difference results largely from the higher cover of weedy species on the topsoiled plots. Shrub species were establishing well in the plots at Colowyo. Mountain big sagebrush appears to have established well in most plots relative to other shrub species. Of the 11 shrub species that were seeded at Colowyo, 9 were encountered in the vegetation surveys (silver buffaloberry and Wood's rose were not found).

The fall 2000 seeding at the Seneca II mine appears to have been somewhat successful. However, with the higher elevation of Seneca II, early results would be less evident at the time of sampling relative to Colowyo. Some of the seeded species were encountered in some of the plots at Seneca II. Like Colowyo and Trapper, Russian thistle dominated topsoiled plots at Seneca II. Shrub density was low at Seneca II relative to Colowyo. However, several seeded species appeared to be establishing during this early phase of the study. Shrub tubelings planted in some of the plots showed good survival at the time of sampling.

Results from the vegetation sampling indicate that the seeding operation at Trapper Mine was not successful. Most of the vegetative cover in demonstration plots at Trapper was attributed to Russian thistle, an annual invasive species. No shrubs were found in the shrub density and height surveys. However, a few widely scattered shrub seedlings were observed in the plots. Dry conditions after the spring 2001 seeding operation may have contributed to the lack of success. Due to the observed failure all of the Trapper plots were reseeded in October 2001.

Monitoring for this project is scheduled to continue for four more years. It has been our experience that after three years in mine reclamation that the annual weeds die out and the characteristics of the long term community are established. After that time we will have a better sense of what reclamation techniques are most successful in establishing native shrubs.

Table 1. Native shrub and forb seed mixture for demonstration plots at Colowyo and Trapper Mines.

SCIENTIFIC NAME	COMMON NAME	SEEDING RATE IN LBS PLS/A
Shrubs	**Shrubs**	
Purshia tridentate	Antelope bitterbrush	5.0
Artemisia cana	Silver sagebrush	0.20
Artemisia tridentata vaseyana	Big sagebrush	0.25
Prunus virginiana	Chokecherry	4.0
Chrysothamnus nauseosus	Big rabbitbrush	0.5
Amelanchier alnifolia	Serviceberry	1.0
Symphoricarpos oreophilus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
Forbs	**Forbs**	
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Balsamorhiza sagittata	Arrowleaf balsamroot	0.5
Achillea lanulosa	Western yarrow	0.1
TOTAL		18.55

Table 2. Native grass, forb, and shrub seed mixture for demonstration plots at Colowyo and Trapper Mines.

SCIENTIFIC NAME	COMMON NAME	SEEDING RATE IN LBS PLS/A
Grasses	**Grasses**	
Agropyron spicatum	Bluebunch wheatgrass	1.0
Festuca ovina	Sheep fescue	0.5
Bromus marginatus	Mountain brome	1.0
Forbs	**Forbs**	
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Balsamorhiza sagittata	Arrowleaf balsamroot	0.5
Achillea lanulosa	Western yarrow	0.1
Shrubs	**Shrubs**	
Purshia tridentate	Antelope bitterbrush	5.0
Artemisia cana	Silver sagebrush	0.2
Artemisia tridentata vaseyana	Big sagebrush	0.25
Prunus virginiana	Chokecherry	4.0
Chrysothamnus nauseosus	Big rabbitbrush	0.5
Amelanchier alnifolia	Serviceberry	1.0
Symphoricarpos oreophilus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
TOTAL		21.05

Table 3. Seed mixture of unpalatable native shrubs and low-competitive native grasses and forbs for demonstration plots at Colowyo and Trapper Mines.

SCIENTIFIC NAME	COMMON NAME	SEEDING RATE IN LBS PLS/A
Shrubs	**Shrubs**	
Chrysothamnus nauseosus	Big rabbitbrush	1.0
Chrysothamnus viscidiflorus	Douglas rabbitbrush	1.0
Rosa woodsii	Woods rose	3.0
Artemisia cana	Silver sagebrush	0.20
Artemisia tridentata vaseyana	Big sagebrush	0.50
Shepherdia argentea	Silver buffaloberry	3.0
Rhus trilobata	Skunkbush sumac	3.0
Forbs	**Forbs**	
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Balsamorhiza sagittata	Arrowleaf balsamroot	0.5
Achillea lanulosa	Western yarrow	0.1
Grasses	**Grasses**	
Agropyron spicatum	Bluebunch wheatgrass	1.0
Festuca ovina	Sheep fescue	0.5
Bromus marginatus	Mountain brome	1.0
Agropyron trachycaulum	Slender wheatgrass	1.0
TOTAL		17.80

Table 4. Native grass, forb, & shrub seed mixture for demonstration plots at the Seneca II Mine.

SCIENTIFIC NAME	COMMON NAME	SEEDING RATE IN LBS PLS/A
Grasses	**Grasses**	
Agropyron spicatum	Bluebunch wheatgrass	1.0
Bromus marginatus	Mountain brome	1.0
Agropyron trachycaulum	Slender wheatgrass	1.0
Poa ampla	Big bluegrass	1.0
Forbs	**Forbs**	
Balsamorhiza sagittata	Arrowleaf balsamroot	1.0
Lupinus alpestris	Mountain lupine	1.0
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
Shrubs	**Shrubs**	
Purshia tridentate	Antelope bitterbrush	3.0
Amelanchier utahensis	Serviceberry	3.0
Symphoricarpos albus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
Ribes aureum	Golden currant	2.0
Prunus virginiana	Chokecherry	4.0
TOTAL		25.0

Table 5. Native shrub and forb seed mixture for demonstration plots at the Seneca II Mine.

SCIENTIFIC NAME	COMMON NAME	SEEDING RATE IN LBS PLS/A
Shrubs	**Shrubs**	
Purshia tridentate	Antelope bitterbrush	3.0
Amelanchier utahensis or *alnifolia*	Serviceberry	3.0
Symphoricarpos oreophilus	Snowberry	3.0
Rosa woodsii	Woods rose	2.0
Ribes aureum	Golden currant	2.0
Prunus virginiana	Chokecherry	4.0
Forbs	**Forbs**	
Balsamorhiza sagittata	Arrowleaf balsamroot	1.0
Lupinus alpestris	Mountain lupine	1.0
Linum lewisii	Lewis flax	1.0
Penstemon palmeri	Palmer penstemon	0.5
Penstemon strictus	Rocky Mountain penstemon	0.5
TOTAL		21.0

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NEW ADVANCES IN DRILLS

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ABSTRACT

In the past few years, increased interest in the seeding of native grasses and forbs has stimulated the development of several pieces of new seeding equipment. At Truax, Inc., we have set out to meet this new demand. The three (3) newest units include:

1. Trillion Seeder
2. Utility Drill
3. Rough Rider Drill

The Trillion is a combination of the Brillion Cultipacker and Truax seed boxes. It is used primarily on fully prepared seedbeds. The Utility Drill is a 4' wide double-disc drill, which is 3-point mounted. It is driven by a small wheel on the back side of the drill. It is designed for use in those hard to get at places. The Rough Rider is a brand new drill designed to bring new technology to the old "Rangeland Drill" users in the West. The basic design is to provide a drill with adequate residue clearance, ability to seed the light fluffy and heavy slick seeds at the same time; and do it on unprepared seedbeds.

INTRODUCTION

This presentation will cover the latest equipment being manufactured at Truax, Inc., for the seeding of legumes, grasses and forbs.

Included are:

- Trillion Broadcast Seeder
- Utility Drill
- Rough Rider Drill

Trillion Broadcast Seeder

The Trillion Broadcast Seeder is a combination of the Brillion Cultipacker and Truax Seed Boxes. It is a 3-point hitch design and comes in 5' and 8' widths. It is capable of uniform shallow seed placement on a prepared seedbed. This results in a broadcast seeding which leaves no visible row effect. The 3 seed boxes include: a small seed box in front for legumes or other small, smooth, slick seed types; a fluffy seed box in the middle with an auger/agitator and picker wheels for hard to seed fluffy seeds; and a cool season box in the back for the heavy grass species or cover crops. Each box can be calibrated independently from the other boxes. The seed is dropped evenly down between the two cultipacker rollers. The leading roller crushes clods, removes air pockets, and presses down small stones and forms a smooth, firm seedbed in front of the seed drop. The second roller splits the shallow ridges formed by the front roller, gently firming the soil around the seeds, ensuring shallow seed placement (1/4" to 1/2") and excellent seed to soil contact.

Utility Drill

The Utility Series Drills are a 3-point hitch drill with a single rear-mounted drive wheel. It will plant grasses, legumes, and/or cover crops in close quarters such as in narrow ditch bottoms or around structural improvements. The basic design is a double-disc opener with depth bands and no-till coulters mounted ahead of the disc openers. Two models are available: a grass drill model with legume and fluffy seed boxes, plus an option for a 3rd cool season/ grain box; and a grain drill model with legume and a cool season/ grain box. A fluffy seed box cannot be added to the grain drill model.

Each model is available in either a four-foot (utility-86) or a five and one-half foot (utility-88) planting width.

This drill will provide excellent seed placement, whether in bare ground or when interseeding into cover crops or sod, and at the prescribed seeding rate desired.

Rough Rider Drill

The Truax Rough Rider is a heavy-duty 10' wide, 12" row planter designed to plant multiple species of grasses and grains on sites that typically would be inaccessible to conventional planting equipment. It utilizes the Truax 3-seedbox design; legume (front), fluffy (middle), and the cool season/grain box (back). Seed delivery is from the boxes through a 3-piece telescoping metal seed tube with 24" travel to the planting unit. The planting units are 20" discs mounted on 6-bolt hubs using tapered roller bearings on 2" diameter. axles. Each unit is rated at 3500 lbs. of load capability and 24" vertical travel between the low and high points. These units are arranged in two ranks, which places the front rank 48" ahead of the rear rank of planting units. The individual units are spaced 24" apart on each rank. This allows for maximum trash, boulder, stump, etc. clearance.

Ground penetration is achieved by having the discs on each planting unit mounted at a 19-degree angle to horizontal.

In order to relieve some of the stress when driving the drill over rocks, stumps, etc. a floating hydraulic system has been incorporated. Hydraulic pressure can be adjusted to the rockshafts (each rank of planters) which in turn control their independent movement. When the front rockshaft goes over a high spot (rock, etc.) in the field, greater pressure is transferred to the rear rockshaft.

Power to drive the seed box shafts is from a floating rubber-tired wheel that rides on top of the right end wheel. A lockout is provided to protect against accidental engagement while transporting the drill. The end wheels are two 11.25 x 28" rib 12-ply implement tires. They are mounted on 8000 lb. capacity axles with 8-bolt hubs.

A rear walk board with handrail and access ladder is standard on all Rough Rider Drills. Optional equipment includes: side-mounted depth gauge wheel, V-tread rubber press wheels, manual hydraulics (to raise and lower drill), light package, lifting beam package (for transporting), and a Transport Jack Package (to stabilize drill during transport).

SUMMARY

Our goal has been to develop seeding equipment that is easy to use, easy to maintain, long lasting and meets your need for precision planting of all the grasses, legumes, grains and wildflowers. These new seeders have been designed to meet those needs.

UPDATE ON HERBICIDES

George Beck

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ABSTRACT

Plateau is a relatively new herbicide from BASF. It is registered for use in pastures, rangeland and non-crop areas. It is a member of the imidazolinone herbicide family and it inhibits the biosynthesis of the branched chain amino acids valine, leucine, and isoleucine. Plateau is readily absorbed foliarly, but root absorption is poor. This makes it safe to use around many trees and shrubs, but it must be kept off the foliage of desirable, susceptible species. The herbicide label has a long list of tolerant and susceptible forbs, grasses, shrubs and trees. Plateau also is safe to use near water because it has a half-life of 6 to 7 hours in water. Leafy spurge is readily controlled by Plateau and the herbicide should be applied at 12 ounces of product per acre in the fall. A methylated seed oil and liquid nitrogen fertilizer also should be added to the spray mixture to maximize absorption and translocation. Annual and perennial mustards also area readily controlled by Plateau. Research conducted by Colorado State University Weed Science found that Plateau shows promise to control Dalmatian toadflax. Fall applications at 12 ounces per acre controlled about 72 percent of Dalmatian toadflax one year after treatments were applied. Downy brome also was present in the study area and the 12 ounce rate controlled 100 percent and 85 percent of downy brome two months and one year after treatments were applied respectively. Oxeye daisy is an escaped ornamental that is invading much of the mountainous area in Colorado. CSU research found that it is readily controlled by Escort, which is a sulfonylurea herbicide whose mechanism of action is identical to Plateau. Escort at 0.5, 0.75, and 1.0 ounce of product per acre controlled 97 to 100 percent of oxeye daisy one and two years after treatments were applied.

Another CSU research project evaluated the interaction of Transline and Tordon with the diffuse knapweed root beetle *(Sphenoptera jugoslavica)*. The beetle was released in Colorado in several locations in the early 1990s, but its control of diffuse knapweed has been inconsistent in space and time. The female lays her eggs at the base of knapweed rosette leaves, but an optimum sized plant is necessary for successful oviposition. Also, in the beetle's origin (the Mediterranean), diffuse knapweed experiences an annual mid-summer growth arrest because of drought. The beetle co-evolved with the drought-induced growth arrest and this must occur to keep from crushing eggs and larvae. Sub-lethal rates of Transline or Tordon were applied during the third week of June or in fall. We hypothesized that sub-lethal rates of these herbicides would selectively thin diffuse knapweed populations to leave a greater number of optimum sized plants for successful oviposition and/or that herbicides would cause a growth arrest. While selective thinning did not occur, more diffuse knapweed root beetle larvae were found in plots that were sprayed than in non-sprayed plots. Spring applications most likely caused a growth arrest and at a minimum, these herbicides are compatible with the diffuse knapweed root beetle.

LARGE SCALE COMPOSTING FOR RECLAMATION

Bill Marty

Marty Farms
Henderson, CO

ABSTRACT

Marty Farms is a family owned agricultural business. Our business originated with farming and cattle feeding and in the last decade have added composting and revegetation as well. Each section of this business compliments one another. Farming is conducted to feed the cattle; the cattle generate manure used to make the compost; and the compost is used to amend the soil for revegetation.

For us, composting begins by gathering manure from what our cattle produce, piling it in static piles for a time, and then placing the manure in windrows. Once the manure is placed in windrows, we turn and mix it accordingly with a composting machine until the final compost condition is reached. Ingredients such as carbon and water are added to maintain the ideal compost environment and condition to achieve the specifications of the end user. We have uniquely adapted the agricultural machinery that we use in our cattle feeding and farming operations, which has allowed us to add the ingredients to the manure in an efficient and effective way.

I will present our process and the equipment used to achieve our enriched-composted manure used to amend soil for revegetation.

INTRODUCTION

Composting for us really begins with farming and feeding cattle. The by-products from these operations generate the materials to compost. Our farming operation is primarily the production of corn. The corn is harvested and used to feed our cattle. After harvesting the grain from the corn plant, the corn stalks are then shredded, windrowed and bailed into large round bales. The bales are then later used as an additional carbon source for our composting or used as bedding for our cattle. The primary feed ingredients that our cattle consume are corn, corn silage, alfalfa hay and a protein supplement such as soybean meal. As the cattle eat this feed they generate manure of which is the primary ingredient of our compost. The manure is cleaned from our corrals and put into piles. These manure piles begin to elevate in temperature and this is where the composting process begins. In order to complete the process, we add carbon, water, oxygen, and monitor the temperature of the compost.

COMPOSTING PROCESS

As mentioned above, the composting process begins in the stockpiles of manure. The temperature in the pile can range from 100 to 120 degrees Fahrenheit. Once we have sufficient manure accumulated in these piles we transfer the material to another location on our farm and place them into windrows. After the basic windrows have been made, we condition the manure and form the rows with our Wildcat Compost Turner. The primary ingredients needed to make compost are nitrogen, carbon, moisture and oxygen. Cattle manure is basically made up of nitrogen and carbon. It will compost nicely without adding additional carbon but moisture and oxygen must be maintained at all times.

Carbon

In order for us to meet the carbon to nitrogen ratio requirements of our customers, we will add carbon to the manure during the composting process. As mentioned earlier, a source of carbon is corn stalks.

Other sources that we have used that give us the same end result are wood shavings and wood chips. The carbon source that is chosen is based on which one is the most economical and readily available at the time. After the manure windrows have been conditioned and formed, we add the additional carbon and water. These ingredients are then blended into the row with our compost turner.

The carbon can be added to the windrows in two different ways. First, we can add our wood shaving and chips by loading them into our feed truck. This truck was designed specifically for mixing feed ingredients to feed cattle, but it works remarkably well for mixing wood chips and wood shavings with water. Adding water to the wood products serves two purposes; it enables us to add additional moisture to our compost in a uniform manner and, it saturates the wood products to prevent them from blowing them off the windrow before we have had a chance to blend them into the row. If the manure is extremely wet, we will add the wood products without additional water in order to reduce the moisture content in the manure windrows. The second way in which we add carbon is by spreading the corn stalks over the windrows. We do this by using our Haybuster hay-processing machine. This is the same machine we use for spreading mulch for revegetation projects.

Water

Water is added to the compost windrow via three different methods. First we may add water directly to the rows by pulling a water trailer along side and spraying water directly to the rows. Second, we can add and mix water to our wood shavings and wood chips before applying the material to the rows. Third, we can add water directly into the row as we are mixing it with our compost turner. We have added a devise to our compost turner that attaches directly to the water trailer which allows the water to be added to the compost as it is being turned which ensures a uniform and thorough coverage.

Temperature

Once all the ingredients are added and blended into the windrows we monitor the temperature of the compost. Temperature monitoring is extremely important because the temperatures tell us when to turn the compost. We maintain a 140° to 150° F temperature in our compost for three or more days at a time because at this range most weed seeds and pathogens are destroyed. When the temperature falls below 140° we will turn the windrow. If the temperature rises above 150° we will turn the row because this high of temperature could start to destroy critical microbial populations needed for composting. Each time the compost is turned the material is pulverized, blended, and most importantly "fluffed", which allows oxygen into the rows, which is necessary for microbial life and reproduction. Composting is complete when the temperature will no longer elevate to the 140° to 150° range with ideal conditions. Once the compost is complete it becomes very stable. That is, it does not change or leach away. At this point we take the compost from the windrows and stockpile it until it is sold.

We personally deliver and spread our compost material with Morhlang spreader trucks that are typically used in farming to spread livestock manure. These trucks have moving chain floors that carry the compost material to the back of the truck box. The material then passes through beaters, which spread the material. The trucks can be used to stockpile compost, or spread compost at variable rates instructed by our customers.

In our farming, cattle feeding, composting and revegetation operations, equipment is perhaps our largest expense. Fortunately, much of the same equipment can be used for each of these operations which dramatically helps spread out the cost.

AERIAL APPLICATIONS AND RESULTS

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ABSTRACT

Western States Reclamation Inc. (WSRI) has completed several aerial revegetation projects in remote mountainous areas where rubber-tired and track equipment could not be utilized. Five of these aerial projects involved the use of helicopters and one involved the use of 802 Air Tractor airplanes. The five projects completed using helicopters consisted of four natural gas pipe lines, two located in Colorado, one in Idaho, and one in Oregon, as well as a water line located near Nederland, Colorado. The aerial revegetation project completed with Air Tractor airplanes was part of the Los Alamos Cerro Grande National Forest burn area and aerial revegetation efforts. Cerro Grande National Forests burn and aerial revegetation efforts are now being considered potentially the largest aerial revegetation project ever completed in the United States. This presentation focuses on materials and methods used for all aerial revegetation projects. Also, the presentation will provide general revegetation results during the first growing season after aerial applications.

INTRODUCTION

In many cases aerial applications of seed fertilizer and mulch material can offer an economic method of completing revegetation projects in remote areas where use of track and rubber-tired equipment is not feasible. However, the lack of industry wide quantitative research coupled with Western States mixed results on past projects while comparing aerial applications to more conventional methods of revegetation make it difficult to document the success and cost effectiveness of aerial applications. It has become apparent to WSRI that the season of planting, variable slope conditions, variable soil types, and differences in seed and mulch materials utilized result in variable revegetation successes among aerial applications.

LOS ALAMOS - CERRO GRANDE FIRE AERIAL REVEGATION EFFORTS

WSRI was contracted to perform a hydro-seeding/mulching operation on slopes (>60%) to speed up environmental recovery of severely burned areas to reduce erosion. The result of this project is from the Cerro Grande fire in Los Alamos, New Mexico area. Burned areas occurred in the summer of 2000.

WSRI began mobilization in the Los Alamos area on June 27, 2000. The Los Alamos airport was selected to stage the aerial hydro-seeding operation. The Los Alamos airport is centrally located to the main bid of 1200 acres on the Forest Service land, Alternate A of 145 acres on the Los Alamos National Laboratory (LANL), and Alternate B of 100 acres on the Santa Clara Reservation land.

Reclamation operations began on July 1, 2000 and completed on July 28, 2000. In the completion of this project, 1200 acres of Forest Service land and 100 acres of Santa Clara land were treated per acre with:

- 900 to 1000 pounds of hydro mulch
- 30 pounds of long fibers
- 60 pounds of Guar tackifier
- 100 pounds of urea fertilizer
- 21 pounds of seed containing Cereal Rye, Mountain Brome, and Slender Wheatgrass

On LANL land 145 acres were completed with a per acre rate of:

- 1800 pounds to 2000 pounds of hydro mulch
- 150 pounds of Plantago tackifier
- 40 pounds of Guar tackifier
- 100 pounds of urea fertilizer
- 50 pounds of seed containing Barley, Mountain Brome, and Slender Wheatgrass

WSRI utilized several material vendors and equipment to execute this project in a professional and timely manner. To complete this project WSRI contracted Aero Tech, Inc. to perform ground crew support and aerial placement of material on to the areas to be treated.

Due to the intense schedule of this project no single material vendor was able to supply all the material. Contracting Officer's Representatives, were made aware of WSRI's need to utilize three types of hydromulch; Turbo, Mat Fiber, and American Excelsior II. LANL supplied a fourth brand for the project, Conwed mulch.

WSRI utilized four Finn T-330 3000 gallon hydro-mulcher units, for the mixing and transfer of the homogenous slurry of materials. The slurry was pumped in to (4) 802 Air Tractor airplanes, which were supplied by Aero-Tech, The slurry was then applied from a bottom drop gate on the airplanes.

The T-330 Hydromulcher units were mixed to full capacity of 3000 gallons, while the 802 Air Tractor planes were filled with 750 gallons of material.

The mapping of completed areas was with an onboard positioning system (SATLOC) was used in each of the four airplanes. SATLOC enabled WSRI and Aero Tech to have an accurate placement of material and a map of material placement.

Throughout the project mixing ratios of material and water varied in order to achieve a homogenous mix compatible with the mixing units and airplanes. This affected airplane loads per acre but no material quantities per acre.

Mobilization in to the Los Alamos area began on June 28, 2000, two days after WSRI was notified by fax that we had been awarded the contract. At the start of operations one filling station with two T-330 units was started up. On July 3, 2000, station two with two additional units was brought on line. On the 3rd of July after station two was online WSRI and Aero Tech combined had a total of twenty-three people to run daily operations on site. Colby Reid of WSRI was project superintendent; Aero Tech employed four pilots on site along with two ground to air tracking personnel.

On July 1, 2000 WSRI was able to start the application of materials on Alternate A area. Alternate A was completed o the 5th of July. Also on the 5th of July the base bid was started on the Forest Service Land,

and was completed on the 28th of July. In concurrence with the main bid Alternate B was done in the most part with one of the four 802 planes, this took place from July 21, 2000 to the 27th of July.

After one growing season the Forest Service feels there are mixed results for aerial revegetation efforts compared to ground based revegetation efforts. The ground based efforts were on significantly less steep slopes than aerial applications and consisted of hand seeding and hand straw mulching at a rate of 2 tons per acre. From WSRI's perspective, there were areas of limited growth as well as areas of fair growth. There was strong evidence that the numerous areas eroded, resulting in seed washing up against straw wattles and log dikes. Forest Service Personnel official called this effect the field of ribbons, since the grass was growing in long narrow strips.

All revegetated areas (aerial vs. hand applications) were impacted by very high soil temperatures after the burn (1200°F and above). WSRI compares the ground based revegetated efforts completed by others to the aerial applications completed by WSRI in the following way.

The ground based efforts were on less steep slopes, straw mulch was used at 2 tons per acre as compared to 1,000 lbs (1/2 ton) of hydromulch per acre. The straw mulch could have better cooled the soil surface than the limited amount of hydromulch specified by the Forest Service.

From WSRI's perspective, it is not feasible to compare steep slope aerial applications to ground based revegetation efforts. It would be beneficial to evaluate the economic feasibility of an aerial straw mulch application process. Given the steepness of the terrain and remote locations of the aerial efforts, no other methods could have been employed on this portion of the project. In general, there was better control over seed and mulch placement on ground based hand revegetation efforts than on aerial efforts.

TABLE MOUNTAIN NATURAL GAS PIPELINE (NEAR GOLDEN COLO.)

This project consisted of several different areas, slopes, and aspects. Both aerial, rubber-tired equipment, and hand labor were used for specific revegetation treatments. An aerial application of Bonded Fiber Matrix (BFM) was placed at the top of a two dimensional slope area which predominately faced east. The aerial application of BFM was on a higher elevation of the pipeline than the installation of an erosion control blanket consisting of straw coconut fibers. Both areas were hand seeded with a mixture of native grasses and forbs prior to the application of BFM and erosion control blankets respectively. A Bell Long Ranger Helicopter was utilized with a gas over hydraulic motor propelled slurry bucket (Isolair Dryslinger II 150 gallon/25 cubic ft. 11 Horsepower gas/electric start). A combination landing zone/loading zone was established on the top of South Table Mountain. The helicopter slurry bucket was filled at the landing zone after each cycle by use of a Finn 3000 gallon hydromulcher in tandem with a 5000 gallon water tank. This procedure allowed for continuous mixing of the BFM, since delays with the helicopter were costly and had to be avoided. The coverage from the helicopter slurry bucket combination was as good as that applied from an actual hydromulcher truck. This was due largely because of the skill of the pilot utilized in the aerial BFM application.

While the canopy cover of grasses and forbs at the end of the first growing season is very comparable between the aerial BFM application and the erosion control blanket, the soil conditions under the BFM were reported by WSRI to be poorer than that existing under the erosion control blanket. Thus, WSRI considered this aerial application to be successful.

VAIL REINFORCEMENT NATURAL GAS PIPELINE

During the early 90's WSRI completed a natural gas revegetation project which consisted of a flat bench area where hand seeding and machine mulching were completed as well as a remote section of the flat bench area and a steep two dimensional slope area where aerial applications of seed, organic fertilizer and straw mulch were applied. Hand raking of seed and organic fertilizer were completed on flatter areas, no hand raking of seed and organic fertilizer were completed on those areas utilizing helicopter aerial applications. The project was completed during late October. Snowfall occurred shortly after all aerial seeding and mulching efforts were completed. Canopy cover and density of native grass and forbs species were comparable on bench areas completed by aerial applications as to those completed with hand broadcast seeding methods. Canopy cover and density of native grasses and forbs on the steep two dimensional sloped area, were less than the flat bench areas, but still quite impressive at the end of the first growing season. The project site was heavily utilized by elk. To WSRI personnel's surprise, the elks hoof prints actually aided in better seed to soil contact as compared to other areas not impacted by elk traffic. Hoof impressions formed, a water retention basin aiding in the germination and growth of native grasses species as compared to adjacent revegetation sites. WSRI felt that snowfall which occurred immediately after the revegetation efforts were complete, aided in keeping the straw mulch in place.

NORTHWEST PIPELINE EXPANSION AERIAL REVEGETATION EFFORTS (NEAR POCATELLO, IDAHO)

A helicopter aided in the seeding and mulching completed near Pocatello, Idaho on the Northwest Pipeline Expansion during the early 90's. This project was WSRI's first attempt at aerial seeding and hydromulching. Since installation of the natural gas pipeline was way behind schedule, government agencies were concerned that the completion of revegetation efforts before winter's conditions would cease operations. After WSRI personnel realized there was no feasible way to negotiate 60% slopes with up to 5 ft high water bars the decision was made to approach the client over the use of the helicopter to aid in aerial seeding and mulching. The company president David Chenoweth had previously heard of successful helicopter seeding efforts on mine sites owned and operated by his first employer, ARCO Coal Company.

A Bell Long Ranger Helicopter was employed from a firm located in Salt Lake City to apply seed and mulch on areas too steep and remote for conventional revegetation equipment. Seed was applied using a Meyer electronic broadcast spreader connected with cables below the helicopter and equipped with electronic controls inside the cockpit. The seed was applied at the rate of approximately 60 acres per hour.

Straw mulch was applied using a cargo net that could be partially opened to drop the mulch. A combination of small square straw bails weighing 65-75 pounds and large square bails weighing 1000 pounds were utilized for mulching. The lift capacity of the Bell Long Ranger was approximately 1000 pounds. Therefore, 12-15 small square bails or 1 large square bail could be utilized per cycle for mulching. Ground crews loaded the straw material into the large net, followed by the pilot flying to the revegetation site and hovering over the area approximately 25 feet in the air and dropping one side of the net. This procedure allowed mulching material to break and explode on impact covering a significant area with each cycle/drop. This process continued until the pilot had virtually all of the steep revegetation sites covered with mulch. The desired application rate was approximately 2 tons of straw per acre.

Initially, clumps and voids in the mulch coverage existed. Moderate winds over a several day period helped to reduce the clumps and fill ground voids with mulch material.

Obviously there was no feasible or cost-effective way to crimp or tack the mulch into place. WSRI benefited by a timely snowfall that covered the mulched area within a few days of the completion of the revegetation operation. The moisture from the snow helped mat down the straw during the winter months thus reducing removal of the mulch by high winds. The risk of broadcasting seeding without soil coverage was also of concern by WSRI personnel. However, visual inspection the next growing season indicated moderate to good germination of native grass species on areas aerially seeded as compared to areas flat enough to drill seed. It is speculated by WSRI personnel that the freeze/thaw cycle during the winter months helped to cover the seed with soil.

KLAMATH FALLS OREGON AERIAL REVEGETATION EFFORTS

After the completion of the aerial seeding and mulching project, the client contracted with WSRI to complete similar revegetation efforts on a segment of natural gas pipeline near Klamath Falls, Oregon. Once again aerial seeding & mulching were completed using a Bell Long Ranger Helicopter. Initially, the aerial revegetation efforts were to be completed in the fall of the year immediately after the completion of the Pocatello pipeline segment. However delays in the backfilling, grading, and clean-up activities by another contractor delayed WSRI from being given access to the site until May of the following year. The delayed spring revegetation, completion date, coupled with little or no precipitation for weeks after the project was completed, resulted in poor revegetation results.

LAKEWOOD PIPELINE PROJECT (NEAR NEDERLAND, COLO)

WSRI completed the Lakewood Pipeline Project several years ago. The waterline was installed in the Rainbow Lakes Region down through the Caribou Ranch directly above the town of Nederland. A small area of the waterline consisted on a narrow bench that had to be constructed in a steep banked canyon. Consequently the bench was positioned in the middle of the site which impeded access for revegetation efforts from both ends. A decision was made by WSRI, the project consultant and the City of Boulder, to hand seed and rake the bench area followed by utilizing a helicopter for aerial applications of Bonded Fiber Matrix (BFM). BFM was utilized for erosion control and protection of the seeded area based on its ability to adhere to rocky uneven terrain that existed on the bench site. It was decided that traditional erosion control blankets would probably not work because of the uneven surface area compounded by rocky sub soil conditions that would prohibit effective pinning of the erosion control blanket. The aerial BFM application was applied by using a Llama helicopter which has a greater lift capacity than a Bell Long Ranger Helicopter utilized by WSRI on previous aerial revegetation efforts. The aerial BFM efforts, while quite expensive represented what appeared to be the best alternative for erosion control and seed protection. The aerial revegetation efforts were considered by the City of Boulder and their environmental consultant to be very successful.

SUMMARY

Aerial applications of seed, fertilizer, hydromulch, bonded fiber matrix and hay/straw mulch can provide a viable alternative to traditional machine revegetation processes and hand labor in select cases. Following are some of the advantages when considering aerial applications for revegetation as compared to traditional methods:

- Cost effective alternative to hand seeding and mulching.
- Potentially the only viable revegetation process for extreme remote and steep slope disturbed sites.
- A quicker method of revegetation especially when time is of the essence and critical planting dates must be met.

POTENTIAL PITFALLS AND PROBLEMS WITH AERIAL REVEGETATION

- Cost prohibitive due to the lack of landing zone/loading sites in close proximity to revegetation sites. This is especially true of applications requiring numerous and long duration per cycle times for hydro mulch and bonded fiber matrix.
- Poor seed to soil contact if roughened soil conditions do not exist and spring planting dates must be utilized. (Especially in semi arid areas).

INVASIVE EXOTIC PLANT CONTROL - A DISCUSSION ON ALTERNATIVE LOW RISK METHODS

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ABSTRACT

Since the 1960's, when Rachel Carson wrote Silent Spring, the general public has had a stronger environmental awareness about the use of chemicals. For many years there has been increasing pressure on governmental agencies to reduce or eliminate the use of chemical herbicides, in particular in the war on weeds. This pressure can come from a variety of sources, such as citizens who suffer from sensitivities to chemicals or from environmental groups and/or government agencies concerned about the environmental effects of chemical herbicides.

The reduction of the use of toxic chemicals is a good thing; however, it is not an easy task. When picking alternatives to chemical pesticides, one must choose something that is safe, something that has no or low impact on the environment and is economically feasible. Further complicating the matter, is the fact that an alternative that works for one person may not be appropriate for another. Environmental factors such as elevation, climate and soil type may make a low risk method effective in one location but not another, and a low risk method that works on one invasive exotic plant may not work on another.

One of the most common mistakes made in choosing alternatives to chemicals is thinking that "organic" is always the answer. It is also important to know if the options you are choosing are truly effective. Get non-biased information before you commit your dollars and time to a new process. Sometimes it is better to consult with your local Cooperative Extension agent or university instead of the manufacturer who is selling the product. Companies that sell a low risk product have lots of good information and often research, but it is clearly biased towards the product they want to sell to you. There are some great machines that will kill your weeds using hot water or foam; however, be prepared to pay up to $30,000 for some of these tools. There are many alternatives to weed control, whether it be soil sterilization hot water treatment, foam, or even something like sugar, however do some research on the subject to make sure that the option you choose is right for you.

This presentation will discuss the various alternative methods available to control invasive exotic species and their effectiveness.

REGENERATING NITROGEN FERTILITY OF DRASTICALLY DISTURBED SOILS USING YARD WASTE COMPOST AMENDMENTS

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ABSTRACT

Reestablishment of plant communities on barren sites requires significant nitrogen (N) incorporation into living plant shoots and roots, surface mulch residues, microbial biomass, and decomposing soil organic matter. Because these biologically active components develop and accumulate through several seasons, a steady supply of N is needed to continue to regenerate these components during community reestablishment. This N can come from residual N in the soil or substrate, from biological N fixation or from atmospheric deposition. In areas that do not have these sources, the large N inputs that are needed can potentially be met with organic matter inputs such as yard waste composts. The study reported here utilized long-term, aerobic incubation chambers to estimate the N release from two topsoils, two associated subsoils and from various types of yard waste compost materials produced in California. The approximate amendment rates of compost materials required to regenerate adequate N fertility on drastically disturbed sites were then estimated by comparison of N yields from composts with those of the reference soil materials. Most compost materials approached the rate of N release of the high elevation soil by the end of the incubation period, but N release patterns in the initial periods were quite variable. Patterns of N release differ according to the type and production methods of the compost. Composts, as sampled in this study, may need to be amended with supplemental nutrient materials to compensate for these initial variations in N release. Amendment of compost or compost/amendment blends is expected to be able to regenerate many of the functions of the original topsoil material.

INTRODUCTION

Revegetation communities sequester significant amounts of nitrogen (N) into various biomass components as they regenerate. For example, the biologically active N (plant shoots, litter, roots and soil microbes) averaged over a number of grassland ecosystem types in the western United States was estimated at 296 kg/N/ha (Reeder and Sabey, 1987)(Table 1). In contrast, the N amendment used for revegetation of harsh, low N sites along roadways in California has been specified at 500 lb of 16-20-0 fertilizer, which is equivalent to 80 lb N/ac, or 90 kg N/ha. This rate is often decreased at revegetation sites in order to reduce rapid growth of invasive weeds. The long-term result is that much less N is available for plant community reestablishment than is needed for full regeneration of biologically active components, in comparison to these referenced grassland communities. This under-capitalization of soil N availability is viewed as a common cause of poor revegetation performance on drastically disturbed soils (sites at which topsoil horizons and biological materials have been completely removed or buried beyond the depth of root growth).

Table 1. Biologically active nitrogen (N) distribution in living or decomposable tissues of grassland ecosystems from the western United States and Canada (Reduced from Reeder and Sabey, 1987; see reference for methods). An average of 296 kg N/ha is incorporated into the biologically active components (standing live plant shoots, litter, roots and soil microbes) of these communities.

	N in Biomass (kg/ha)				**N in Soil (kg/ha)**	
Ecosystem Type	**Standing live**	**Litter**	**Roots**	**Soil microbes**	**Organic matter N**	**Mineral N**
Great Basin shrub-steppe SE. Washington	30	30	140	50	4,170	21
Desert grassland S. New Mexico	20	20	20	20	810	4
Shortgrass prairie NE. Colorado	30	90	240	50	5,500	28
Mixed-grass prairie SW. South Dakota	30	70	150	130	8,400	42
Mixed-grass prairie S. Saskatchewan	20	70	140	130	5,400	27

If nearly 300 kg N/ha needs to be incorporated into living or decomposable tissue at a revegetation site, how can this large nutrient load be delivered to plants that grow slowly and establish on a site over a several year period? If excessive amounts of N are available early in the establishment period, growth and invasion of weedy species may be encouraged. Insufficient N availability later in the establishment period, however, may limit full establishment of the plant community, and, if the plant canopy and surface mulch layers are not fully regenerated, the site may more susceptible to surface erosion. Data from the two right-hand columns of Table 1 provide examples from undisturbed soil systems. Typically, they contain large amounts of well stabilized, total soil organic matter N, but provide only a low percentage yield, or release rate, of mineral N. The large pools provide long-term capacity, and the low rate of N availability restrains weedy growth while supporting continued growth of perennial species.

A potential source of large volumes of slow-release, organically stabilized N is composted yard waste material, which is produced in large quantities by diversion from municipal landfill waste streams. These materials mimic several of the functions of the native soil organic matter that are missing from drastically disturbed sites, including maintenance of macropores for water infiltration, support of microbial activity for decomposition, and, of course, production of a slow, steady release of N through decomposition and mineralization of the organic materials. A state-wide survey of commercial and municipal compost producers in the state of California was conducted at the University of California, Davis to evaluate the resources that potentially would be available to the California Department of Transportation for large-scale use of composts for revegetation of drastically disturbed sites.

MATERIALS AND METHODS

Selection of compost materials

Twenty-three commercial and municipal compost producers located throughout the state of California were selected to evaluate the type of compost material that would be available for application on large scale revegetation projects. Producers were visited in December 1998 and January 1999. Four replicate samples were taken from "finished" windrow piles that were, according to the producer, "ready for sale." Additional details, including data on non-N nutrient analysis, are available in the High Altitude Revegetation Workshop Proceedings No. 14 (Claassen, 2000) or at the California Integrated Waste Management website, www.ciwmb.ca.gov/publications / select "Organics" then "Compost Demonstration Project, Placer County: Use of Compost and Co-Compost as a Primary Erosion Control Material (443-99-018)" (Claassen, 1999).

Several general categories of composted materials were collected that exemplify the range of processes used by compost producers in the state. A group that could be described as "minimally cured" composts are those that meet EPA 503 regulations, but have minimal curing time. The entire process from initial processing to sale is allowed less than 4 months time. Larger municipalities tend to shorten curing times to reduce holding and storage costs. The "YWC-1" plot on the graph represents this category. A second group that could be described as "typical compost materials" is represented by "YWC-2" and "YWC-3" plots. These materials are cured for various lengths of time, with "YWC-2" having about a 6 to 9 month process and "YWC-3" having an 18 month process. In this last case, the producer couldn't sell all the material because cool, wet weather reduced demand. The stockpile was held over another winter and sold the following season. The third category would be specialty composts, those that are carefully turned, cured, and held until they are well stabilized. The "YWC-4" plot is selected from this type of producer. Most yard waste composts in the state are similar to YWC-1 or YWC-2.

Nitrogen yields were also measured from biosolids materials that were bulked with yard waste materials, and are shown in the plots labeled co-composted materials (CCM) on the graph. CCM-1 is from a windrow compost process, while CCM-2 is from an intensive, bio-reactor system with frequent (daily) turning.

Selection of reference soil materials

Nitrogen yields from compost materials are compared to yields from a variety of topsoil and subsoil materials taken from field sites in California. The soils labeled with a "G" are from high elevation granitic soils in the Lake Tahoe Basin (2400 meters elevation). Soils labeled with a "S" are on sedimentary geological material in the Coast range north of San Francisco (300 m elevation). "GT" represents a well vegetated granitic topsoil (mountain big sage, Jeffrey pine, mule's ears), while "GS" represents a granitic subsoil material that is moderately well vegetated (intermediate wheatgrass, lupine). "ST" represents a sedimentary topsoil collected from beneath a dense perennial grass and scattered oak canopy. "SS" represents a sedimentary/siltstone subsoil material from a barren, newly constructed cutslope. "DG" represents the raw decomposed granite talus taken from a non-vegetated, actively eroding cutslope. Data are plotted as N mineralization (gm N/pot) with the DG matrix amounts subtracted from the compost yields.

Table 2. Carbon and nitrogen characteristics of incubated soils and composts

sample	material type	total N	total C	C/N	particle size (g kg^{-1})		
	wildland soils	(g kg^{-1})	(g kg^{-1})	(g kg^{-1})	sand	silt	clay
GT	granitic topsoil	1.17	28.24	24.18	890	80	40
GS	granitic subsoil	0.15	2.53	16.46	910	60	40
ST	sedimentary topsoil	2.14	31.84	14.88	430	320	260
SS	sedimentary subsoil	0.39	2.77	7.07	470	220	320
DG	decomposed granite	0.12	2.44	20.31			
	Yard waste composts						
YWC 1	yard waste	17.04	313.19	18.38			
YWC 2	yard waste	11.46	171.78	14.99			
YWC 3	yard waste	15.86	242.66	15.30			
YWC 4	yard waste	13.77	201.73	14.65			
	co-composts						
CCM 1	biosolids / yard waste	15.77	143.74	9.12			
CCM 2	biosolids / yard waste	29.13	346.02	11.88			

Nitrogen analysis methods

Nitrogen release from compost materials was measured by aerobic incubation (Stanford and Smith, 1972) in 500 mL PVC chambers with porous lysimeter extraction filters positioned in the bottom of the chamber. Chambers were maintained in aerated conditions at slightly less than field capacity at 30 °C. At various time intervals, extractant solutions were leached through the chambers and the leachate was measured for soluble ammonium and nitrate. Soluble N was measured by continuous flow, conductimetric analysis using a column of copper-coated zinc shavings to reduce nitrate to ammonium (Carlson, 1978, 1986). After the first few weeks, all leached N was in the nitrate form.

Composts were loaded into the incubation chambers at a uniform rate (based on chamber volume) equivalent to 500 kg total N/ha into a matrix of decomposed granite. Soils were mixed at a 50:50 ratio of soil to clean quartz sand in order to improve water flow and aeration and were loaded to the same volumes as the compost/DG mixtures.

RESULTS AND DISCUSSION

The plots of the granite topsoil (GT) and the sedimentary topsoil (ST) show cumulative net N mineralization from well vegetated field soil materials (Figure 1). The plot of the granite subsoil (GS) shows N mineralization from moderately vegetated field soil materials, while the sedimentary subsoil (SS) and decomposed granite (DG) plots show N mineralization from barren, non-vegetated substrates. The GT and SS soils yielded less than 5 percent of their total N content during the incubation period, while the ST samples mineralized approximately 11percent and the GS soil mineralized approximately 20 percent of its total N content. These higher rates are interpreted as reflecting the relative amount of soil organic matter that is not stabilized by clay films, aggregates, humic materials or mineral oxides and is therefore more "bio-available" during incubation. The interpretation of a relatively low 5 or 10 percent yield rate is that mineralization from these soils could potentially continue for many additional years, and would continue to support plant growth on the site.

When compost materials are loaded into the incubation chambers at a uniform N basis equivalent to 500 kg total N/ha, the mineralization yields of YWC-2, -3, and -4 roughly matched the N mineralization rate of the moderately well vegetated GS soil. A loading rate at twice that used in this study would approximately match the GT soils. The intensively cured YWC-4 shows the greatest rate of N mineralization later in the incubation, while the poorly cured, fibrous YWC-1 has the slowest release rate and has a negative N yield (immobilizes N) until 400 days of incubation. If these temperatures are assumed to approximately generate three times the biological activity as in field conditions, this would mean approximately a 3 year lag time before net mineralization would occur. This could be interpreted to be a benefit if the project needs a long lasting surface mulch or soil physical amendment to remediate compaction, but it would reduce plant available N if these composts were used as the sole soil nutrient amendment. On the other hand, low mineralization rates observed (less than 5 percent) suggest that reserve N in the amendment will not be quickly depleted and will be likely to continue for many additional years during plant community development. In this way, the large amounts of N needed for incorporation into the biologically active components of a plant/soil community can be steadily provided; ideally at the same rate that N is incorporated into the standing biomass of the community.

The amount of initial N release is equivalent to approximately 25 kg N/ha (YWC-2) and 15 kg N/ha (YWC-3), which are amounts that can be potentially taken up into plant biomass for establishment at field growth rates. The N mineralization rates from YWC-1 and YWC-4 are initially negative (less than the DG matrix material), indicating that they are immobilizing (incorporating into microbial biomass) all of their available N plus additional N from the surrounding soil. An interpretation of these data for water-shed scale impacts is that the mineralizable N yield from YWC materials will have minimal likelihood of producing excess N to the surrounding watersheds.

Rates of N mineralization from CCM materials match the GT material later in the incubation, and the total N yield is intermediate between the ST and GT materials. The large initial rapid release could easily result in N leaching losses to watersheds unless plant growth and uptake is very rapid. The break-point in the plots occurs at a release level of about 100 kg N/ha for CCM-1, which is a windrowed material, and about 75 kg N/ha for CCM-2, which is the more intensively composted and cured material. After this initial period of available N release, mineralization continues very similar rates to the soil materials and releases between 25 and 30 percent of the total N contained in the material. At this N release rate, only a few additional years of N release is expected to occur before the total N pool is depleted.

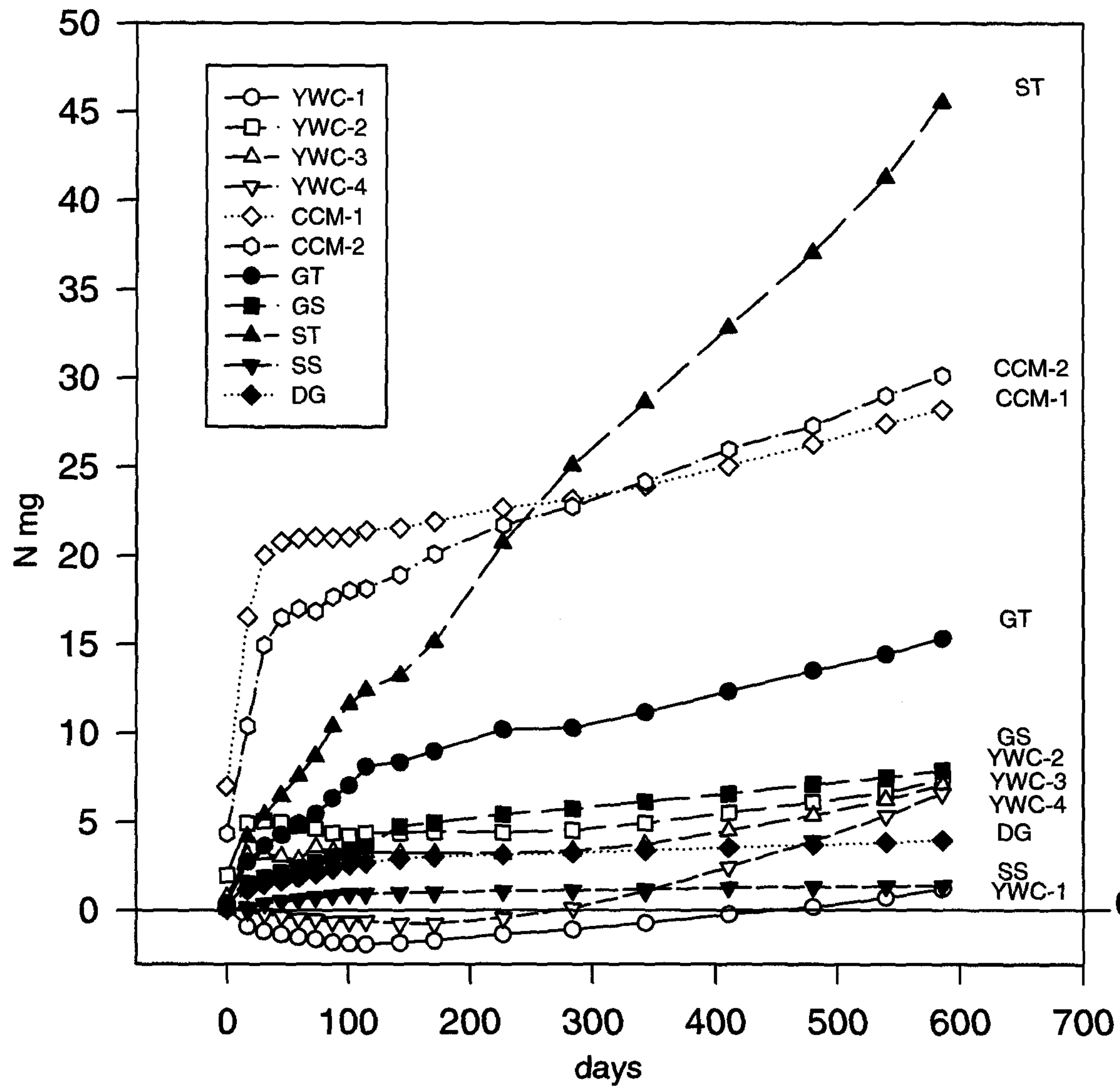

Figure 1. Nitrogen yield (N mg) over a 586 day aerobic incubation of field soils and amended substrates (net mineralization minus control substrate).

Key: Closed symbols indicate soil or substrate materials: well vegetated sedimentary topsoil (ST), well vegetated granite topsoil (GT), moderately vegetated granite subsoil (GS), non-vegetated decomposed granite (DG) and sedimentary subsoil (SS). Open symbols indicate yard waste compost materials (YWC-1 through YWC-4) and co-composted biosolids/ yardwaste blends (CCM-1, CCM-2). All compost materials were loaded at rates equivalent to 500 kg total N/ha.

CONCLUSIONS

Well cured yardwaste compost materials appear to be able to release N at rates similar to medium and low fertility topsoil materials. Appropriate loading rates corresponding to N release from soil materials appear to be approximately 1000 kg total N/ha. Initial periods of immobilization appear to occur for uncured or minimally cured composts. Net nitrogen mineralization rates of co-composted materials appear similar to measured soils in the later periods of the incubation, but sizable initial releases of available N may result in leaching losses to watersheds or excessive growth of weedy species. Net mineralizable N released during the incubation period was approximately 5 percent of the total N contained in the yard waste composts, in contrast to about 25 percent of the total N in the co-compost materials. These experimental data suggest that yard waste composts have the potential to continue to mineralize N for many years after application to field soils and may be appropriate for regenerating soil organic matter N levels on drastically disturbed sites.

ACKNOWLEDGEMENTS

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THE INDEPENDENCE PASS FOUNDATION – RESTORING AN ECOSYSTEM THROUGH PARTNERSHIPS

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The Independence Pass Foundation (IPF) is a private, non-profit foundation based in Aspen, Colorado. Founded in 1989, the mission of the Independence Pass Foundation is to foster and promote the environmental quality, natural beauty and safety of the Independence Pass area. The Foundation plans, funds and supervises stabilization projects along Highway 82; sponsors and organizes reclamation and revegetation projects; promotes recreational improvements that foster user safety and reduce environmental impacts; undertakes educational programs to broaden understanding of the Independence Pass environment; and lobbies for funding and programs that support those activities. IPF is managed by a 12-person volunteer Board of Directors, which sets policy, prioritizes projects, and takes an active role in planning Foundation activities. The Foundation also employs an Executive Director to plan and supervise projects and a Development Director to carry out fundraising and public outreach activities.

Independence Pass is the location of Colorado State Highway 82, which traverses the Continental Divide over the Pass between the Arkansas Valley and the Roaring Fork Valley. Road cuts associated the road have led to severe erosion in a number of locations along the Pass, erosion which threatens riparian and wildlife habitat, water quality and traveler safety. IPF has led the effort to preserve the environmental integrity of Independence Pass and to halt and reverse the degradation of the Pass caused by human activities. The Foundation also organizes regular meetings of the Independence Pass Restoration Team, a multi-agency, inter-disciplinary group that brings together the Foundation's partners to plan projects in a cooperative and coordinated fashion. The Foundation is funded by private donations, government and private grants and public fundraising activities. Much of the Foundation's work, including plantings, terrace construction and other projects are carried out by volunteers and by inmate work crews from the nearby Buena Vista Correctional Facility. See Table 1 for lists of planted/seeded species.

The Foundation has carried out a multi-faceted reclamation and revegetation program focused on reclaiming eroded and degraded roadside areas adjacent to Highway 82. The various aspects of the Foundation's projects can be summarized as follows:

TOP CUT STABILIZATION

The Top Cut refers to about 1.5 miles of roadway just west of the summit of the Pass. The Top Cut is the site of the most severe erosion problems on the Pass. In this location, road cuts have destabilized the poorly consolidated rock which underlies the thin layer of topsoil. Road cuts have raveled uphill over the years, creating large areas of active erosion above the road. Eroded material which was deposited on the road was simply dumped over the downhill side of the road for many years, leading to loss of native vegetation below the road. One of IPF's primary missions is to halt and reverse the erosive process above the road that is contributing to loss of rare tundra vegetation and scenic quality. IPF works regularly with the Colorado Department of Transportation (CDOT) to plan and carry out stabilization projects in cooperation with CDOT's maintenance department. IPF is currently engaged in a major effort to fund a five-year, $1.5 million program aimed at completing stabilization and reclamation projects at the Top Cut.

Top Cut stabilization consists of the following elements:

- **Construction of rock retaining walls at the base of eroding slopes to halt ongoing erosion at the base of raveling slopes.** These rock walls are designed and constructed according the specifications developed by the Colorado Geological Survey. The walls consist of a boulder rock face and layers of compacted fill soil interspersed with sheets of geotextile reinforcement to lend the fill structural integrity. These are referred to as MSE (Mechanically Stabilized Earth) Walls and have been constructed in three separate locations on the Top Cut.

- **Rock scaling and bolting.** Loose rocks have been scaled from slopes above the road and unstable rock formations have been bolted to mitigate rockfall hazards and to create slope surfaces where revegetation might have a chance of success.

- **Installation of erosion-control blankets.** Erosion control blankets made of various materials have been installed above the road to further retard erosive activity. Wire-mesh blankets were draped over slopes to keep larger rocks from migrating downhill and onto the road while denser plastic/coconut fiber blankets have been installed to hold fine-grained material in place along the tundra edge.

- **Slope reconstruction and revegetation.** Slopes above the MSE walls described above are rebuilt to provide a site for installation of native grasses, wildflowers and trees.

In 2001, the Foundation partnered with the Colorado Department of Transportation (CDOT) to carry out a major rockfall stabilization and erosion control project. The Foundation provided partial funding for the project, which included wire mesh installation at the Big Cut, one of IPF's high priority work areas. In addition, CDOT installed wire mesh, rock bolts, and shotcrete to reduce rockfall hazard. This project required early closure of the Pass to through traffic, but the project was completed ahead of schedule and under budget due to the skill of the contractor and mild fall weather. It is this kind of cooperative project that makes it possible for IPF to leverage it modest annual budget to accomplish major improvements along the Pass. Since the Pass is a seasonal road, it is difficult to CDOT to provide significant funding or resources given their responsibilities for more heavily-traveled year-round highways. Thus IPF has taken on the task of improving and maintaining this uniquely beautiful and heavily-used area.

PLANTING TERRACES CONSTRUCTION

Since 1997 IPF has built 34 planting terraces on the slopes below the Top Cut. These terraces, built from logs and boulders found on the site, provide a planting site for native vegetation. The terraces are anchored at right angles to the slope and filled-in with topsoil and fertilizer. Previously-built terraces were found to be degraded by gravel migrating downhill and accumulating on the terraces, sometimes choking out plants. To address this problem, turf reinforcement matting was installed above the new terraces to stabilize the uphill areas. Matting has also been installed below the terraces and in several other locations too steep for terrace construction. The terraces and the matting planted with nursery stock supplied by the Pleasant Avenue Nursery in Buena Vista and the Colorado State Forest Service in Fort Collins. Labor crews from the Buena Vista Correctional Facility provided the manpower for this difficult project. Since 1997, IPF has installed about 8,000 square feet of matting and over 2,500 plants. Survival rates are good, averaging about 75 percent per terrace, but we still have a long way to go to recreate a self-sustaining native plant community below the road.

TREE PLANTING

IPF has planted around 2,500 seedling trees at various locations along the Pass. Many of these trees were planted at the student and volunteer planting areas along Highway 82, but the vast majority were planted on the slopes below the Top Cut. Planting was done by inmate labor crews volunteers from America's Adventures Camps and local school groups. Tree varieties included Englemann Spruce, Lodgepole Pine, Subalpine Fir, and Quaking Aspen. Recently the proportion of Lodgepole Pine plantings has increased because they are very hardy and seem to thrive on our highly-exposes planting sites. IPF has used 50 boxes (1,000 quarts) of Dri-Water time-release water. This water in gel form (made up of non-chemical cellulose and alum) serves as a plant-specific watering system for up to 90 days after planting. It helps the seedlings get established and the packaging biodegrades after the gel is gone.

OTHER PROJECTS

The Foundation carries out smaller projects every year utilizing the assistance of many volunteers, part-time employees and inmate work crews from the Buena Vista Correctional Facility. These projects included trail planning and improvements, reclamation of old construction sites and roadside areas, grass seeding, planting, recreational site improvements, signage and general monitoring of environmental conditions.

Table 1. List of plant materials installed in 2002.

Species Planted	Number of Individuals Planted
Engelmann Spruce Seedlings	420
Subalpine Fir Seedlings	420
Lodgepole Pine Seedlings	510
Quaking Aspen Seedlings	210
Total Tree Seedlings	1,560
Engelmann Spuce (4-foot stock)	3
Miscellaneous Native Shrubs[1]	108
Miscellaneous Native Wildflowers[2]	412
Miscellaneous Hardy Grasses[3]	180
Total Shrubs, Trees, Wildflowers and Grasses	700
Plus approx. 60 lbs. of Native Grass/Forb Seed[4]	

[1] Native shrubs include: Bog birch *(Betula glandulosa)*, native willow *(Salix brachycarpa)*

[2] Native wildflowers include: Fremont senecio *(Senecio fremontii)*, pinnate-leaf erigeron *(Erigeron pinnatisectus)*, alpine sorrel *(Oxyria digyna)*, purple fringe *(Phacelia sericea)*, golden aster *(Heterotheca villosa)*, alpine sunflower *(Hymenoxis grandiflora)*, Hall's Penstemon *(Penstemon hallii)*, pussytoes *(Antennaria alpina)*, and golden ragwort *(Senecio atratus)*

[3] Native grasses include: Tufted hairgrass *(Deschampsia caespitosa)* and Canada reedgrass *(Calamagrostis canadensis)*

[4] Grass/Forb Seed Mix: Western yarrow *(Achillea lanulosa)*, black sedge *(Carax atrata)* popcorn sedge *(Carex microptera)*, sulfur paintbrush *(Castilleja sulphurea)* tufted hairgrass *(Deschampsia caespitosa)*, alpine fescue *(Festuca brachyphylla)*, dusky beardtongue *(Penstemon whippleanus)*, alpine timothy *(Phleum alpinum)*, and alpine bluegrass *(Poa alpina)*

AN INTERPRETATION OF THE NEW DEPARTMENT OF THE INTERIOR POLICY TOWARD BURNED AREA EMERGENCY STABILIZATION AND REHABILITATION.

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ABSTRACT

For the past two years, an interdepartmental adhoc committee has been developing a policy relating to the uniform application of emergency stabilization and rehabilitation treatments following wildland fire. The Burned Area Emergency Stabilization and Rehabilitation (ESR) policy provides for the emergency stabilization of critical cultural and natural resources and infrastructure immediately following a wildland fire. A review of the policy and its nuances will be presented in poster format.

AN INTERDISCIPLINARY APPROACH TO TREATING FIRE SUPPRESSION IMPACTS AND FIRE EFFECTS TO NATURAL AND CULTURAL RESOURCES

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ABSTRACT

Prior to 1994, the Department of the Interior did very little to address the fire effects to cultural and natural resources. In 1994, the first Department of the Interior Burned Area Emergency Rehabilitation (BAER) Team responded to a fire for the purposes of assessing the emergency stabilization and rehabilitation needs of natural, cultural, and infrastructural resources as a result of fire suppression activities and the effects of fire. The objective of emergency rehabilitation is to protect human life, property, and critical cultural and natural resources. Within ten days of control of a fire the Agency Administrator is handed a BAER Plan that documents the fire suppression impacts and the fire effects to critical natural and cultural resources and the agency's infrastructure. The BAER Plan identifies personnel and equipment needs to rehabilitate suppression impacts. The BAER Plan identifies emergency, short-term watershed treatments necessary for the protection of life and property and the long-term monitoring requirements for threatened and endangered species as well as the protection of critical cultural resources. The BAER Plan includes a cost package, which identifies the funding necessary to carry out the treatment specifications. The Agency Administrator then uses the BAER Plan as a justification for a funding request, which is reviewed and acted upon within seven days. Today there are two DOI BAER Teams; each team is an interdisciplinary-interagency team made up of eleven members. Within the past seven years the teams have produced over 50 plans recommending emergency rehabilitation treatments in excess of $300 million. The poster will demonstrate the interdisciplinary approach of BAER Plan preparation and implementation of the treatments.

FATE OF FALL-PLANTED BITTERBRUSH SEED AT MAYBELL COLORADO

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ABSTRACT

Approximately 50,000 acres of a nearly pure stand of bitterbrush, *(Purshia tridentata)*, near Maybell Colorado has burned in the past two decades. Attempts at reclaiming bitterbrush from seed on burned land have been largely ineffective. A research project funded by the Colorado Division of Wildlife Habitat Partnership Program was initiated in the fall of 2000 to determine the causes of seeding failures. Initial observations on seeds planted in the fall of 1999 indicated that insects such as wireworms and cutworms may have been responsible in part for seeding failures. Seeds planted November 2000 had germinated by early April 2001, with little impact from insect or other predators noted during the 2001 growing season. More than 90percent of those seedlings died during the summer from drought. Seeds treated with insecticide and fungicide/rodent repellent and untreated seeds were planted in seed caches on two dates (Oct 11 and Nov 15) in 2001. Samples taken on Nov 15 and Dec 19 showed that much of the seed planted on either date had already germinated. Two fungal pathogens, *Fusarium* sp., and *Rhizoctonia* sp. were isolated from germinated seed on both sample dates. Germinated seeds that were taken from frozen soil on Dec 19 resumed growth when placed under greenhouse conditions. Further sampling in the spring of 2002 will determine if fall germination of bitterbrush seeds and the presence of fungal pathogens affect their survivability.

INTRODUCTION

The rangeland west of Maybell, Colorado (Moffat County) was at one time the largest continuous stand of bitterbrush, *(Purshia tridentata)*, in North America. More than 50,000 acres of this stand has burned since 1980. Bitterbrush is a primary winter browse source for many large game mammals, including a large elk herd that winters in the area. Winter browse has been in short supply since the fires, and elk are increasingly moving to private lands, where they are causing considerable damage to pastures. The bitterbrush has not regenerated from seed on the burned lands. Several attempts at reseeding have resulted in failure. The causes of the failures are not well documented, and a research project was funded in 2001 to determine the fate of fall-seeded bitterbrush at Maybell.

Maybell Rangeland

The rangeland near Maybell is classified as 'Sandhills' range, within Land Resource Area 34. It is located at an elevation of 5900 to 6300 ft. The deep sandy soils are classified as Cotopaxi loamy sands. They vary from fine sandy loams in the swales to loamy fine sands on hills and upland areas. Annual precipitation is 12 to 15 inches, with about half of the total moisture falling as snow. The average annual temperature is 42° F. Winter temperatures are very cold, with numerous instances of -50° F recorded.

The site is dominated by bitterbrush in unburned areas. Other shrubs associated with bitterbrush are big and silver sagebrush, gray horsebrush, and low and rubber rabbitbrush. These shrubs now dominate the burned areas. The principal grasses are Indian ricegrass, needle and thread, sand dropseed and Sandberg bluegrass. Cheatgrass is a dominant weed in burned areas. Conspicuous forbs are hairy golden aster, buckwheat, lupine, loco, arrowleaf balsamroot, yarrow, wormwood, death camas, scarlet globemallow, crypthantha, evening primrose and daisy fleabane.

FALL PLANTING STUDIES - 2000 AND 2001

Fall 2000 Study

A simple non-replicated fall seeding trial was planted in the fall of 2000 with the intention of observing seed fate and seedling behavior to use as a basis for more detailed studies in the fall of 2001. The studies were planted in two wildlife exclosures (referred to as 'Windmill' and 'North') located approximately five miles west of Maybell. Two hundred seeds were planted in each of two 10-foot long strips at each site. One strip was planted with seed treated with Gaucho 480 FS (2 oz/cwt) and Thiram 42-S (5 oz/cwt) and the other strip was planted with untreated seed. The Gaucho 480 FS is an insecticide intended to control soil-inhabiting insects such as wireworms and white grubs and above ground insect pests such as cutworms. The Thiram 42-S is primarily used as a fungicide, but also has rodent repellent characteristics when applied at high rates. The rate used in this study is recommended to repel rodents. The strips were planted on November 7, 2000. There were approximately three inches of snow on the ground at the planting, but the soils were not yet freezing. There was nearly continuous snow cover throughout the winter after planting.

The plots were visited on April 4, 2001, at which time many seedlings were observed. One foot of row in each strip was dug, and seeds recovered and inspected. Germination was calculated to be 79percent. The plots were visited several times during the spring and summer. Most seedlings had emerged by mid April. A slight amount of insect and rodent feeding was observed on the seedlings throughout the spring, but the amount was insignificant. Feeding damage was observed in both treated and untreated strips.

Many natural bitterbrush seedlings were observed in the area during the spring of 2001. Virtually all seedlings observed appeared to be from rodent seed caches. The number of seedlings per cache varied from seven to thirty. The seed caches were most easily found along the sandy edges of roadways near mature bitterbrush stands. No caches were observed more than thirty feet from mature bitterbrush stands. This is probably due to the limited range of the rodents responsible for burying the seed. There was a slight amount of insect and rodent feeding damage on natural seedlings, but it was rare.

Northwest Colorado suffered from severe drought during the summer of 2001. Most natural seedlings and those in the fall-seeded strips had died from lack of water by early August. Only a few seedlings in the planted strips showed any green leaf material in the fall of 2001.

Fall 2001 Study

The same two wildlife exclosures used in 2000 were used again in 2001. The 2001 experiment was a replicated three factor (planting date, seed treatment, location) randomized complete block design with four replications. All seeds were planted in 10 seed caches. The two planting dates were October 11 and November 15, 2001. The seed treatments were the same as used in 2000: Gaucho 480 FS (2 oz/cwt) and Thiram 42-S (5 oz/cwt) or untreated. Twenty-five caches of each treatment were planted in each replication. Five randomly chosen caches were dug on each sample date to determine seed fate. The October 11 sample date was sampled on November 15, the day the second planting date was seeded. Both planting dates were sampled on December 19, 2001. Only one replication per location was sampled on that date because of snow and frozen soils. Data from the November 15 sample date was subjected to analysis of variance. Final sampling of the plots will occur in April 2002.

- Data from fall 2001 sampling is displayed in Table 1. The major findings are summarized:
- Most seed planted on October 11 had germinated by the November 15 sample date.
- Seed planted on November 15 had begun the germination process at one site by the December 19 sample date. The other site appeared to be drier, and germination was not observed.
- Seed treatments enhanced germination slightly. The appeared to give some protection against seed predators and soil borne pathogens.
- Recovery of seed was at very low levels for the November 15 planting date at one site.

Table 1. Percent seed recovery and germination for fall 2001 planted bitterbrush seed on two sample dates. Damaged seed was counted on the November 15 sample date only. Seed was considered damaged if it showed physical injury from insect or rodent feeding, or had fungal growth and appeared rotten. Only one replication was sampled on December 19, so there was no statistical analysis of data from that sample date. Means followed by different upper or lower case letters are not significantly different (P=0.10).

	Windmill Site		North Site		Combined Sites		
	Treated	Untreated	Treated	Untreated	Treated	Untreated	P-Value
	Planted October 11, Sampled November 15, 2001						
% Recovery	65	65	80	60.5	72.5	62.8	NS
% Germination	86.8	79.9	77.6	63.2	82.2 a	71.6 b	0.078
% Damaged seed	4.7	7.3	3.4	10.7	4.1 A	9.0 B	0.066
	Planted October 11, Sampled December 19, 2001						
% Recovery	54	78	60	38	57	58	
% Germination	100	84.6	96.7	89.4	98.4	87	
	Planted November 15, Sampled December 19, 2001						
% Recovery	90	94	20	4	55	49	
% Germination	10	29.8	0	0	5	14.9	

Insect Seed Predators

Several adult ground beetles (Coleoptera: Carabidae) were found during 2001 sample dates. Several of the ground beetles are seed predators, but it is not known which species of seed they were utilizing. White grub larvae (Coleoptera: Scarabidae: *Phyllophaga* sp.) were collected in soil samples in the fall of 2001, and many adult June beetles were collected during other visits. Insect seed predation appeared to be of little significance to seedling establishment. All specimens are deposited in the insect collection at the Western Colorado Research Center at Fruita.

Plant Pathogens

Two fungal pathogens were recovered from germinated seeds in the fall of 2001. They were cultured and identified as *Fusarium* sp. and *Rhizoctonia* sp. Two *Rhizoctonia* isolates were identified. One produces white mycelia, and produced sclerotia after two weeks of growth on PDA media. This is the most common isolate. A second *Rhizoctonia* isolate produced brown mycelia, but had not produced sclerotia in culture. Both *Rhizoctonia* isolates were recovered from seed samples on December 19, 2001, from both 2001 planting dates.

Two *Fusarium* species were also present but not frequently isolated. One isolate produced a carmine red colony with brown cottony mycelia (slow growth) and was present in samples from both planting dates. The second *Fusarium* species produces very light pink to yellow colonies and was present in the sample from the November 15 planting date.

The Thiram fungicide appeared to have some impact on protecting seedlings after emergence. Seed collected on the December 19 sample date was grown out in the greenhouse, and damping off symptoms were more common on untreated seed than treated seed.

CONCLUSIONS AND RECOMMENDATIONS

- Fall plantings are not necessarily dormant plantings. Soil temperatures and seed dormancy characteristics are probably more important than planting date in determining fall dormancy.

- Seed that has been in storage for a number of years loses dormancy and chilling requirements for germination. If a fall dormant seeding is desired, the use of freshly collected seed may be required.

- The role of seed treatments as an aid in seedling establishment will be more fully known after the spring 2002 sampling.

ACKNOWLEDGMENTS

This research was funded by a grant from the Colorado Division of Wildlife Habitat Partnership Program. Melissa Foley assisted with all aspects of planting and sampling.

NATIVE PLANTS FOR NATIONAL PARKS: A COOPERATIVE PLANT MATERIALS PROGRAM BETWEEN THE USDI - NATIONAL PARK SERVICE AND THE USDA - NATURAL RESOURCES CONSERVATION SERVICE

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ABSTRACT

Since 1989, an interagency agreement between the National Park Service and the Natural Resources Conservation Service (NRCS) (formerly Soil Conservation Service) has led to an exchange of technical information, the development of indigenous plant materials, new seed/plant technologies and revegetation methodologies for park revegetation projects.

The program provides assistance to parks through NRCS Plant Materials Centers (PMCs) to identify plant species needed; collect and process native seed; provide high quality custom grown transplants and field production of native forb and grass seed from site specific collections; ensure genetic integrity; and provide technical assistance on site preparation, plant establishment, weed control, seed collection and processing.

In the past twelve years the program has assisted 31 national parks, under 105 project agreements with 12 PMCs. Approximately 29,000 pure live seed (PLS) pounds of indigenous native grass/forb seed and 740,000 transplants have been produced and provided. Over 800 native species or ecotypes have been tested and increased. Propagation protocols developed from the program research have been placed on an interagency website (http//nativeplantnetwork.org) for access by nurseries, seed producers and the general public.

NRCS PLANT MATERIALS CENTERS PROVIDE VEGETATIVE SOLUTIONS: VEGETATIVE AND TECHNOLOGICAL SOLUTIONS IN THE NORTHERN GREAT PLAINS AND ROCKY MOUNTAINS

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ABSTRACT

Many of today's environmental problems can be addressed through the use of plants. Current land management practices are highly complex involving holistic approaches to achieve good land health and environmental quality. The Natural Resources Conservation Service provides conservation planning and program administration to private landowners. Plant Materials Centers (PMCs), together with a multitude of partners, select plant materials and transfer technologies regarding their use. To date, about 475 cultivars and natural ecotypes of superior plants have been released. Most have been placed into the commercial seed and plant production industry with great success. Approximately 200 million dollars in revenues are generated annually from commercial seed sales. Today, 26 PMCs are conducting nearly 500 studies related to plant selection, propagation, establishment, and management. More than 90 percent of the plants tested are native species. Current technology development provides information for many environmental concerns, such as revegetation of disturbed areas and critical habitats; buffer strips; soil bioengineering; waste management; wetland and riparian area enhancement; windbreaks; prairie ecosystem restoration; and noxious/invasive plant suppression. On average, PMCs release 35 new grass, forb, and shrub cultivars/germplasms annually, including technology for their successful establishment for multiple land uses in the United States and potential use in other areas of the world.

SHEEP GRAZING ABOVE TIMBERLINE IN THE SAN JUAN NATIONAL FOREST

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ABSTRACT

The San Juan National Forest located in Southwestern Colorado covers 2,000,000 acres of land. There are over sixty mountains with elevations over 12,000 feet. All of this area is divided into domestic sheep grazing allotments except for the Needle Mountains, which are too treacherous and steep for grazing, and the Weminuche Wilderness in which part of the Needle Mountains lie. Approximately 10,000 sheep are brought into this area for three summer months on a rotational grazing plan. The area above timberline is of the most environmental concern, however, because potential damaging impacts can be severe and irreversible.

An area chosen to study impacts to the alpine ecosystem by sheep grazing was near Clear Lake on the north border of San Juan County. Clear Lake is located in a basin 1,000 feet below South Lookout Peak (13,357 feet). The area is useful because a natural rock barrier prevents sheep from reaching the west side of the lake. This provides a natural control area, giving a basis of comparison of environmental impacts between grazed and ungrazed areas.

Vegetation plot studies were done on an area inaccessible to domestic animals (Plot A) and on land that had been grazed (Plot B). Plot A was on the west end of Clear Lake, Plot B was on the northeast of the lake. There were no obvious differences in variables (topography, geological substratum and snow accumulation) between the plots. From the shores of the lake the land slopes gradually then becomes steeper as it reaches the summit of Lookout Peak. The plot studies were done approximately 60 feet from the shores of the lake on gradual inclines.

Results showed that plot A had a thick vegetative cover and was abundant in many alpine species. Plot A is accessible to wildlife from the ridge above but inaccessible on the sides. In contrast, Plot B showed greatly decreased vegetative cover in comparison to Plot A. Plot B contained pedestals or half-inch stubs of live plants or the roots of live plants. As the study was done in the latter part of August, it is unlikely that there would be much regrowth the next year because the buds of alpine plants are formed during the previous growing season, usually late in the growing season. Vegetation damage in Plot B was noted to be more severe as the land became steeper; and the topsoil was severely eroded, leaving bare rock in some places.

Results of this study and sheep grazing in the alpine zone are discussed in relation to potential impacts on plant and animal species and on various ecological processes. Mountainous land above timberline is a fragile environment. The growing season is short, from 40 to 75 days, and most of the plants are perennial. The topsoil is shallow and delicate because of steep slopes, and where eroded by even light grazing, the soil is easily removed by wind and water.

THE FIRST CONSTRUCTED WETLAND PERMITTED IN NEVADA AS A RESIDENTIAL SEWER EFFLUENT TREATMENT PLANT

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ABSTRACT

This poster presents a recently constructed wetland, which is serving as a residential sewer effluent plant. Rural areas along the Sierra front in western Nevada are beginning to have problems with bacteria showing up in domestic well water and this system may be a cost effective solution. This system presents the first application to the State of Nevada for a residential sewer effluent plant and a permit from the state was necessary before the county would issue a building permit for a resident in a 100-year floodplain. Beginning in the summer of 2002, water samples will be taken to a local lab to measure the system performance. Stay tuned.

INTRODUCTION

The following project is located in the Carson Valley four miles south of Gardnerville, Nevada. Parallel tributaries of the Carson River border this valley. Seasonal flooding and high water tables have limited the use of traditional leach fields and have required homeowners to construct expensive pressurized treatment systems that are typically raised earthen mounds. Also, in rural areas along the Sierra front, fecal coliform has been showing up in well water. In rural areas, public sewer installation is cost prohibitive and there are few other alternatives. We think this is a viable solution.

During a literature search, we found that several municipal constructed wetlands have been built including those in Arcata, California and Columbus, Ohio. These large systems move sewer effluent through riparian plant communities. Effluent nutrients are broken down and digested by the microbial communities and absorbed by the riparian plants. Extensive residential applications have been constructed for homes in the Central and Eastern U. S. with the assistance of the Tennessee Valley Authority. The TVA has over ten years of experience with residential systems and has published a booklet with their latest designs. Please see their report below.

We submitted the TVA design to the Nevada Department of Health and were issued a permit, which we submitted to the Douglas County Health Department. Historically, the building department has denied building permits to valley residents where leach field problems were at issue however; we were issued a building permit due to our constructed wetland permit.

PROJECT COSTS

The following costs were incurred:

Engineering/permitting		$3000
Physical construction		$11,300
Liner		$500
Plant materials		
	250 super cells 1.10/cell	$275
	1 lb seed supplied by owner	
	150 transplants supplied by owner	
	50 hrs labor supplied by owner	
		$18,075

This cost far exceeds the cost of a conventional leach field. However, the low-pressure earthen mound systems in our area are costing between $20,000 and $30,000. Also, the alternative proposed by our county commissioners, involving sewer installation to rural residents would exceed $20,000 per household. The more rural areas will exceed that amount. Liner prices vary widely. We received quotes from $500 to $3500 for the same 60-mil material.

The benefits are numerous, primarily the improvement in aquifer quality; habitat benefits to wildlife, and public education. Such passive effluent systems require no electricity and will not be vulnerable to blackouts and mechanical depreciation.

CONSTRUCTION DETAILS

The design of our system is fairly simple. It consists of two identical 400 square foot cells. The first cell is lined with a 60-mil liner and filled with gravel and riparian plants which receive the effluent from the septic tank. An unlined safety cell sits adjacent to the lined cell and six inches lower in elevation. The State required this cell. The septic tank is two-celled to assist in filtering solids for long-term maintenance of the wetland. The cells are connected by a manhole containing an adjustable standpipe that regulates the water level in the wet cell. We have set the pipe level such that there is never standing water in the wet cell. This eliminates problems with disease, vector, and odor. In fact, we walk on the surface occasionally to pull weeds and observe the plant material. The liner's edge is buried into a six-inch trench on the ridge around the cell to prevent erosion problems. Lastly, we filled both cells with 2-inch river rock around the perforated intakes followed by 18" of ¾ inch pebble.

We installed a water meter at the house to measure domestic consumption. The local utility told us that at 75 percent of water entering the house exits through the septic system. The monthly meter readings will give us a fairly accurate estimate of the wetland consumption. The system is designed for 360 to 650 gallons per day (gpd) assuming a rate of 120 gpd per bedroom with three bedrooms combined with our system being 80 percent larger than the design recommendations.

PLANT MATERIAL

We agreed to fill the wet cell with plants on a one-foot density. We accomplished this with a combination of super-cells from the Nevada Division of Forestry Nursery and transplants from the surrounding agricultural ditches. Last, we over-seeded with riparian species. The three groups are itemized below.

Super-cell species	From Nevada Division of Forestry Nursery
• *Carex simulata*	
• *Juncus balticus*	
• *Agrostis scabra*	
• *Carex rostrata*	
• *Scirpus pungens*	
Transplant species	From the adjacent drainage areas
• *Typha latifolia*	
• Miscellaneous turf communities	
Seed species	From various sources; sown after bark layer put down
• *Mimulus guttatus*	
• *Juncus balticus*	
• Annual flower blend	
• *Lolium multiflorum*	1 lb used as nurse-crop on interior berm in wet cell only
Exterior berms plant material/seed	
• *Eriogonum umbellatum*	300 super-cells
• *Eriogonum umbellatum*	1 lb seed
• *Hordeum vulgare*	2 lb used as nurse-crop on exterior berms of dry cell only

Since the transplants were installed on one-foot centers, we installed over 300 plants. The design cell size for a three-bedroom house is 220 square feet. However, we enlarged our cells to 400 square feet. Once installed, we added 3 inches of coarse bark mulch. We complimented the three hundred plants with a one-pound over-seeding using the above seed list. Lastly, we seeded and transplanted 300 *Eriogonum umbellatum* super-cells around the outer periphery of the cells. This area is raised and quite dry, thus we chose the Buckwheat. We decided to include a nurse crop experiment and we added 2 lbs of *Hordeum vulgare* to the dry cell berms. The decomposing granite that was used for the berms is highly erodible and we felt an urgency to obtain slope stability, thus the *Hordeum.*

IRRIGATION

The installation and seeding were complete by late August and we immediately installed a temporary irrigation system comprised of four rain-birds on a hose-bib timer. We set the time to run for five minutes an hour from 10 a.m. to 4 p.m. for two weeks.

PERFORMANCE

We began using the system in the fall of 2000 and had several concerns. Would the wetland perform without a mature plant community during the first winter or year? Would the system work at all during the winter with less vascular activity in the plants? With a dry winter, would the wetland contain sufficient effluent to maintain its growth? Would we meet water quality standards?

Aside from the water quality standards, the system seems to be working well. We are initiating water testing this summer and will begin a record. The plant material grew rapidly the first season, so much so that we chose to burn the wetland during the winter of 2001-2. Also, several wetland specialists have told us that even during the winter the system is performing. Even with reduced plant vascular activity, the microbial community is still busy digesting organic compounds.

We have not yet measured the plant community diversity but our initial feeling is that the super-cells were not necessary. The transplanted cattail and sod clumps dominate the obligate community in the basin while the annual rye and flowers dominated the slopes. The flush of annual flowers made the system quite aesthetic!

The nurse-crop barley was a disaster. It grew so dense that it provided a food source and shelter for field mice, which prohibited the growth of any preferable species. We burned both cells shortly after this discovery. We did not have the same rodent problem in the wet cell. Thus, very few of the *Eriogonum* super-cells survived on the dry cell berms while the wet cell has a much higher percent of survival.

During mid December, we had 12 inches of snow in two days that buried both cells. It melted off and percolated shortly thereafter. We were more concerned with the high water table during the irrigation season from April to August. Through the season in 2001, there would be standing water in the dry cell as the water table fluctuated on two-week cycles. However, the dry cell would always be empty within twenty-four hours after the irrigation cycle. The liner at this point became essential to isolate the wet cell from the groundwater. Some would argue that a properly performing wetland would not need a liner if the plants and microbes are actively cleansing the effluent and this may have some merit for well-drained uplands. Yet, I would not want to see contamination in areas with high water tables.

Our average water consumption over the first year has been 4000 gallons per month or a conservative 133 gallons per day for the house. We were initially concerned that the system would not receive enough water so we all took long lazy showers for a month. Once we witnessed the overwhelming growth of the vegetation we quit worrying about the wetland but our consumption has remained low.

CONCLUSION

This poster has led to several points

1) We are becoming confident that this system is performing well and the track record around the country looks positive as well.

2) If our current system is oversized and our water conservation is high, how small could these systems become and still properly function? The smaller size would be more adaptable to higher density residential development.

3) The peripheral benefits to habitat and ground water can be much broadened if we include the negative externalities associated with centralized waste water systems and their sheer cost. You be the judge.

4) We plan on building others and hope to venture away from the "grid" architecture.

5) Stay tuned; these types of projects do not begin and end, they grow.

PINE CREEK MINE RECLAMATION

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ABSTRACT

I am presenting this project today because issues were brought up during planning that involve species selection and the ongoing debate about natives, cultivars, and local genetic material. These issues have a common thread with most projects that we are involved with today and the final reclamation plan at each project has varied due to the philosophical outlook of the parties involved.

This project involved stabilizing 90 acres of historic tailings ponds. The tailings are located at the top of Pine Creek Canyon, which is located on the eastern front of the Sierras 15 miles northwest of Bishop California. Heavy winds and harsh winter conditions were continually sending sediments down the canyon. The United States Forest Service (USFS) reached an agreement with the current owner to stabilize these ponds by placing six inches of local alluvium on the ponds as a cap and seeding with a desired seed mix. Fortunately, the client analyzed the tailings and found them to be relatively benign and saturated with water. The alluvium was excavated from a historic barrow pit just east of the tailings. The cap was installed to leave a slight grade to the tailings and the seed blends were broadcast just prior to winter. Snow was falling during the last few days of seeding.

The USFS in Bishop California requested that the client arrange for a seed collection program that would supply the seed for this project. As with all projects, sufficient seed had to be supplied to cover 90 acres of reclaimed areas and this project required 19 PLS lbs per acre or 1710 PLS lbs. The USFS acknowledged that a priority ranking system would have to be applied to available seed such that if sufficient seed was not available of a given species, other local species could be used and additional seed may have to come from the closest available sources. Many of our current projects perform this ranking hoping to obtain the most local seed sources.

We agreed to collect as much local seed as possible but emphasized to the USFS that this priority should be balanced against our mutual desire to achieve physical stability at this site. Indeed, our goal at many such projects has been to harvest local species that exhibit aggressive colonizing behavior.

We have seen with several projects where the native philosophy has compromised the potential for the project to succeed by excluding species that would provide short-term physical stability. We have supplied seed blends that only contained highly dormant woody plants that could take years to germinate under natural conditions.

In sum, we agree with the USFS and others that we should emphasize native and local source material but we feel that flexibility is also necessary to satisfy short term success. In the end, we will continue to expand our inventory of early seral natives and hope to strike a good balance between these opposing goals without introducing aggressive species that may interrupt normal seral advance.

THE SEED BLENDS

Two seed blends were created, one for the tailings surfaces and the other for the sloped wind deposition dune areas. These slopes consisted of course unstable sand that typically presents our hardest challenge in reclamation. The parties agreed that we would design a separate seed blend for these areas that emphasized the most aggressive species.

Dune Stablization Blend

Species		PLS #/ACRE
Grasses		
Indian ricegrass	*Achnatherum hymenoides*	.15
Squirreltail bottlebrush	*Elymus elymoides*	1.30
Desert needlegrass	*Achnatherum speciosa*	.20
Shrubs		
Rabbitbrush rubber	*Chrysothamnus nauseousus*	.25
Desert bitterbrush	*Purshia glandulosa*	1.00
Basin sagebrush	*Artemisia tridentata tridentata*	.25
Forbs		
Giant blazing star	*Mentzelia laevicaulis*	.25
Buckwheat sulfur	*Eriogonum umbellatum*	.25
Louisiana sagebrush	*Artemisia ludoviciana*	1.00
Prickly poppy	*Argenome munita*	.50
Penstemon	*Penstemon speciosa*	.10
Nurse crop		
Cereal white oats	*Avena sativa*	5.00
	Total:	10.25

This was the final approved blend and the oats were applied as an experiment on 50% of the dune areas. The USFS would not allow any commercial source species such as slender wheatgrass, which is commonly used in the Lake Tahoe Basin as a short lived perennial nurse crop. Likewise, they did not allow any commercial source Indian ricegrass. We were fortunate to obtain the forbs, most of which exhibited aggressive colonizing behavior on the disturbed sights where we found them. This seeding rate represents 138 pure live seeds per square foot.

Standard Tailings Blend

Species		PLS #/ACRE
Grasses		
Indian ricegrass	*Achnatherum hymenoides*	.15
Bluegrass sandberg	*Poa secunda var. juncifolia*	2.50
Wildrye Great Basin	*Leymus cinereus*	4.00
Wildrye creeping	*Leymus triticoides*	1.25
Squirreltail bottlebrush	*Elymus elymoides*	1.30
Desert needlegrass	*Achnatherum speciosa*	.25
Shrubs		
Rabbitbrush rubber	*Chrysothamnus nauseousus*	.15
Desert bitterbrush	*Purshia glandulosa*	3.00
Basin sagebrush	*Artemisia tridentata tridentata*	.50
Bittercherry	*Prunus emarginata*	.25
Desert peach	*Prunus andersonii*	.65
Forbs		
Giant blazing star	*Mentzelia laevicaulis*	.10
Buckwheat sulfur	*Eriogonum umbellatum*	.30
Buckwheat nakedstem	*Eriogonum nudum*	.08
Buckwheat flat-top	*Eriogonum fasciculatum*	.10
Louisiana sagebrush	*Artemisia ludoviciana*	.45
Prickly poppy	*Argenome munita*	.20
Penstemon	*Penstemon speciosa*	.10
Dusty maidens	*Chaenactis douglasii*	.10
	Total:	15.43

Again, this blend was light in the Indian ricegrass but had a strong component of early seral forbs. This blend represented 160 pure live seeds per square foot. Even with the much broader species diversity, we encouraged the USFS to allow commercial source wheatgrass and ricegrass to no avail. We have found that *Poa*, *Leymus*, and *Achnatherum* all exhibit slow germination and slow seedling development unlike the wheatgrasses.

We were fortunate that seeding occurred in the fall, allowing the species to winter over and gain the benefits from the cool stratification and spring freeze/thaw cycles.

We are awaiting the spring and hoping for additional snow fall. The Sierras had exceptional snowfall in December and has had little since.

CONCLUSION

The debate regarding natives will continue and projects will continue to add depth to our experience. We are convinced that a balancing concept will evolve over time whereby projects are designed using more localized species, but still accommodate a wider array of native material than the market can supply. In the meantime, we will continue to expand our efforts to collect and cultivate more natives that exhibit aggressive colonizing behavior.

ECOSYSTEM RESPONSES TO BIOSOLIDS APPLICATION FOLLOWING FOREST FIRE

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ABSTRACT

Soil stability and revegetation is a great concern following forest wildfires. Biosolids application might enhance revegetation efforts while improving soil physical and chemical properties. In May 1997, we applied Denver Metro Wastewater District composted biosolids at rates of 0, 5, 10, 20, 40, and 80 Mg ha^{-1} to a severely burned, previously forested site near Buffalo Creek, CO to improve soil fertility and help establish 7 native, seeded grasses. Soils on the site are Ustorthents, Ustochrepts, and Haploborols. Vegetation and soils data were collected in 1998, 1999, 2000, and 2001, 1, 2, 3, and 4 years following treatment. For the first 3 years following treatment, as biosolids rate increased, total biomass of grasses increased to a maximum of 222g m^{-2} in 1998. Percent bareground decreased with increased rates of biosolids application in all years. Canopy cover increased in 1998 and 1999 to a maximum of 52percent with application of biosolids in 1998. Biosolids application created an increase in plant tissue N, P, and Zn concentrations in the dominant species (thickspike wheatgrass, *Agropyron dasystachyum*, (Hook) Scribn.) in 1998, while only Zn concentrations exhibited a response in 1999, 2000, and 2001. In the top depth, biosolids addition increased NO_3-N and NH_4-N in 1998, 1999, and 2000. The application of biosolids to this site has improved soil fertility and plant production, thus enhancing postfire recovery and soil stability.

INTRODUCTION

With the settlement of the West and subsequent fire suppression starting in the early 1900's, fuel buildup in forested lands was imminent. The resulting accumulation of fuels has resulted in more frequent high-intensity forest fires than prior to suppression (Caldwell, 2002). The Buffalo Creek Fire of May, 1996 was a very high-intensity, fast moving crown fire that burned approximately 12,000 acres of forested land. Two tree species common to the Buffalo Creek area are ponderosa pine (*Pinus ponderosa*) Laws. var. *scopulorum* Engelm. and Douglas-fir (*Pseudotsuga menziesii*) (Mirb.) Franco. Both trees, along with their associated understory of *Ceanothus fendleri*, *Achillea millefolium*, *Elymus elymoides* and other species, are fire-adapted species that depend on specific fire regimes for regeneration, disease and pest control, and ecological succession. However, because this was a high-intensity fire, all plant and litter cover was removed, leaving the site susceptible to erosion and further degradation. Two months following the fire the site received high intensity rainfall in a short period of time from a localized thunderstorm. Subsequent erosion and flooding caused two deaths and over $5 million in property damage as well as huge losses in valuable topsoil. Even though fire is a natural part of these ecosystems, unprotected slopes on burned areas can result in catastrophic events.

Fire may adversely affect the physical, biological, and chemical aspect of forested systems, depending on the intensity and duration of the heat produced, the degree of biotic destruction, and climatic conditions at the time of fire (Neary et al., 1999). A moderate to severe fire can result in soil surface temperatures greater than 500 ^{0}C, and temperatures over 400 ^{0} C 25 mm deep which can oxidize and volatilize essential plant elements (DeBano et al., 1998). Laven (2000) reported that forest ecosystems associated with wildfires such as the Buffalo Creek Fire also suffer greater nutrient losses due to the extreme heat that destroys soil organic matter leading to substantial N loss. Soil productivity as well as streamwater quality can thus be adversely affected by fire (Belillas and Feller, 1998).

Organic matter both above and below the soil surface holds and releases nutrients and because of its high cation exchange capacity it has a great capacity for cation adsorption in mineral soils. Fire, especially those of high severity or long duration, can result in volatilization of nutrients held on the exchange sites of organic matter. The amount of nutrients lost due to soil heating is dependent on the depth of penetration of volatilizing temperatures. While low-severity fires may result in soil temperatures of 50^0 C at 5 cm depths, hot fires like those at Buffalo Creek can produce temperatures of 250^0 C at depths of 10 cm and be over 100^0 C up to 22 cm deep (Neary et al., 1999). Soil organic matter can begin to be lost at temperatures below 100^0 C while 85 percent can be lost at temperatures between 200 to 300^0 C (DeBano et al., 1998). Nutrients with low volatilization temperatures, notably N and S, can be lost at relatively low temperatures as well. Whereas S can be volatilized at 300^0 C, N can begin to volatilize at temperatures as low as 200^0 C (Fisher and Binkley, 2000). Because most soil N is contained in organic matter, the amount of N lost by volatilization is very closely related to the amount of organic matter lost (DeBano et al., 1998). Those nutrients with high volatilization temperatures such as Ca, K, and Mg, are usually incorporated into ash (Covington and Sackett, 1984; Fisher and Binkley, 2000). These nutrients may thus show an increase in concentration at or immediately below the soil surface where they are subject to movement by wind and/or water erosion (Wells et al., 1979).

As a result of severe fire, the loss of plant nutrients and destabilized soils can reduce plant regeneration and watershed quality. The greater the soil heating, the slower the vegetation recovery and organic matter deposition, which are essential for reducing erosion potential on bare soil. Detrimental changes in hydrological functioning such as water holding capacity, porosity, and infiltration rate can result in a decrease in ecosystem sustainability (Neary et al., 1999). Surface runoff can increase by as much as 70 percent when less than 10 percent of the soil surface is covered with plants and litter. Due to this increase in runoff, erosion can be three times greater (Robichaud et al., 2000). Severe fire can also cause vaporization of organic substances in the upper soil layers. These substances then move downward in the soil and condense in the cooler underlying layers, causing water repellency at that depth. The more severe the fire, the deeper in the soil is the water repellent layer. Coarse soil textures also result in a deeper water repellent layer. Once a water repellent layer is formed, water can only infiltrate the soil to that point (DeBano et al., 1998). Thus, heavy rainfall or prolonged rainstorms can cause significant runoff, which in turn can lead to extensive erosion. Areas that have experienced substantial erosion due to fire are less productive and become difficult sites for vegetation establishment. Additionally, due to the immediate increase in available N and a decrease in soil organic matter, annual plant species may invade the site (Hobbs, 1991). If remediation of these lands is not attempted, the effects of fire and flooding may cause long-term degradation of plant community productivity, soil stability, and water quality.

Rehabilitation of ecosystems through the use of biosolids is common. Research has been conducted on the effects of municipal biosolids application as fertilizer and soil amendment on forest and agricultural lands since the 1970's. Several studies have shown that biosolids significantly increased total forest production (Cole et al., 1986; Harrison et al., 2002; Luxmoore et al., 1999). Biosolids can improve soil structure, increase soil water retention and nutrient levels, and enhance root penetration (Rigueiro-Rodriguez, 2000). A study by Jurado and Wester (2001) found that biosolids not only increased forage production, but improved forage quality as well. Accompanying this increase in production would be an increase in total leaf area, which is important in reestablishing prefire hydrologic conditions to burned sites (Fisher and Binkley, 2000). Biosolids can improve the survival, growth, and nutrient uptake of plants used for the restoration of mine tailings (Kramer et al., 2000). Sewage sludge has been shown to alleviate erosion when applied to land degraded by mining activities (Sort and Alcaniz, 1996). A study by Meyer et al.(2001) found that increased vegetative cover due to biosolids application reduced sediment yield from runoff. Other studies have shown that biosolids can increase biomass production on over-grazed rangelands and semi-arid shrublands, as well as on desert areas (Pierce et al., 1998; Harris-Pierce et al., 1993; Jurado and Wester, 2001)). Denis and Fresquez (1989) found that soil chemical properties as well as the soil microbial community improved with increasing application rates of biosolids.

Forest ecosystems are commonly limited by N (Henry and Cole, 1994; Newland and DeLuca, 1999; Caldwell et al., 2002). Although chemical fertilizers have been employed to increase productivity in these ecosystems, commercial fertilizers are subject to leaching and/or runoff and thus may pose a threat to ground or surface water (Binkley et al., 1999). Biosolids, however, can supply slowly released N over an extended period of time, usually one to two years, through mineralization (Cowley et al., 1999; Gilmour et al., 1996; White et al., 1997). Nitrate leaching and NH_3 volatilization appear to be slight for this form of N (Sopper, 1993).

Since the ocean dumping of sewage sludge was eliminated in 1992 the alternative means of disposal are limited. As the population of the world increases, biosolids recycling will become more important. However, even though biosolids can significantly improve the chemical and physical properties of soils, their use is not without risk. Trace metal concentrations of some biosolids, notably Cu, Ni, and Zn, may be phytotoxic. Plant toxicity depends on soil acidity, concentrations of the metal, and plant species present on the site (Chang et al., 1986). Additionally, nutrients and other metals in biosolids can pose serious risks to surface and ground water supplies, and thus human health.

Past biosolids research has focused on application rates that not only enhance forest productivity, but simultaneously supply a balance of nutrients (Harrison et al., 1996; Aschmann et al., 1990). Research has shown that biosolids can increase the rate of vegetation recovery of burnt soils (Villar et al., 1998). However, no available research has focused on the application of biosolids for post-forest fire rehabilitation. Our objective was to determine the effects of a one-time application of up to 80 Mg dry Denver Metro composted biosolids ha^{-1} on plant canopy cover, biomass production, and plant tissue and soil concentrations of N, P, and Zn. Our first hypothesis was that the addition of biosolids would increase plant canopy cover and biomass production because these sites are usually N limited for optimum plant growth. A second hypothesis was that biosolids will increase plant concentrations of N, P, and Zn and soil NO_3 and NH_4 levels because biosolids contain substantial amounts N, P and Zn.

MATERIALS AND METHODS

The study was conducted at the 1996 Buffalo Creek fire site in Pike National Forest approximately 22 km southeast of Pine Junction, CO. The site is located at 39°22'4.4" N, 105°14'26.5" W at an average elevation of 2235 m. Mean annual precipitation at the site is 52 cm and mean annual temperature is 8 ^{0}C. Nearly 75 percent of the annual precipitation occurs in spring or summer, while fall and winter months are comparatively dry (Marr, 1967).

Soils at the study site are classified as sandy-skeletal, mixed, frigid, shallow Typic Ustorthents, have developed from Pike's Peak granite, and are contained in the Sphinx Soil Series (U.S.D.A. Forest Service and Soil Conservation Service, 1983). These soils are typically up to 25cm deep, well drained, have low water holding capacity, a gravel content of 15-75 percent, are slightly acidic to neutral pH, and exhibit a low shrink/swell. The A horizon is generally 0-10 cm and consists of dark brown, gravelly coarse sandy loam. The AC horizon, 10-25 cm, is a yellowish brown, very gravelly loamy coarse sand. The Cr horizon is from 25-150 cm and consists of weathered granite. Slopes at the site range from 25 to 50 percent.

Dominant vegetation of these soils is ponderosa pine and Douglas-fir with an understory of kinnikinnick, common juniper, ceanothus, and grasses. Average annual production of dried vegetation ranges from 17-34 g m^{-2}.

The study site contains a total of 24 treatment plots, each 300 m long and 3 m wide, with a distance of approximately 15 m between each plot. The experimental design was completely randomized with four replicates. Denver Metro Wastewater District used bulldozers to clear trees and to level the surface so that a dump truck could safely apply the biosolids. Plots either received no biosolids (control) or composted biosolids (5, 10, 20, 40 or 80 dry Mg ha^{-1}) from Denver Metro Wastewater District in Spring, 1997 (Table 1). Compost application was accomplished using calibrated broadcasting with a dump truck fitted with rear discharge manure-spreading capabilities. Biosolids were incorporated in the soil to a depth of 10-20 cm with a commercial disc. Control plots were also disced to a depth of 10-20 cm. The disc was large enough to cut through tree stumps and roots remaining on the soil surface after the bulldozing operation.

Table 1. Nutrient and trace metal composition (dry weight basis) of Denver Metro composted biosolids applied to the Buffalo Creek site, May 1997. Results determined using ICP-AES, ICP-MS, and Semi-Automated Colorimetry (USEPA, 1983).

Constituent	g kg^{-1}	Constituent	mg kg^{-1}
Organic N	51.0	Ag	22.2
NH_4-N	5.22	As	3.1
NO_3-N	0.45	Hg	1.6
Na	0.90	Se	1.6
K	3.6	Pb	74.5
P	32.0	V	14.3
Al	14.0	Cu	386
Fe	10.0	Zn	490
		Ni	63.9
		Mo	15.9
		Cd	3.9
		Cr	134
		Sr	211
		B	33.5
		Ba	338

The U.S. Forest Service drill seeded each plot with a mixture of native grasses at the rate of 27 kg pure live seed ha $^{-1}$ following biosolids application. The seeded species included thickspike wheatgrass *Agropyron dasystachyum*, Hook.), streambank wheatgrass (*Agropyron riparium*, Scribn. and Smith), green needlegrass (*Stipa viridula*, Trin.), mountain brome (*Bromus carinatus*, Hook and Arn.), Canby bluegrass (*Poa canbyi*, Scribn.), Idaho fescue (*Festuca idahoensis*, Elmer.), and Arizona fescue (*Festuca arizonica*, Vasey.). After biosolids application, discing, and seeding, a chain link fence was dragged on the surface to cover the seed and smooth the soil.

We collected biomass and plant cover information and plant tissue samples in July 1998, 1999, 2000, and 2001. We determined aboveground plant production using 15 randomly placed 0.5 m^2 quadrats in each treatment plot. Plant biomass was harvested at ground level in each quadrat, separated by species, and placed in labeled paper bags. Following field collection, harvested biomass was oven-dried at 50 ^{0} C for 48 hours, and then weighed. Plant species richness was determined by summing the total number of species that were clipped from each plot. Plant canopy cover was determined by species using randomly placed 100 m line transects in each plot (Bonham, 1989). Cover was recorded at 1 m intervals (100 points per transect) as plant, bare-ground, litter, or rock. We collected plant tissue samples of the dominant species, thickspike wheatgrass, and we analyzed the samples for N content using a LECO 1000 CHN auto analyzer (Miller et al., 1998). Plant tissue samples were also analyzed for P and Zn using HNO_3 digestion (Ippolito and Barbarick, 2000) followed by analysis by inductively coupled atomic emission spectroscopy (ICP-AES) (USEPA, 1983). Composited soil samples were collected at 0-8, 8-16, and 16-30 cm depths from each plot. We determined total soil C and N (Miller et al., 1998).

All plant and soil parameters were compared for all years with the biosolids application rate using analysis of variance (SAS Institute, 1989-1996, version 6.12).

RESULTS AND DISCUSSION

Plant biomass production increased with increased application rates of biosolids in 1998 and 1999 (Fig.1). Total production, however, declined at all treatment rates each year of the study. Maximum total biomass for all years occurred at the highest treatment rate. Increasing biomass production with increasing biosolids rate is similar to the results reported by Fresquez, et. al. (1990) on a degraded plant community in New Mexico in which they used biosolids to increase yield and cover of grasses. Navas et al. (1999) reported that productivity increased significantly with increasing biosolids addition on semi arid degraded lands in Spain. Nutrients added to the soil by biosolids application, especially N and P, can favor biomass production. Redente et al. (1984) reported that moderate fertilization rates of N and P improved the production of grasses on a disturbed site in northwest Colorado. For 1998 highest production was 222 g m^{-2} on plots with the highest application rate of biosolids, in 1999 production in the same plots was 202 g m^{-2}, in 2000 total production was 100 g m^{-2}, and in 2001 production at the highest treatment rate was 76 g m^{-2}. All treatment rates showed a decline in total production that averaged 13 percent from 1998 to 1999, 49 percent from 1999 to 2000, and 40 percent from 2000 to 2001. Some of the biomass decline over time is likely due to the mineralization of biosolids and the depletion of N and P. Additionally, the study site received below normal precipitation from late June through mid-July, 1999. In 2000, the May, June, and July growing season precipitation was only 58 percent of normal, while rainfall in July 2001 was 61 percent of normal (Colorado Climate Center, 2002; Moody and Martin, 2001). Because sampling took place during the period of peak production, which is late July at this elevation in Colorado, it is likely that the lack of moisture during the growing season contributed to some of this decline. In their study of drought effects on dry matter production in Africa, Moolman et al. (1996) reported that drought stress induced by 15 days without water resulted in production declines ranging from 35 to 78 percent. A biosolids study by Benton and Wester (1998) concluded that a decline in production of two grasses was due to below average rainfall.

Grasses accounted for more than 99 percent of total biomass production in 1998 and 1999, over 96 percent in 2000, and more than 90 percent in 2001 (data not shown). Thickspike wheatgrass was the most responsive species to the application of biosolids. Forb and shrub production did not respond to increased application rates in any of the four years. Doerr et al. (1983) reported that the lack of response by forbs in their study of fertilized seeded plant communities was a result of increased grass competition resulting from higher N availability.

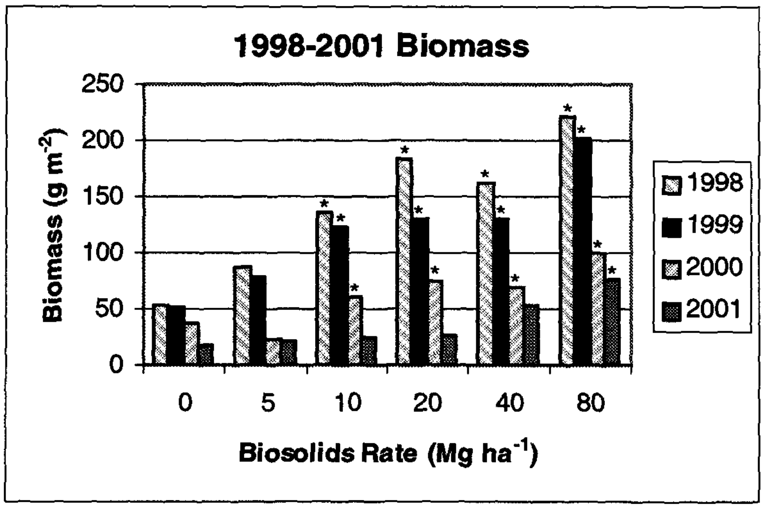

Figure 1. Mean total biomass (g m^{-2}) at all treatment rates for 1998-2001. Asterisks above bars show data that are significantly different than control plots for that year.

Total plant cover increased with increased application rates of biosolids in three of the four years (Fig. 2). In 2001 plant cover was highest at the 40 Mg ha^{-1} rate. Grasses accounted for more than 90 percent of total plant cover in all four years (data not shown), with thickspike wheatgrass being the most responsive species. Canopy cover of forbs and shrubs showed no change with increasing application rates of biosolids in any year (Meyer, 2000). Biosolids did not significantly influence plant cover in 1999. Again, in part due to the significant decrease in late growing season precipitation from 1998 to 2001, plant growth was restricted. Conversely, percent bareground decreased in all four years (Fig. 3). A decrease in bareground was expected because litter would continue to accumulate despite the reduction in rainfall and the resulting production decrease. Based on biomass and percent bareground data, application rates above 40 Mg ha^{-1} did not afford any potential improvement in two of the parameters that would influence soil erosion.

Thickspike wheatgrass N and P concentrations increased with increasing application rates of biosolids in 1998 (Table 2). Because biosolids contain bioavailable N and P, this increase in plant-tissue nutrient concentration was expected. Increases in tissue concentrations of nutrients, particularly N and P, can significantly enhance forage quality and improve nutrient cycling. In 1999, 2000, and 2001 biosolids application rate did not affect tissue concentrations of N and P in thickspike wheatgrass. On account of 1999 being the third growing season following the single biosolids applications, the bioavailable N and P probably had been depleted by mineralization of the biosolids. In a greenhouse study using spring wheat (*Triticum aestivum*, L. 'Sylvan'), Barbarick and Ippolito (2000) found that a single biosolids application had no effect on the wheat N uptake by the third continuous cropping after the single application.

Thickspike wheatgrass Zn concentrations increased with increasing application rates of biosolids in 1998 (Table 2). According to Kabata-Pendias and Pendias (1984), the deficiency range for tissue Zn is 10-20 mg kg $^{-1}$. Tissue Zn levels would be less than 20 mg kg^{-1} for biosolids rates of less than 22 Mg ha $^{-1}$, indicating that the application of Denver Metro biosolids above this rate provided a bioavailable Zn source that helped correct potential Zn deficiencies. Analysis of tissue Zn levels in thickspike wheatgrass in 1999 showed a quadratic response to increasing biosolids rates. In 1999, 2000, and 2001 tissue Zn levels ranged from 16-22 mg kg $^{-1}$ for all treatment rates, all of which were within the deficiency range reported by Kabata-Pendias and Pendias (1984).

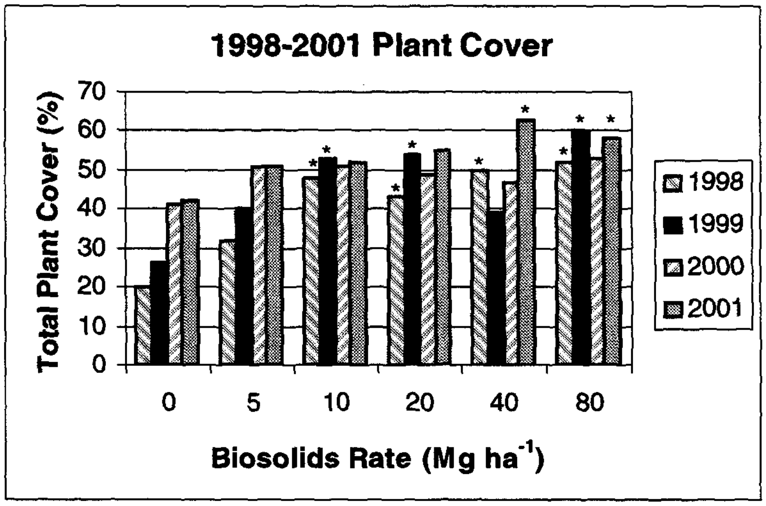

Figure 2. Mean total percent plant cover at all treatment rates for 1998-2001. Asterisks above bars show data that are significantly different than control plots for that year.

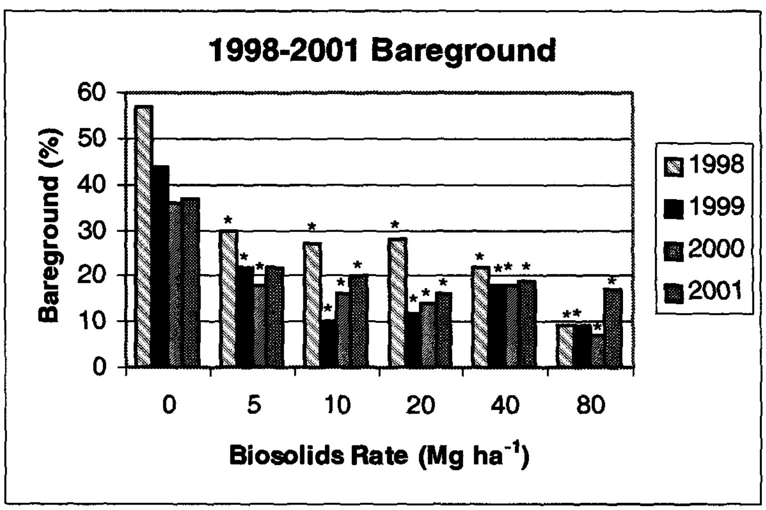

Figure 3. Mean total percent bareground at all treatment rates for 1998-2001. Asterisks above bars show data that are significantly different than control plots for that year.

Plant toxicity can result from high levels of some elements, especially Zn and Cu. Additionally, animals that consume plants grown on biosolids treated soils can be at risk from high tissue levels of some elements, notably Cd, Cr, and Pb (Sopper, 1993). However, none of the elements that were tested in any year exceeded levels that are considered toxic to either plants or herbivores by Kabata-Pendias and Pendias (1984).

Table 2. Plant tissue concentrations of the dominant species of selected nutrients and trace metals for biosolids plots from 1998-2001. Means with different lower case letters within rows are significantly different ($p<0.05$).

			Application Rate (Mg ha^{-1})						
Nutrient	Year	Units	0	5	10	20	40	80	
N	1998	%	0.6b	0.7b	0.8b	0.6b	1.0b	2.1a
	1999	%	1.3b	1.3b	1.3b	1.3b	1.3b	1.5a
	2000	%	1.1c	1.2abc	1.2bc	1.3abc	1.3abc	1.4a
	2001	%	1.3c	1.4abc	1.4abc	1.3bc	1.5ab	1.5a
P	1998	g kg^{-1}	1.6c	1.7c	1.6c	1.5c	2.4b	3.2a
	1999	g kg^{-1}	1.5a	1.5a	1.4a	1.4a	1.2a	1.3a
	2000	g kg^{-1}	1.6b	1.9ab	1.6b	1.9ab	1.9ab	2.1a
	2001	g kg^{-1}	1.6c	1.6bc	1.7abc	1.7abc	1.8ab	1.9a
Zn	1998	mg kg^{-1}	20.3ab	22.1ab	19.3ab	15.6b	37.1a	30.7ab
	1999	mg kg^{-1}	12.3a	13.1a	11.0a	11.5a	12.3a	12.6a
	2000	mg kg^{-1}	15.9c	16.5bc	15.4c	15.4c	19.1b	22.2a
	2001	mg kg^{-1}	12.8c	14.0bc	13.9bc	13.5bc	14.6ab	15.7a
Cu	1998	mg kg^{-1}	3.7bc	3.7bc	3.5c	3.3c	5.7b	8.1a
	1999	mg kg^{-1}	2.0a	2.2a	1.8a	1.7a	2.0a	2.1a
	2000	mg kg^{-1}	2.5b	2.9ab	2.4b	2.9ab	3.1ab	3.6a
	2001	mg kg^{-1}	2.5b	2.6ab	2.6ab	2.6ab	2.8ab	2.9a

Soil concentrations of NO_3-N and NH_4-N showed significant increases in 1998, 1999, and 2000 (Figs. 4 and 5). Biosolids application provided no appreciable effects for these forms of N in 2001. These results are similar to the findings of Zebarth et al. (2000) in their study of the use of biosolids for dryland forage grass. They reported that after three years most of the N supplied by biosolids had been immobilized or had accumulated in plant tissue.

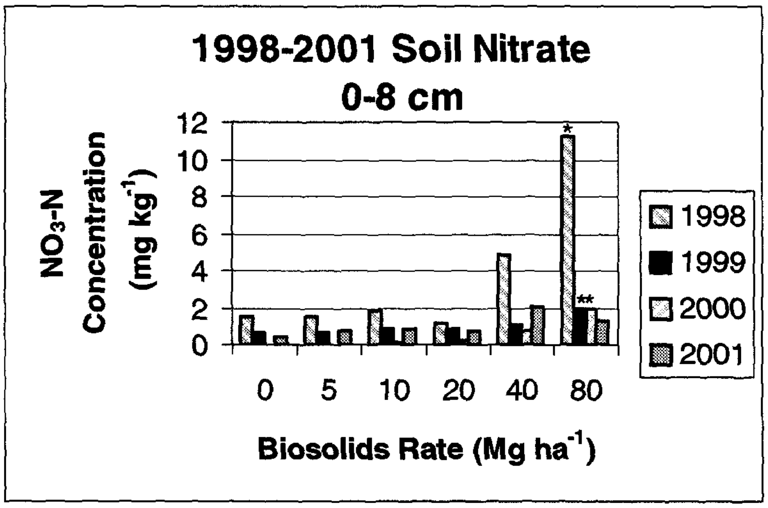

Figure 4. Mean soil concentration of NO_3-N at all treatment rates for 1998-2001. Asterisks above bars show data that are significantly different than control plots for that year.

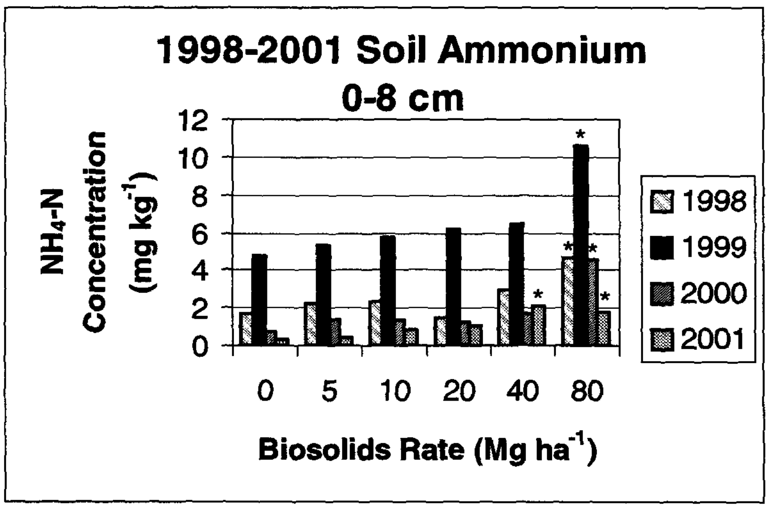

Figure 5. Mean soil concentration of NH_4-N at all treatment rates for 1998-2001. Asterisks above bars show data that are significantly different than control plots for that year.

SUMMARY AND CONCLUSIONS

Application of Denver Metro composted biosolids to the Buffalo Creek wildfire study plots in 1997 produced significant increases in plant biomass in 1998, 1999, and 2000 and in plant canopy cover in 1998. Additionally, increasing biosolids rate caused decreases in percent bareground all four years. As such, we would accept our first hypothesis that increasing biosolids rate would increase biomass production and canopy cover. The seeded grasses in general, and thickspike wheatgrass in particular, dominated each plot.

Plant tissue concentrations of selected elements were below toxic levels for livestock consumption or for plants. Thickspike wheatgrass N and P tissue concentrations increased as biosolids rates increased in 1998, but we observed no biosolids effects in 1999, 2000, or 2001.

Significant increases in biomass production and reductions in percent bareground generally occurred with biosolids application rates of 20 to 40 Mg ha^{-1}. In order to provide maximum plant growth and soil cover while preventing significant uptake and accumulation of plant nutrients and trace elements, we recommend application rates of 20 to 40 Mg biosolids ha^{-1}. Even though the site was further disturbed by the dozing and discing operations, we feel the benefits outweighed the costs. The temporary improvement in infiltration and seedbed preparation afforded by discing could only enhance the site for successful revegetation. The increase in productivity and cover through the use of biosolids can aid in the rehabilitation of wildfire sites and reduce soil erosion in ecosystems similar to the Buffalo Creek, CO area.

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LANDFILL COVER REVEGETATION AT THE ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

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ABSTRACT

In 1998, a revegetation project was begun on a landfill cover at the Rocky Flats Environmental Technology Site near Golden, Colorado. After final contouring of the landfill cover, the area was broadcast seeded with native species including: *Agropyron smithii*, *Bouteloua gracilis*, *Buchloe dactlyoides*, *Andropogon gerardii*, *Andropogon scoparius*, and *Linum perenne*. In May 1999, the cover was treated by helicopter with Tordon22K® to control the noxious weed, *Centaurea diffusa*. During 2001, vegetation cover and species richness was measured along five 50-m transects. A total of 25 species (56% native) were recorded along the transects. Total vegetation cover averaged 71%. Basal cover was dominated by rock (41.2 %), litter (28.6 %), bare ground (23 %), and vegetation (7.2 %). Graminoids and forbs comprised 92 % and 8% of the total relative cover, respectively. The dominant plant species were *B. gracilis*, *A. smithii*, *B. dactlyoides*, *B. curtipendula*, all native, perennial grass species. Total relative native species cover on the landfill cover was 89 percent with 85 percent of this coming from native grasses (Table 2). Graminoid cover was dominated by warm-season species (74% relative foliar cover). Only 18% of the relative foliar cover came from cool-season graminoids. Compared to the surrounding native prairie plant communities, rock and bare ground cover amounts remain high and litter cover is low. Total native species cover is considerably higher on the revegetation area compared to the surrounding prairie. Thus far the revegetation effort has proven very successful and has required little maintenance other than weed control.

INTRODUCTION

A sanitary landfill cover (approximately 21 acres) at the Rocky Flats Environmental Technology Site was revegetated with native species in spring 1998 to provide a vegetative cover and prevent wind and water erosion. Monitoring was conducted during fall 2001 to evaluate the revegetation effort and qualitatively assess the condition of the vegetation on the landfill cover.

BACKGROUND INFORMATION

In May 1998, after final contouring, a native seed mix was broadcast on the landfill cover (Table 1). Biosol® fertilizer was added to the surface of the to provide some basic plant nutrients for growth because no topsoil was available. After seeding, straw mulch was crimped in and then hydromulched with a tackifier and wood mulch to prevent wind and water erosion. In May 1999, the landfill cover was sprayed with Tordon 22K® by helicopter to control the noxious weed diffuse knapweed (*Centaurea diffusa*) that had become a problem on the cover.

Table 1. Seed Mix for Landfill Cover

Scientific Name	Common Name	Application Rate (PLS lbs/ac)
Agropyron smithii	Western Wheatgrass	12.0
Bouteloua gracilis	Blue Grama Grass	8.0
Buchloe dactlyoides	Buffalo Grass	8.0
Andropogon gerardii	Big Bluestem	8.0
Bouteloua curtipendula	Side-Oats Grama Grass	8.0
Andropogon scoparius	Little Bluestem	8.0
Linum perenne	Blue Flax	4.0
Total PLS per acre application		56.0

PLS = pure live seed

SAMPLING METHODS

In late September 2001, species composition was measured on the landfill cover using a modified line-intercept methodology. Five 50-m transects were established across the cover parallel to some methane monitoring transects for which the data was also being gathered (Figure 1). Endpoints of all transects were recorded using global positioning system (GPS) equipment for entry into the Site geographic information system (GIS).

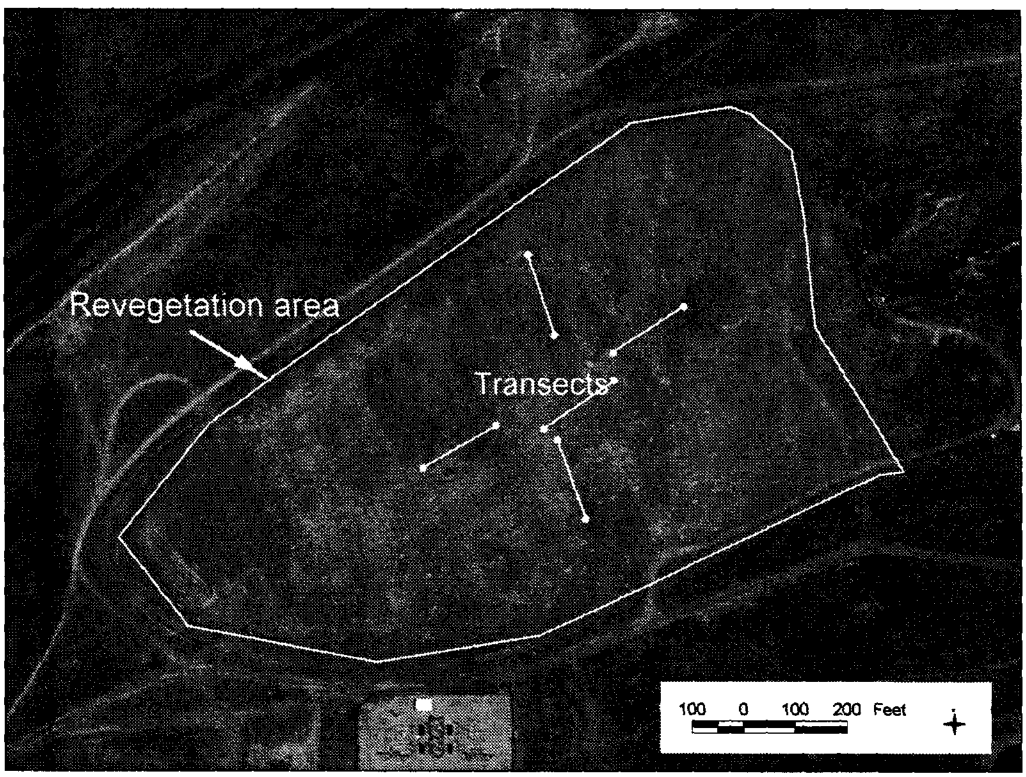

Figure 1. The landfill cover at Rocky Flats is the lighter area in the center of the photograph. The five transects were located along some methane monitoring transects that were also being sampled.

Basal cover and foliar cover were estimated using a modified line-intercept method along each 50-m transect. A 2-m-long, 6-mm-diameter rod was dropped vertically at 50-cm intervals along the length of each transect to record a total of 100 intercept points. Two categories of hits were recorded, basal and foliar. Basal cover hits were recorded based on what material was hit by the rod at the ground surface. Hits could be vegetation (live plants), litter (fallen dead material), rock (pebbles and cobbles greater than the rod diameter), bare ground, or water, in that order of priority based on the protection from erosion provided by each type of cover. Vegetation hits were identified to species. Basal vegetation hits were recorded only if the rod was touching the stem or crown of the plant where the plant entered the ground. Foliar vegetation hits (defined as a portion of a plant touching the rod) were recorded by species in three categories as defined by height and growth form. The topmost hit of each growth form was recorded. The growth forms measured were herbaceous, woody <2 m in height, and woody >2 m in height.

Additionally, a single photograph was taken of each transect to visually document the condition of the transects. Photographs were taken from near the 0-m end of the transect looking toward the 50-m endpoint. A placard was placed in the photograph against the 0-m endpoint to provide the site and transect number, and date.

Cover data were summarized for both basal and foliar cover by combining the data from the five transects. Foliar data was summarized by species and by various life form categories. Basal cover data are reported as total percent cover of vegetation, litter, rock, and bare ground. Foliar cover data are reported as frequency, absolute cover, and relative cover for each species encountered. Frequency from the cover data was defined as the percent of line-intercept transects on which a species occurred, out of the total possible five sampled at each site. Absolute foliar cover was the percentage of the number of hits on a species out of the total number of hits possible at a site (500). This value is the actual cover of a species. Relative foliar cover was the number of hits a species had relative to the total number of vegetative hits recorded per site (i.e., the percent of total vegetative cover [100 percent] represented by the species). Both absolute and relative foliar cover values are presented as means. Comparisons were made to previously sampled native grassland locations at the Site.

RESULTS

The monitoring results are presented in Table 2. A total of 25 species were recorded along the transects in 2001. Of these, 56 percent were native species. Total vegetation foliar cover was 71.2 percent. Basal or ground cover on the landfill cover was dominated by rock (41.2 percent), litter (28.6 percent), bare ground (23 percent), and vegetation (7.2 percent). The vegetation on the landfill cover was dominated by graminoid species that comprised approximately 92 percent of the total relative foliar cover. The dominant plant species were blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), buffalo grass (*Buchloe dactlyoides*), and side-oats grama (*Bouteloua curtipendula*), all of which are native, perennial grass species. Total relative native species cover on the landfill cover was approximately 89 percent with 85 percent of this coming from native grasses. Graminoid cover was dominated by warm-season species which comprise approximately 74 percent of the total relative foliar cover. Approximately 18 percent of the total foliar cover came from cool-season graminoids. Forbs accounted for only approximately 8 percent of the total foliar cover. A Shannon-Weaver diversity index value of 0.88 was calculated from the relative foliar cover data.

Table 2. Landfill Cover Foliar Cover Data Summary.

Scientific Name	Speccode	Growth Form	Native	Cool/ Warm Season	Frequency	Percent Absolute Cover	Percent Relative Cover
Centaurea diffusa Lam.	CEDI1	F	N		40	1.2	1.7
Dyssodia papposa (Vent) Hitchc.	DYPA1	F	N		20	0.2	0.3
Melilotus alba Medic.	MEAL1	F	N		20	0.2	0.3
Melilotus officinalis (L.) Pall.	MEOF1	F	N		60	1.8	2.5
Plantago lanceolata L.	PLLA1	F	N		20	0.2	0.3
Ambrosia psilostachya DC.	AMPS1	F	Y		100	1.4	2.0
Grindelia squarrosa (Pursh.) Dun.	GRSQ1	F	Y		40	0.6	0.8
Helianthus annuus L.	HEAN1	F	Y		40	0.4	0.6
Bromus japonicus Thunb. ex Murr.	BRJA1	G	N	C	20	1.2	1.7
Bromus tectorum L.	BRTE1	G	N	C	60	1.6	2.2
Dactylis glomerata L.	DAGL1	G	N	C	20	0.2	0.3
Schedonnardus paniculatus (Nutt.) Trel.	SCPA2	G	N	C	20	0.4	0.6
Echinochloa crusgallii (L.) Beauv.	ECCR1	G	N	W	20	0.2	0.3
Setaria viridis (L.) Beauv.	SEVI1	G	N	W	40	0.8	1.1
Agropyron smithii Rydb.	AGSM1	G	Y	C	100	9	12.6
Sitanion hystrix (Nutt.) Sm. var. brevifolium (Sm.) Hitchc.	SIHY1	G	Y	C	20	0.2	0.3
Andropogon gerardii Vitman	ANGE1	G	Y	W	60	1	1.4
Andropogon scoparius Michx.	ANSC1	G	Y	W	40	0.4	0.6
Bouteloua curtipendula (Michx.) Torr.	BOCU1	G	Y	W	100	6	8.4
Bouteloua gracilis (H. B. K.) Lag ex Griffiths	BOGR1	G	Y	W	100	33.2	46.6
Buchloe dactyloides (Nutt.) Engelm.	BUDA1	G	Y	W	100	7	9.8
Panicum capillare L.	PACA1	G	Y	W	40	0.8	1.1
Panicum virgatum L.	PAVI1	G	Y	W	40	0.4	0.6
Sporobolus asper (Michx.) Kunth	SPAS1	G	Y	W	40	1.4	2.0
Sporobolus neglectus Nash	SPNE1	G	Y	W	40	1.4	2.0
Total foliar cover						71.2	100.0
Total forb cover						6	8.4
Total native forb cover						2.4	3.4
Total non-native forb cover						3.6	5.1
Total graminoid cover						65.2	91.6
Total native graminoid cover						60.8	85.4
Total non-native graminoid cover						4.4	6.2
Total native cover						63.2	88.8
Total non-native cover						8	11.2
Total warm-season graminoid cover						52.6	73.9
Total cool-season graminoid cover						12.6	17.7

Absolute cover = Absolute foliar cover is the percentage of the number of hits on a species out of the total number of hits possible (500).
Relative cover = Relative foliar cover was the number of hits a species had relative to the total number of all vegetative hits recorded per site (i.e., the percent of vegetative cover the species represented).
All cover values presented are means (n = 5).
Native categories: Y = Native, N = Non-Native
Form categories: C = Cactus, F = Forb, G = Graminoid
Cool/Warm Season categories: C = Cool season species, W = Warm season species

DISCUSSION

The revegetation effort on the landfill cover at the Site has done very well in the three years it has been in place (Figure 2). In 2001, the vegetation on the landfill cover was predominantly native, warm-season, perennial, graminoid species. It is dominated by blue grama (which accounts for almost half the total relative foliar cover [46.6 percent] of the cover), western wheatgrass, buffalo grass, and side-oats grama, all of which were planted species in the seed mix. Other seeded species that accounted for smaller cover amounts included big bluestem (*Andropogon gerardii*) and little bluestem (*Andropogon scoparius*). Compared to native plant communities at the Site, the amount of native species cover is already equal to or greater than that found on the native grasslands (K-H, 2001). The vegetation on the landfill cover has the greatest similarity to that of the mesic mixed grassland, a blue grama/western wheatgrass dominated native community at the Site. The health and vigor of these grasses on the landfill cover appeared good, as indicated by the size of the plants and amount of flowering observed during sampling. No sign of chlorosis or wilting was observed. Although total vegetation cover on the cover was approximately 15-20 percent below that of the native grasslands in an average year, the plants have begun to spread and fill in the spaces between the initial establishment locations. The overall vegetation cover should continue to increase over the next few years and form a solid stand of native vegetation.

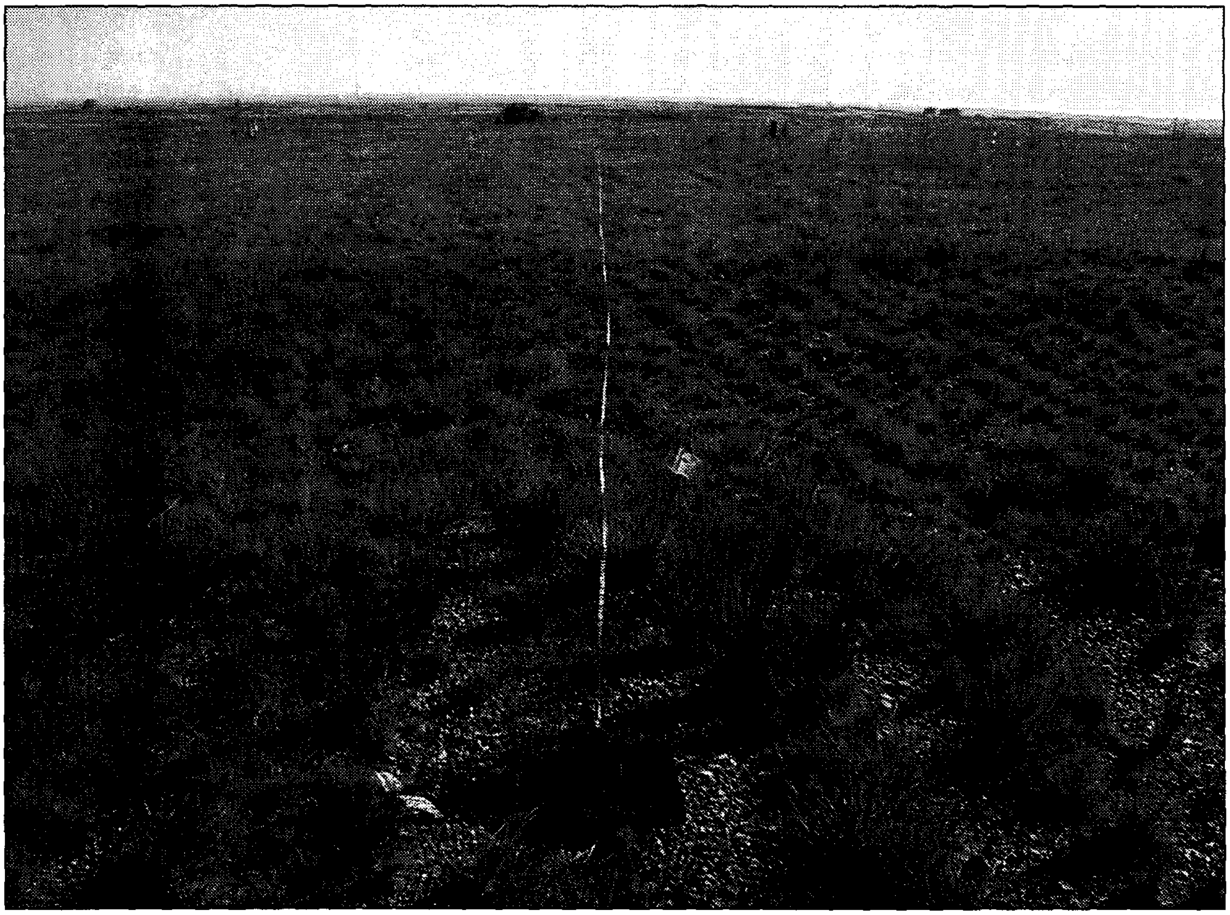

Figure 2. Vegetation on landfill cover three years after seeding. The area is dominated by native, warm-season graminoid species like blue grama, western wheatgrass, buffalo grass, and side-oats grama.

Species diversity on the landfill cover is still somewhat low (Shannon-Weaver index = 0.88) compared to the native mesic mixed grassland which in 2000 ranged in diversity from 0.984 to 1.276 at three different locations. However, the lower diversity is not unexpected given that only one forb species was in the seed mix planted on the landfill cover and considering that the landfill cover was also sprayed with Tordon 22K®, a broadleaf herbicide, used to control diffuse knapweed, in May 1999. Eventually more forbs may immigrate onto the cover, increasing diversity. Currently noxious weeds, mainly diffuse knapweed, were only noticed at a few spotty locations and with continued control should remain low in abundance.

Ground cover on the landfill cover was dominated by rock. The amount of rock cover (41.2 percent) and bare ground cover (23 percent) is considerably higher than that found on the mesic mixed grassland at the Site. In 2000, at three locations on the mesic mixed grassland, rock cover ranged from 8.4 to 23 percent while bare ground cover varied from 2.6 to 9.2 percent. Much of this is due to the low level of litter cover currently present on the landfill cover (28.6 percent), which is far below that on the native prairie (64 to 79 percent in 2000). Because unvegetated areas still exist between many of the individual plants and the revegetation effort is only three years old, only a small amount of dead plant litter has built up on the ground surface. This will change as the vegetation continues to grow, produce litter, and expand into the spaces between the original plants.

At a few locations patches of taller vegetation were present on the landfill cover where a higher component of taller growing native plant species, such as big bluestem, little bluestem, and side-oats grama, along with taller weed species such as yellow and white sweet clover (*Melilotus officinale* and *Melilotus alba*) were growing. All seeded species, with the exception of blue flax (*Linum perenne*), were recorded along the transects. The blue flax was observed on the cover, just not along the monitored transects.

The rooting depth of some of the plants was observed at four holes dug for soil samples on the landfill cover. The maximum depth to which roots were observed at these holes was approximately 30 cm (12 in), with most being observed within the top 15 cm or so. It is likely that the plant roots actually go deeper than this, but at most of the holes it was rare to find a plant growing right at the edge of the hole.

CONCLUSIONS

The revegetation of a landfill cover at the Rocky Flats Environmental Technology Site has been very successful. Seeded in 1998, by 2001 the cover is now dominated by native, warm-season, perennial, graminoid species. The vegetation appears healthy and thriving based on the size of the plants and the flowering observed during the monitoring fieldwork. Although rock and bare ground cover remains higher than that found on the native grassland, the native species are filling in the spaces between plants and should in time form a solid stand of vegetation across most of the cover. Weed control will continue to be necessary to keep competition from noxious weeds low and allow the native species to expand their range. Thus far these results suggest a very successful revegetation project.

LITERATURE CITED

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HIGH ALTITUDE REVEGETATION EXPERIMENTS ON THE BEARTOOTH PLATEAU PARK COUNTY, MONTANA AND PARK COUNTY, WYOMING FIRST YEAR MONITORING RESULTS

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ABSTRACT

The Federal Highway Administration (FHWA) is conducting revegetation tests on the Beartooth Plateau on a portion of the Beartooth Highway that is proposed for reconstruction. The revegetation tests are designed to assist in planning revegetation for potential impacts along U.S. Highway 212, the Beartooth Highway. The road traverses alpine areas of the Beartooth Plateau between Red Lodge and Cooke City, Montana, near the northeast entrance to Yellowstone National Park. ERO Resources Corporation (ERO) has conducted revegetation tests over 3 years to identify revegetation techniques applicable for revegetating alpine areas. ERO is conducting the work for FHWA. This paper presents the findings of the first year of annual monitoring on these test plots.

In September 1999, ERO placed revegetation tests plots in an existing gravel borrow area along the Beartooth Highway. The test plots were designed based on studies of revegetated disturbances in Rocky Mountain alpine environments. Three variables were tested: soil salvaging, seeding rates, and soil amendments. Additional revegetation test areas were created to determine the feasibility and cost effectiveness of planting greenhouse-grown seedling plant materials from locally collected seed. Native seed was collected on the Plateau and used for direct seeding of the revegetation test plots and for production of plant materials. ERO completed statistical analysis on the fall 2000 monitoring data, and is analyzing the fall 2001 monitoring data. Monitoring data included vegetation cover, species richness, and soil nutrients. Monitoring data for 2001 also includes soil moisture.

Results are preliminary because only the first year's data has been analyzed statistically. From the analysis of the first year's data, it appears that vegetation cover was higher on plots where organic amendments were used. There was no apparent effect of seeding density, and the effect of topsoil was not apparent.

INTRODUCTION

The Federal Highway Administration (FHWA), in cooperation with the U. S. Forest Service, and the National Park Service, is proposing to reconstruct portions of U.S. 212 (FH 4), the Beartooth Highway, in Park County, Wyoming. Several alternatives are being evaluated for the proposed project, as part of an Environmental Impact Statement, and all of the proposed alternatives would disturb alpine plant communities. To assist in project planning, the FHWA retained ERO to evaluate and identify revegetation techniques applicable for reclaiming native vegetation in alpine areas. As part of the evaluation, ERO constructed revegetation test plots in an existing gravel borrow area along the Beartooth Highway in Montana in the September of 1999. Three variables were tested at the revegetation test plots: soil salvaging, seeding rates, and soil amendments. Two additional revegetation test areas adjacent to the plots were created to determine the feasibility and cost effectiveness of planting plant materials grown in a greenhouse from locally collected seed.

The revegetation test plots were designed based on information gathered from past research in high alpine disturbances, especially research conducted by Dr. Ray Brown north of Cooke City, Montana and along the Beartooth Highway in Montana. Input from Dr. Ray Brown, representatives of the FHWA Central Federal Lands Highway Division, Kent Houston, soil scientist on the Shoshone National Forest, and John Samson, of the Wyoming Department of Transportation, also was integrated into the design. Troy Smith, owner of Arrowhead Reclamation and Excavating, is knowledgeable in revegetation of disturbed mine lands, Forest Service lands, and alpine areas, and was chosen to construct the revegetation test plots. Wind River Seed collected seed from the Beartooth Plateau and supplied additional commercially available seed for the project. Bitterroot Restoration has grown all of the plant materials for the project.

This report describes the 2000 annual monitoring of revegetation test plots placed at an abandoned gravel borrow area north of the Montana/Wyoming state line along the Beartooth Highway. Annual monitoring also took place in the fall of 2001, and also will take place in the fall of 2002, 2003, and 2004. Results from these monitoring events will be presented in future papers.

LITERATURE REVIEW

Revegetation of high altitude disturbances is often a slow process because of a short growing season, low temperatures during the growing season, and plants' exposure to wind, snow, and ice (Barbour and Billings 1988). The growing season ranges from 40 to 90 days, and frost may occur throughout the season (Brown and Chambers 1989). Frequently, soils are willow, rocky, and weakly developed (Brown et al. 1976). Additionally, many species adapted to the alpine environment are not commercially available or do not establish well from seed.

ERO consulted with several people knowledgeable in the reclamation of sensitive natural areas, including Ray Brown formerly with the Rocky Mountain Research Station (RMRS), Dale Wick and Joyce Lapp of Glacier National Park, Eleanor Williams Clark of Yellowstone National Park, Mark Majerus of the USDA Bridger Plant Materials Center, Steve Parr of the USDA Meeker Plant Materials Center, several contractors specializing in the reclamation of natural areas, and suppliers of plant materials, seed, soil amendments, and surface mulches. Several variables have been tested in alpine areas, including seed types and sources, soil salvaging, and soil amendments such as fertilizer, organic amendments, and surface mulches. The studies relevant to revegetation along the Beartooth Highway are summarized in the following sections.

Soil Amendments

In a 1989 study, Brown and Chambers (1989) concluded that fertilizer, organic matter, and surface mulching were essential to re-establish alpine vegetation. Other studies have shown that the application of fertilizer is very important to establishing alpine vegetation (Brown et al. 1976; Brown and Johnston, 1976, Brown and Johnston 1978). Microbial activity is slow at high altitudes because of cool temperatures and a short frost-free season. This lack of microbial activity slows the decay of plant material into available nutrients. Brown et al. has acquired evidence that it may be advantageous to fertilize in a systematic manner over a period of years to generate organic material from colonizer species that will help to build the soil for later successional species (Brown et al. 1996; Brown, pers. comm. 1999). However, in test plots conducted on Craig Pass in Yellowstone National Park, results indicated that there was no increase in vegetation cover with the application of fertilizer (Majerus 1987).

Organic matter incorporated into the soil was shown to greatly enhance vegetation establishment in previous studies on the Beartooth Plateau (Brown et al. 1976). Organic material helps sustain the nitrogen cycle in the soil by providing microbes and nutrients necessary to support a plant community. In addition, Eleanor Williams Clark, Chief Landscape Architect of Yellowstone National Park has expressed concern that the use of compost could introduce seed of undesirable species to a site. A second reason that Yellowstone avoids the use of compost, fertilizer, or other organic material, is that wildlife may be attracted the nutrients in these materials, and the use of these materials along roadsides may bring wildlife into conflicts with vehicles (Clark 2001).

Organic material such as sewage sludge or manure is heavy, bulky, and hauling costs are high. In some highway projects in Idaho, KiwiPower™ and Fertil-Fibers NutriMulch™ have been successful in revegetating drastically disturbed sites (Arriago 2001). KiwiPower™ is an organic soil treatment that, according to the manufacturer, contains organic enzymes, bacterial activators, and biostimulants. Fertil-Fibers NutriMulch™ is an organic fiber bulk with an N-P-K ratio of 6:4:1. It is intended to work as an organic amendment and a fertilizer. It is more expensive than ordinary fertilizer, but much cheaper than organic material such as compost, sewage sludge, or manure, because of lower transportation costs.

Soil Salvaging

Soil salvaging has been shown to be advantageous in numerous reclamation settings, especially in the alpine environment. Salvaged soil contains seed microorganisms and nutrients adapted to or generated by the unique combination of parent materials, organisms, topography, and climate of a given site (Williams and Marvel 1990). In alpine areas, where topsoil may be thin (2 to 5 cm {1 to 2 inches]), collecting the upper portion of subsoil near the soil surface is important, because of the plant materials and microbes it contains. Transplanting soil was the most successful revegetation technique in Brown and Johnston's trials on the Beartooth Plateau (1976). In Yellowstone National Park, topsoil salvaging and replacement is considered to be the most important factor in revegetating disturbances (Clark 2001). When topsoil is redistributed, it should be graded unevenly, to provide microsites for establishing vegetation. Other items, such as rocks and logs also help to provide microsites (Clark 2001).

Plant Materials

FHWA recognizes the importance of the use of native plant species on highway disturbances (Harper-Lore and Wilson 2000). Researchers also have studied the effect of seed source on alpine revegetation. Three studies showed that commercially available introduced species are not appropriate for alpine disturbances (Guillaume 1978, Carlson 1986; Brown and Johnston 1978). In addition, a limited number of native alpine species are available (Brown and Amacher 1997). In addition, although commercially available seed may be the same species as one that grows above timberline, they may not be specifically adapted to alpine area (Johnson and VanCleave 1978).

While collection of native seed from an area near a project site may be superior for plant establishment, limiting the introduction of weeds to a site, and for maintaining the genetic integrity of the vegetation in an area, collection and growout of native seed requires careful planning, as was noted by Johnson (1981) on the Alaska pipeline project. A seed growout was planned, but was not successful in producing the desired amount of seed for this project, because of the unpredictability of seed crops. Native seed production may be unpredictable—some stands may not produce seed in some years, or individuals of a species may be scattered throughout an area, and difficult to collect (Dunne 1997). Proper harvest and storage are essential to the viability of collected seed (Weisner 1997). There are constraints on seed production that are difficult to predict, such as climatic conditions in a particular year (Chambers, et al. 1994).

In its revegetation projects, the National Park Service has collected seed on or near project sites to preserve the genetic integrity of the seed on the site, and to provide a seed source that is well adapted to the area (Majerus 1997a, Clark 2001, Majerus 1997b). In studies conducted in Grand Teton National Park comparing the use of native seed collected from a project site versus native seed from commercial sources, researches found that the seed collected on-site outperforms commercially available seed (Cotts and Redente 1991; Cotts and Redente 1995; Guillame et al. 1986). Also, researchers have noted the importance of incorporating species with a number of adaptations and from early and later seral stages in seed mixes (Brown and Chambers 1989). Often it is not possible to acquire this variety of species from commercial sources. Ecologists refer to the transition stages that a plant community passes through from the time it is first disturbed to the time it reaches a climax state as seral stages (Burrows 1990). Examples of seral stages include pioneer communities, which are those dominated by weeds or annual species. An old growth forest is a climax community, and is considered the highest sere of a plant community. In between these two extremes, a plant community may be in transitional stages, or seres, for years. The length of time required to reach a climax community may range from 20 to 300 years, depending on the plant community type. Forests often take much longer to reach a climax state.

In recent years, reclamation in Glacier National Park has included the use of containerized stock grown from seed collected in the park. Plantings included grass and forb species, as well as some shrub species. The Park has found these plantings to be very successful (Wick, pers. comm. 1999; Lange and Lapp 1997). These plantings occurred in subalpine environments, and this technique has not been tested in alpine areas of the Park. It appears likely that planting alpine species would be more successful than seeding because of the low germination and establishment rates from seed, and because of the nature of many alpine species to spread through rhizomes.

Ray Brown formerly with the RMRS has had very good success planting and transplanting live plant materials at mine disturbances near Cooke City, Montana (Yousef 2000). Although these plantings are very successful, the benefits may not outweigh the costs.

Surface Mulch

Surface mulch such as straw, erosion control fabric, or hydromulch can moderate surface temperatures, limit wind at the soil surface, and may prevent the formation of needle ice on the soil surface (Brown and Chambers 1989; Berg et al 1986). The use of surface mulches such as straw, hay, or hydromulch likely would be ineffective on the Beartooth Plateau because of the high winds.

The use of erosion control mats, or blankets, as a surface mulch to moderate the environmental conditions at alpine revegetation sites has been shown to be effective (Munshower 1994). Several kinds of erosion control blankets are on the market, some consisting of straw, coconut fiber, a mix of the two, or jute netting for areas of high erosive energy such as streams. Straw mats are the least expensive blankets. However, they decompose the most readily, and do not hold together well on steep slopes or in areas subjected to intense erosion. Coconut fiber mats are almost twice as expensive as straw fabric, but have more structural integrity. Coconut mats will hold together on slopes, withstand more erosion than straw fabrics, and breakdown more slowly (Munshower 1994). This type of blanket is thicker and darker than straw, which may inhibit seed germination and emergence. Another type of blanket is constructed from 70% straw and 30% coconut. These blankets are significantly less expensive than coconut fiber blankets, but have some of the structural qualities of coconut fiber mats. They are intermediate in price.

By shading the soil surface, surface mulches moderate soil surface temperatures (Munshower 1994). It is possible, however, that in alpine areas, where average soil surface temperatures are already quite low, surface mulches, especially erosion control mats, that limit solar radiation on the soil surface may lower soil surface temperatures to such an extent that germination does not take place. An alternative to erosion control blankets may be wood chips. Yellowstone National Park has successfully used wood chips, composed of 70% fir/pine, and 30% cedar for several years (Clark 2001). The advantages of wood chips are that they are unlikely to blow away in high winds. Also, the combination of cedar and pine or fir is important, because cedar whips are more fibrous, and form a matrix on the soil surface, which helps to hold the mulch in place. However, cedar chips are acidic, and combining these chips with either fir or pine reduces the acidity of this mulch.

ADDITIONAL STUDIES BEING CONDUCTED ON THE BEARTOOTH PLATEAU

In addition to the revegetation tests placed in 1999, FHWA has contracted with ERO to design and place revegetation test plots in 2000 and 2001, to examine additional revegetation variables. All revegetation test plots were placed in existing disturbances along the Beartooth Highway. The second set of test plots were placed in the summer of 2000, at the West Summit of the Beartooth Highway and at a pullout near the Gardiner Headwall. The variables tested in 2000 were organic soil amendments, seed source (locally collected v. commercial), slope and aspect. The variables tested at the West Summit in 2001 were seeding density, surface mulch, sod transplants, and organic amendments. All of the revegetation test plots were created to assist in project planning and to help identify revegetation techniques applicable for reclaiming areas disturbed by construction activities in alpine areas.

Two seed growout experiments also are being conducted. The first tests the practicality of collecting and growing seed of forb and sedge species for direct seeding or transplanting onto alpine disturbances. The second will examine the practicality of a large seed growout to obtain enough seed for a road reconstruction project.

REVEGETATION TEST PLOT DESIGN

The study has a randomized block design. Combinations of the three variables were tested for a total of eight treatments plus one control treatment. Each treatment was replicated four times for a total of 36 test plots. Each plot measures 25 square meters (267 square feet). Control plots (C), on which the lower density seeding rate and fertilizer were applied, also were established. The design and construction of the revegetation test plots are described in the As-Built Report for the revegetation test plots (ERO 1999). The three variables tested on the plots were:

- Topsoil salvaging (S) versus no topsoil (N)
- Lower seeding rate (L) versus higher seeding rate (H) (Table 1)
- Organic amendments plus fertilizer (O) versus surface application of Kiwi Power™ and Fertil-Fibers NutriMulch™ (K)

Prior to test plot placement, soil, including mineral soil, organic material and plant material, and that portion of the subsoil horizon where plant roots and rhizomes were present, was scraped from the revegetation test plot area. After salvaging, the subsoil surface was graded uniformly along the existing slope.

About 5 cm (2 inches) of topsoil was placed on the 16 plots treated with topsoil. Topsoil was then graded as evenly as possible using a tractor and hand rakes. The topsoil was of higher quality than expected; it had a sandy loam texture and 6.2 percent organic matter.

In half (16) of the test plots, compost and fertilizer were applied. Compost was applied at a rate of 18 metric tons/ha (50 tons/acre) of dry weight organic material. The rate should provide about 2.5 percent organic matter to the test plot soil. Fertilizer, ratio 17:17:17 Nitrogen-Potassium-Phosphorus (N-P-K) was broadcast at a rate of 675 kg/ha (600 lbs/acre).

In the remaining 16 test plots, Kiwi Power™ was applied at a rate of46.8 l/ha (5 gal/ac) with 7,791 l/ha (833 gal/ac) of water using a backpack sprayer, and Fertil-Fibers NutriMulch™ was applied at a rate of 2,250 kg/ha (2,000 lbs/ac) in dry pellet form with a hand-held broadcast seeder.

Before seeding, plots were disced to incorporate organic amendments. Plots with no topsoil or organic amendments were also disced to ensure even treatment of all plots. Because of the rocky soils, it was necessary to disc the plots four times, twice in an east-west direction, and twice in a north-south direction.

The seed mixes listed in Table 1 were placed on the revegetation test plots. Seeding densities were designed based on past research on the Beartooth Plateau by Dr. Ray Brown (pers. comm. 1999). The high seeding density mix (45 seeds/species/inch^2) was applied to 20 of the plots, and a very high density mix (90 seeds/species/inch^2) was applied to 16 of the plots.

In a separate, less formal test, the practicality and cost effectiveness of growing and transplanting plant materials were examined (planting test plots). The 2000 monitoring of the planting test plots is described in the *Transplant Survival* portion of the *Results and Discussion* section.

Table 1. Seeding Rates 1999 Montana Revegetation test Plots

		SEED DENSITY			
		Lower Density Plots		Higher Density Plots	
Scientific Name	Common Name	PLS† (lbs/ac)	Seeds/ft^2	PLS (lbs/ac)	Seeds/ft^2
Deschampsia caespitosa	Tufted hairgrass	0.88	45	1.75	90
Poa alpina	Alpine bluegrass	1.48	45	2.95	90
Phleum alpinum	Alpine timothy	1.25	25	2.5	50
Festuca ovina	Sheep fescue	1.75	32.5	3.5	65
Trisetum spicatum	Spike trisetum	0.38	12.5	0.75	25
Antennaria lanata	Wooly pussytoes	0.40	45	0.8	90
Artemisia scopulorum	Rocky Mountain sage	1.02	45	2.05	90
Lupinus argentea	Lupine	7.50	4.5	15.0	9
	Total	14.66	254.5	29.3	509

†PLS = Pure Live Seed

METHODS

On September 20 and 26, 2000, ERO monitored the revegetation test plots by visiting the revegetation test plots and recording information on the sites' vegetation and soil. Quantitative monitoring was conducted in all 36 revegetation test plots, and involved measurement of vegetation cover, species richness in five 20 cm x 50 cm (7.8 inch x 19.8 inch) randomly chosen quadrats in each test plot. In each quadrat, cover values were recorded for each vegetation species, rock, soil, litter, and erosion control fabric. One sample of soil nutrients and organic matter was collected from each test plot.

Results were compared using parametric or non-parametric Analysis of Variance (ANOVA), Tukey's Tests, paired T-Tests, and non-parametric Rank Sum Tests. Total vegetation cover data for each treatment were analyzed using ANOVA. When the ANOVA indicated a significant treatment effect, Tukey's tests were conducted to determine which treatment groups had significant differences. The total vegetation cover data also were grouped and compared according to organic amendment treatment, soil treatment, and seeding treatment. All test plots that were treated with organic matter were grouped together (16 plots, 80 quadrats) and tested against those treated with Kiwi™ products (16 plots, 80 quadrats) and against the control plots (4 plots, 20 quadrats). Likewise, all higher seeding rate data were compared to lower seeding rate data, and all data from plots with topsoil were compared to plots without topsoil.

Soil Quantitative Monitoring

One soil sample was collected from each of the 36 test plots. The Colorado State University Soils Laboratory analyzed the samples for pH, electrical conductivity, organic matter, nitrate-nitrogen, phosphorous, potassium, zinc, iron, molybdenum, and copper; texture and lime (carbonates) were estimated. The soil parameters examined in this report are organic matter, nitrogen, phosphorus, and potassium, were statistically analyzed and the results are discussed in this report. Soil sample results were analyzed statistically using ANOVA and Tukey's tests.

Species Richness Quantitative Monitoring

Species richness, or the number of plant species present, was recorded in each plot, and the species richness of all treatments was compared. Species richness data from each plot were grouped into each treatment. Quadrat data from the 36 plots were grouped into nine treatment groups; for each treatment, 20 quadrats from four plots were analyzed. Species richness data for all treatments were analyzed statistically using ANOVA. Species richness data were also grouped according to organic amendment treatment, soil treatment, and seeding treatment, and compared using T-Tests in the same manner that vegetation cover treatments were grouped (i.e., all topsoil treatments were grouped and compared with all non-topsoil treatments, regardless of seed or organic amendment treatment).

Apparent Soil Moisture

During revegetation test plot monitoring, some plots were holding moisture more than others. Total vegetation cover on the plots that apparently had moister soils was noted, and was statistically analyzed. Dunn's pairwise tests were conducted to determine the effect of apparent soil moisture on vegetation cover.

Transplant Survival

Percent survival of transplants was determined by counting the live plants present in the fall of 2000. The estimated cost of collecting seed for and growing the transplants versus the estimated cost of seed collection and seeding was examined on a cost/square foot basis.

RESULTS AND DISCUSSION

All raw data and statistical output are presented in the 2000 Monitoring Report, Montana Borrow Area Revegetation Test Plots for the Beartooth Highway, portions of U.S. 212 (FH 4) Wyoming and Montana (ERO 2001). All of the results listed as being statistically significant are significant at a probability of 0.05 or less.

For clarity, the following abbreviations are used in discussing the results:

O	Organic matter
K	Kiwi™ products
L	Lower seeding rate
H	Higher seeding rate
S	Salvaged topsoil
N	No salvaged topsoil
C	Control

For example, the abbreviation OLS means a plot was treated with organic material, lower seeding rate, and topsoil.

Vegetation Cover Analysis

All Treatments

The ANOVA conducted on vegetation cover showed significant differences among treatments. The treatments with the highest mean percent cover were OHS, OLS, and KLN. The treatments with the lowest mean cover were C, KLS, and KHS. The groups between which there were statistically significant differences (P = 0.05) were (Table 2) OHS v. C, OHS v. KHS, OHS v. KLS, OLS v. C, KHN v. C, and KLN v. C.

Table 2. Vegetation cover analysis: all treatments.

TREATMENT	Mean Vegetation Cover (%)	TREATMENT								
		C	KLS	KHS	KLN	KHN	OLS	OHS	OLN	OHN
C	14.55				Y	Y	Y	Y		
KLS	17.75							Y		
KHS	17.15							Y		
KLN	22.05	Y								
KHN	21.45	Y								
OLS	21.80	Y								
OHS	23.50	Y	Y	Y						
OLN	18.85									
OHN	19.20									

Y = significant difference (P=0.05)

The results from the ANOVA on the first year data show that four of the treatments (KLN, KHN, OLS, OHS) yielded significantly higher cover than the control treatment, and that OHS yielded higher cover than KHS and KLS. However, no general trends are apparent at this point. It may take several years before statistical differences among treatments are apparent.

Soil Treatments

When vegetation cover was separated according to soil treatment only, vegetation cover was significantly higher on plots treated with and without topsoil than the control plots (P=0.05) (Table 3). There was no significant difference between plots with and without topsoil. This statistical test was meant to test for the effect of soil treatments, but it appears from this result that any organic amendment is better than none. Although there were differences between both treatments and the control, the topsoil treatment was not statistically different from the no topsoil treatment. Both the topsoil (S) and non-topsoil (N) treatments were treated with an organic amendment, either Kiwi™ products or organic matter, but the control was not. A difference in vegetation cover on the non- topsoil treatment plots and the control plots can be attributed to the application of an organic amendment to the non-topsoil plots.

Table 3. Vegetation cover analysis: grouped by soil treatments.

TREATMENT	Median Vegetation Cover (%)	TREATMENT		
		C	S	N
C	15.50		Y	Y
S	19.00	Y		
N	20.00	Y		

Y = significant difference (P=0.05)

Organic Amendment Treatments

When vegetation cover data was analyzed according to organic amendment treatment only, vegetation cover on both treatments was significantly higher than on the control plots (Table 4).

Table 4. Vegetation cover analysis: grouped by organic amendment treatments.

TREATMENT	Median Vegetation Cover (%)	TREATMENT		
		C	K	O
C	15.50		Y	Y
K	18.50	Y		
O	20.00%	Y		

Y = significant difference (P=0.05)

Seeding Rate Treatments

Cover was significantly higher for both seeding rate treatments than the control plots, which were seeded with the lower seeding rate (P=0.05) (Table 5). There was no significant difference in vegetation cover between the higher seeding rate and the lower seeding rate. These results lead to the conclusion that there is a positive effect from the application of any organic amendment, because the lower seeding rate was used on the control plots and on the test plots with organic amendments and lower seeding rate.

Table 5. Vegetation cover analysis: grouped by seeding treatments.

TREATMENT	Median Vegetation Cover (%)	TREATMENT		
		C	L	H
C	15.50		Y	Y
L	19.00	Y		
H	20.00	Y		

Y = significant difference (P=0.05)

Species Richness

The species richness of each treatment was examined using ANOVA. The analysis detected no statistically significant difference between the test plot treatments (P=0.05). The species richness data also were grouped according to soil treatment, organic amendment treatment, and seeding rate, and examined using a T-Test. The T-Test revealed no significant differences between the groups.

There could be three reasons for the lack of a significant difference between treatments. First, there may actually be no difference in species richness. Second, the sample size may be too small to detect a difference. Third, it is possible that only a few species are capable of voluntarily establishing at a high elevation site. Although some plots or treatments may have more individuals, or more of a given species, all of the plots could have one or two individuals of this same set of species, making it difficult to detect a significant difference. Over time, a difference may become apparent. Also, it may be necessary to test species-specific cover differences between treatments.

Apparent Soil Moisture

During revegetation test plot monitoring, it was observed that some plots were retaining more moisture on the soil surface than others, which could be attributed to differences in soil texture, snow ablation, or drainage patterns on the test plots. Total vegetation cover on the plots that apparently had moister soils (Plots 3-OHS, 4-KHN, 5-KLN, 17-KLS, 23-C, 32-KHN, and 34-KHN) was statistically compared to those that had drier soils. The effect of soil moisture on vegetation cover could be confounding the effect of the treatments on these plots, especially because five of the seven plots that apparently retained soil moisture are plots treated with Kiwi products, and of these five, four are plots that were not treated with topsoil.

T-Tests and the Rank Sum Tests showed that vegetation cover was statistically significantly different between plots that held water and those that did not. The plots that held water (median cover 20.05%) had significantly higher vegetation cover than those that did not (median cover 18.00%).

Soil moisture was not measured in 2000, so the groupings of plots with apparent soil moisture are based on researcher observations of the plots. In the fall of 2001 and in future monitoring, soil moisture levels will be measured with soil moisture probes.

Soil Laboratory Analysis

A soil sample was taken from the top 15cm (6 inches) on each test plot and analyzed by the Colorado State University Soil Laboratory. The results from these analyses are presented in Appendix B. The soil samples were grouped according to treatment (four samples/treatment), and ANOVA and Tukey's tests were performed on the data. For the phosphorous data, a non-parametric ANOVA on Ranks was necessary because the data were not normally distributed. The variables tested were organic matter, phosphorous, potassium, and nitrate.

Organic Matter

The ANOVA of the soil data indicated that percent organic matter varied significantly between treatments. All plots with the highest percent organic matter were treated with topsoil, and either Kiwi™ products or organic material (Table 6).

Tukey's tests revealed significant differences between the following treatments: OLN v. KLN, OLN v. C, OLN v. KHN, OHN v. C, OLS v. KLN, OLS v. KHN, OLS v. C, KLN v. OHN, KHN v. OHN, KLS v. KLN, KLS v. C, KLS v. KHN, KHS v. KLN, KHS v. C, and KHS v. KHN.

Table 6. Soil laboratory analysis: organic matter.

TREATMENT	Mean Organic Matter (%)	TREATMENT								
		C	KLS	KHS	KLN	KHN	OLS	OHS	OLN	OHN
C	3.38		Y	Y			Y		Y	Y
KLS	7.78	Y			Y	Y				
KHS	6.98	Y			Y	Y				
KLN	3.15		Y	Y			Y		Y	Y
KHN	3.40		Y	Y			Y		Y	Y
OLS	6.63	Y			Y	Y				
OHS	5.5									
OLN	8.00	Y			Y	Y				
OHN	6.05	Y			Y	Y				

Y = significant difference (P=0.05)

The three treatments with the lowest percent organic matter were the control treatment and the two treatments that combined Kiwi™ products and no topsoil. The three treatments with the highest percent organic matter were treated with either topsoil and Kiwi™ products (KLS and KHS) or organic matter (OLN). All plots with significantly higher organic matter were treated either with topsoil or organic matter. Table 7 shows the relationship between soil organic matter, nutrients and vegetation cover. There is no clear relationship between organic matter and soil nutrients and vegetation cover at this time.
Over the monitoring period, however, a more clear relationship may develop.

Table 7. Soil laboratory analysis and vegetation cover.

TREATMENT	Mean Veg. Cover (%)	Mean OM (%)	NO3 (ppm*)	Median K (ppm)	Median P (ppm)
C	14.6	3.4	19.3	381.3	33.4
KLS	17.8	7.8	241.5	273.5	8.8
KHS	17.2	7.0	214.0	255.5	6.8
KLN	22.1	3.2	38.5	253.0	27.8
KHN	19.1	3.4	11.8	276.3	12.2
OLS	18.7	6.6	87	670.8	74.0
OHS	23.5	5.5	187.5	845.5	78.0
OLN	18.9	8.0	48.2	866.8	130.0
OHN	21.5	6.1	119.5	879.5	132.0

*The laboratory results for nitrates varied widely and may not be accurate. Further testing may yield more accurate results.

Phosphorous

An ANOVA on Ranks conducted on the phosphorous data revealed significant differences between the following treatments (Table 8): OHN v. KHS, OHN v. KLS, OLN v. KHS, and OLN v. KLS.

Table 8. Soil laboratory analysis: phosphorous.

TREATMENT	Median Phosphorus (ppm)	TREATMENT								
		C	KLS	KHS	KLN	KHN	OLS	OHS	OLN	OHN
C	33.40									
KLS	8.75								Y	Y
KHS	6.80								Y	Y
KLN	27.75									
KHN	12.20									
OLS	74.00									
OHS	78.00									
OLN	130.00		Y	Y						
OHN	132.00		Y	Y						

Y = significant difference (P=0.05)

These statistics are difficult to interpret, and further tests during subsequent years of the monitoring period may reveal more about the relationship of this nutrient and vegetation cover. The plots on which Kiwi™ products were combined with salvaged topsoil had lower phosphorous levels than the plots with Kiwi™ products and no salvaged topsoil. Phosphorous is an important nutrient for seed germination, and the soil phosphorous results could help to explain why Kiwi™ plots without topsoil had higher vegetation cover than Kiwi™ plots with topsoil (Table 2).

Potassium

The ANOVA and Tukey's tests revealed significant differences in potassium concentrations in the treatments (P=0.05) (Table 9). All treatments with organic matter had significantly higher potassium levels than those without. Based on these results, organic matter, or fertilizer with which it was applied, apparently adds potassium to the soil.

Table 9. Soil laboratory analysis: potassium.

TREATMENT	Median Potassium (ppm)	TREATMENT								
		C	KLS	KHS	KLN	KHN	OLS	OHS	OLN	OHN
C	381.25						Y	Y	Y	Y
KLS	273.50									
KHS	255.50						Y	Y	Y	Y
KLN	253.00						Y	Y	Y	Y
KHN	276.25						Y	Y	Y	Y
OLS	670.75	Y		Y	Y	Y				
OHS	845.50	Y		Y	Y	Y				
OLN	866.75	Y		Y	Y	Y				
OHN	879.50	Y		Y	Y	Y				

Y = significant difference (P=0.05)

Nitrates

Nitrate levels between the treatments were not significantly different. The analytical results for nitrates varied widely with some concentrations far exceeding the expected range for this nutrient. The variability of nitrate levels within each treatment was almost as high as the variability among treatments, so no statistical differences could be detected. The Colorado State University Soil Lab rechecked the data and re-ran the suspect nitrate tests, but the results were similar to the first analysis. Nitrate concentrations will be re-evaluated in 2001.

Transplant Survival

Thirteen species grown from seed collected on the Beartooth Plateau were planted on June 27, 2000. The transplants were monitored on September 26, 2000. The number of live plants of each species in the two planting areas was counted to determine the percent survival. The results are listed in Tables 10 and 11. All of the transplant test plots were treated with organic matter, fertilizer, and erosion control blankets in the same manner as the revegetation test plots treated with organic matter. It is important to note that the above-ground portions of some plants apparently became dormant in the fall of 2000, as larger number of plants were recorded in the fall 2001 monitoring (not included in this paper).

Table 10. Percent survival in planting area 1 (north of revegetation plots, south-facing slope).

Scientific Name	Common Name	No. Planted	No. Live*	% Survival
Grasses and Sedges				
Carex paysonii	Payson's sedge	20	4	20
Carex scirpoidea	Downy sedge	17	13	76
Deschampsia caespitosa	Tufted hairgrass	20	20	100
Festuca ovina	Sheep fescue	20	14	70
Phleum alpinum	Alpine timothy	20	10	50
Poa alpina	Alpine bluegrass	20	15	75
Trisetum spicatum	Spike trisetum	20	6	30
	Total Grass Survival	**137**	**82**	**60**
Forbs				
Antennaria lanata	Woolly pussytoes	20	2	10
Artemisia scopulorum	Rocky Mountain sage	20	5	25
Geum rossii	Alpine avens	20	5	25
Lupinus argenteus	Silvery lupine	20	4	20
Sibbaldia procumbens	Sibbaldia	20	8	40
Trifolium parryi	Parry's clover	20	3	15
	Total Forb Survival	**120**	**27**	**23**
	Total	**257**	**109**	**42**

*Note: Because most grass and sedge species did not produce seed heads in 2000, differentiation between species was difficult, especially in the case of *C. scirpoidea* and *C. paysonii.*

Table 11. Percent survival in planting area 2 (south of revegetation plots, north-facing slope).

Scientific Name	Common Name	No. Planted	No. Live*	% Survival
Grasses and Sedges				
Carex paysonii	Payson's sedge	20	7	35
Carex scirpoidea	Downy sedge	18	17	94
Deschampsia caespitosa	Tufted hairgrass	20	20	100
Festuca ovina	Sheep fescue	20	17	85
Phleum alpinum	Alpine timothy	20	16	80
Poa alpina	Alpine bluegrass	20	18	90
Trisetum spicatum	Spike trisetum	20	5	25
	Total Grass Survival	**138**	**100**	**72**
Forbs				
Antennaria lanata	Woolly pussytoes	20	5	25
Artemisia scopulorum	Rocky Mountain sage	20	6	30
Geum rossii	Alpine avens	20	8	40
Lupinus argenteus	Silvery lupine	20	3	15
Sibbaldia procumbens	Sibbaldia	20	16	80
Trifolium parryi	Parry's clover	20	3	15
	Total Forb Survival	120	41	34
	Total	**258**	**141**	**55**

*Note: Because most grass and sedge species did not produce seed heads in 2000, differentiation between species was difficult, especially in the case of *C. scirpoidea* and *C. paysonii.*

On the south-facing slope, total transplant survival was 42% after the first year. Grass and sedge survival was 60% and forb survival was 23%. On the north-facing slope, total survival was 55%. Grass and sedge survival was 72% and forb survival was 34%. Total survival and forb survival may be higher on the north-facing slope because more moisture is retained than on a south-facing slope, where moisture evaporates more readily.

CONCLUSIONS

Vegetation Cover Analyses

The ANOVA on all treatments revealed that there half of the experimental treatments yielded higher vegetation cover than the control plots, but the ANOVA did not show any conclusions about which organic amendment, soil, or seeding treatment yielded higher cover. Because 2000 was only the first year of monitoring, the results only indicate the germination and emergence success of the plots. Revegetation generally takes from 3 to 5 years, so the effects of the treatments may not be evident for a few more years. Also, the lack of statistical differences detected by this ANOVA could be related experimental variability. For example, there may be experimental variability related to the site topography or microsites created by rocks and general drainage patterns. Seven plots apparently held more moisture than other plots (Plot 3-OHS, 4-KHN, 5-KLN, 17-KLS, 23-C, 32-KHN, and 34-KHN).

Vegetation cover data were analyzed according to only one treatment (soil treatment, organic amendment treatment, or seed treatment) to test the effect of the one treatment. The results showed that plots with any organic or soil treatment had statistically higher vegetation cover than the control plots (to which fertilizer and seed, at the lower seeding rate, were applied).

Soil Treatments

There was no statistically significant difference in vegetation cover between the plots treated with topsoil than those that were not. Plots treated with organic matter and those treated with Kiwi™ products had statistically higher vegetation cover than the control plots.

Organic Amendment Treatments

When vegetation cover data were analyzed according to organic amendment treatment, the plots treated with organic matter had significantly higher vegetation cover than those treated with Kiwi™ products. Plots treated with Kiwi™ products had significantly higher vegetation cover than control plots.

Seeding Rate Treatments

There was no significant effect of seeding rate, which probably indicates that a lower seeding rate is sufficient. The lower rate used on the plots is representative of a standard seeding rate used in reclamation. Alpine revegetation researchers, however, have speculated that higher seeding rates may be appropriate in revegetating alpine disturbances where extreme environmental conditions are limiting to vegetation establishment, and plant competition may be a less important variable. However, there may be a threshold beyond which higher seeding rates have diminishing returns and beyond which competition increases, potentially lowering diversity.

Soil Laboratory Analyses

Organic Matter

Topsoil and organic material (compost) are important sources of organic matter. Because organic matter is known to reduce bulk density and increase available water holding capacity, treatments that increase percent organic matter may be important for increasing soil moisture content. The soil moisture tests that will be analyzed in future monitoring will examine this. The topsoil used in this experiment was obtained from a borrow site about 100 meters (300 feet) south of the revegetation test plots.

Phosphorous

The data regarding phosphorous are difficult to interpret. Plots to which Kiwi™ products were applied along with topsoil had significantly lower phosphorous than those where organic material was applied to plots without topsoil.

Potassium

Potassium was higher on plots with organic matter, regardless of topsoil treatment. The plots with the lowest potassium concentrations were plots to which Kiwi™ products and topsoil were applied. Lower levels of both phosphorous and potassium were found on plots with Kiwi™ products and topsoil. It is possible that the microbes present in the Kiwi™ products deplete these nutrients from topsoil; however, the microbes potentially also deplete phosphorous and potassium from plots on which topsoil was not applied.

Apparent Soil Moisture

Several plots appeared to retain more moisture than others. The plots that retained moisture had significantly higher vegetation cover than the others. This demonstrates that available water is potentially more important than any soil amendment, topsoil salvaging, or seeding rate. While it is not practical to irrigate disturbances at this elevation, water appears to be the limiting factor in establishing vegetation in these revegetation plots, and surface mulches and organic amendments that retain soil moisture may be important in alpine areas.

Transplant Survival

On the south-facing test plot, 60% of the grass plugs planted survived, 23% of the forbs survived, and a total of 42% of the transplants survived. On the north-facing slope, 72% of the grass plugs planted survived, 34% of the forbs planted survived, and a total of 55% of the transplants survived the first growing season. These results are preliminary, and much higher success was recorded during fall 2001 monitoring.

Species Richness

There was no significant treatment effect on species richness. This may be due to the limited number of species capable of colonizing the plots or because of the high variability within treatments.

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EVALUATION OF THE POT-IN-POT SYSTEM FOR PRODUCTION OF ROCKY MOUNTAIN NATIVE TREES

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ABSTRACT

A nursery system, the Pot-In-Pot (PIP) system, has a potential application for production of native trees for revegetation applications. A first growing season evaluation of the PIP system has been completed. Multi-stem trees of *Alnus tenufolia and Betula occidentalis* were grown in a pair of #20 commercial containers designed for the PIP system. Two main experiments were conducted. The first experiment compared two above-ground and two below-ground PIP systems. The second experiment evaluated the effect of doubling the recommended rate of slow release fertilizer and doubling the amount of irrigation water on tree growth. Trees in the second experiment were grown in a conventional, below-ground PIP system. Tree growth data from the first experiment indicate that plants of both species, when grown in below-ground containers, outperformed those grown in above-ground containers. The data from the second experiment, the fertilizer and irrigation water trial, indicate that water was a limiting factor for growth, as trees that received double amount of water had largest increase in diameter of trunks. The temperature of the growing medium, an artificial mix containing 1/3 soil by volume, was monitored during the later part of the growing season. The media temperature in above-ground pots fluctuated; in contrast to the temperature of the in-ground containers which was stable and followed closely soil temperature. Salinity-like symptoms were observed on mature leaves of both tree species tested, the symptoms were more severe on alder than birch trees. The differences in growing medium infiltration rates, among containers, were observed and measured. These infiltration rate differences accounted for some variability in tree performance. The plants are over wintered in the field at the site of experiment and the trial will continue during the 2002 growing season.

EROSION AND SEDIMENT CONTROL AT THE WHITE PINE MINE ONTANOGAN COUNTY, MICHIGAN

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Lakewood, CO

ABSTRACT

The White Pine Mine is a closed underground copper mine with over 2,226 hectares (ha) (5,500 ac) of erosive tailings located in three separate surface impoundments. The site is located between the shore of Lake Superior and the town of White Pine, Michigan. The following paper discusses methods used to control wind erosion at the site. During operations, continual slurry deposition protected the tailings from wind erosion. Upon mine closure, the tailings surface dried and severe dusting events occurred during dry, windy periods. During winter the tailings are wet or snow-covered and the prevailing southwesterly winds take dust toward Lake Superior. However, during summer months, the tailings can dry between storms. During this season, the prevailing northeasterly winds can blow a wall of dust over the town of White Pine. To select the best closure alternative, an evaluation was conducted and direct revegetation of the tailings was selected as the primary means of erosion control. Past research indicated revegetation of the tailings would be difficult due to:

- Lack of water and nutrient holding capacity;
- Abrasion from saltating sand and silt;
- The physical nature of the silt/sand sized tailings; and,
- Chemical imbalances.

A site evaluation was conducted to identify:

- Existing vegetation tolerant of site conditions;
- The physical and chemical make-up of the tailings; and,
- Existing sources of organic amendments in proximity to the mine.

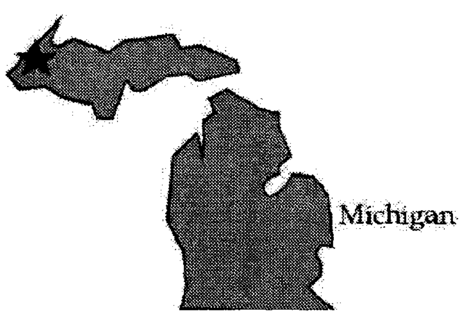
During the site evaluation, copper was identified at potentially phytotoxic levels in the tailings. Local paper mill sludge, previously slated for land-filling, and wood-chips, were identified as inexpensive amendments which would effectively treat the phytotoxicity concerns. A greenhouse study was developed in which four organic amendment rates, two inorganic fertilizer rates and fourteen plant species were tested. Boron, Phosphorus, Manganese, and Nitrogen deficiencies were identified during the greenhouse study. The results of the greenhouse study were used to develop large-scale field trials that compared ten physical methods of wind erosion protection. Crimped straw mulch, combined with

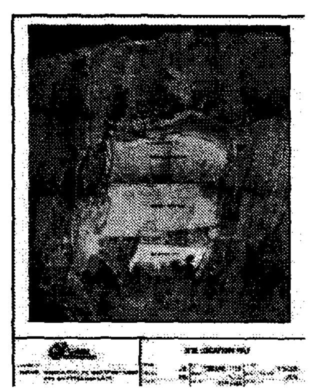
revegetation, was identified as an effective means to control wind erosion. The results of the field trial were used to develop specifications for the entire site. Approximately 202 ha (500 ac) were fully treated using the paper mill sludge and another 486 ha (1,200 ac) were temporarily stabilized using a green manuring approach in 1999. Additional acreage was treated in 2000. No dusting events have occurred since 1999 and the site is well on the way toward permanent stabilization.

INTRODUCTION

The White Pine Mine is owned and operated by the Copper Range Company, a subsidiary of Inmet Mining Corporation. It is located in Ontanogan County, Michigan along the shores of Lake Superior in a region known as the Upper Peninsula of Michigan. The project was in operation for over 70 years and is currently in the process of site wide closure. The project consists of an underground copper mine, processing facilities, and approximately 2,630 ha (6,500 ac) of tailings. The tailings are impounded in three separate facilities: the South Dam; North Pond 1; and North Pond 2. The South Dam was not filled to capacity, and was closed and stabilized by dozing the surrounding remaining embankment clays onto the tailings surface, and revegetating using standard agricultural means. The North Pond 1 and 2 tailings facilities, which total approximately 2,023 ha (5,000 ac), are being stabilized from wind and water erosion by direct revegetation of the tailings themselves. Previous attempts to establish vegetation on the tailings were initially successful, but after two to three years a dieback of vegetation occurred, and ultimately failure. The sand blasting effect of the blown tailings, burial by the moving dunes of tailings, the physical nature of the tailings, and possibly chemical or nutrient imbalances, were all suspected of causing the failure. The tailings have remained relatively barren for over 20 years.

In 1997, a program was undertaken to logically and scientifically identify the reasons for the past failures, and determine if direct revegetation was a feasible means of stabilizing the tailings. The importation of sufficient clay material to cover the tailings facilities would cost over $72,000,000. Therefore, a self-sustaining and permanent means of directly revegetating the tailings was highly desirable. The following paper discusses the methods used since 1997 to control wind blown tailings sufficiently to establish vegetation, which has been the ultimate means of controlling erosion from the site.





Climate and Setting

The Mine is situated about 2.4 kilometers (km) (1.5 miles) south of the shore of Lake Superior, at a Latitude of 47^0 North. The climate is cold and wet in the winter and hot and wet in the summer. The growing season is short (June to October). There are seasonal winds, which are from the southwest in the winter and from the northeast in the summer. Precipitation is approximately 96.5 centimeters (cm) (38 inches (in)), distributed monthly as shown below:

Month	White Pine, Michigan			
	Avg. Total Precipitation		Average Total Snowfall	
	cm	in.	cm	in.
January	8.38	3.30	8.38	3.30
February	5.21	2.05	5.21	2.05
March	6.35	2.50	6.35	2.50
April	10.49	4.13	7.87	3.10
May	2.67	1.05	0.64	0.25
June	12.14	4.78	0.00	0.00
July	14.76	5.81	0.00	0.00
August	3.51	1.38	0.00	0.00
September	6.43	2.53	0.00	0.00
October	10.41	4.10	0.33	0.13
November	8.26	3.25	4.57	1.80
December	7.70	3.03	7.70	3.03
Totals	**96.31**	**37.91**	**41.05**	**16.16**

Reclamation Goals

The 1997 goals for reclamation of the tailings included the following:

- Minimize Wind Erosion and Wind Born Dust
- Minimize Water Erosion and Sediment Transport
- Reduce Deep Percolation of Precipitation by Increasing Evapotranspiration
- Establish a Low/No Maintenance, Stable, Self-Sustaining Plant Community Which Will Promote "Natural" Succession

The intent of the revegetation plan is to control amounts of organic matter, nutrient inputs and species composition during reclamation in order to encourage microorganism establishment. The successful establishment of soil microorganisms necessary for decomposition will allow natural nutrient cycling to begin. Ultimately, the cycling will lead to improved ecosystem stability, ground cover, and erosion control. Initially, in a barren tailings, establishing this cycle requires adding a supply of organic matter and nutrients approximating a natural system that will lead to a stand of vegetation which functions as a self-sustaining ecosystem. An alternative approach might be to intermittently apply inputs of nitrogen. However, high and continual inputs of nitrogen inhibit soil microorganism development and often lead to stagnant vegetation and soil microbial communities, unable to cycle nitrogen and other nutrients.

Technical Approach

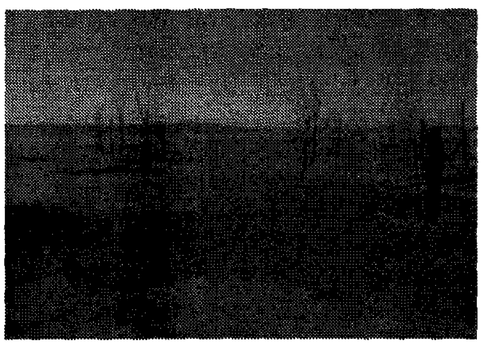
The technical approach taken for the project was to logically and scientifically determine the limiting factors to plant establishment and find the most cost effective method of addressing these factors. The following tasks were undertaken to accomplish this:

- Review existing information
- Evaluate site conditions
- Survey the existing vegetation in the area
- Conduct an agricultural and geochemical soils survey of the tailings
- Conduct a survey for sources of organic matter
- Conduct a greenhouse study
- Test erosion control methods in a field trial
- Develop and implement full scale revegetation

Each of these tasks are discussed in detail below.

Review of Existing Information

An initial site investigation and records search identified that prior revegetation research had been done during the mid to late 1960s. This work had involved the installation of several test plots including a number of species and planting methodologies. No soil agricultural- or geo-chemistry testing had been done associated with the trials, other than metallurgical work related to ore quality control.



Initially, the results of these trials were encouraging. However, after approximately five years, the vegetation was identified as being chlorotic (yellowing or spotting) or had died. The final conclusions were that the abrasive nature of the wind blown tailings, the sterile and low water and nutrient holding capacity of the tailings, and possibly phytotoxicity related to soil chemistry, were too severe to allow direct revegetation of the tailings. No further study had been conducted.

Evaluation of Site Conditions

The 1997 evaluation of site conditions indicated that the tailings facilities were large enough to generate their own microclimate. Although the area is relatively moist, with an average annual precipitation of almost 96.29 cm (38 in) and cool temperatures during most of the year, the tailings are more accurately characterized as a desert ecosystem. The tailings allow precipitation to quickly infiltrate and the surface dries within hours of a rainfall. The surface few inches of tailings, when dry, blow and develop dunes that move across the site. The tailings are a light to medium gray in color, which leads to solar heating. When the moisture levels drop due to drying, and evaparative cooling stops, the soil temperatures can climb to over 37.7^{0}C (100^{0}F) in the summer months.

The tailings facilities were constructed by building the embankments around the detainment area, and then depositing tailings. No vegetation removal occurred prior to deposition. The topography of the area includes low ridges and shallow valleys, which traverse the impoundments from east to west. Therefore, where ridge tops occurred, there are areas within the tailings with exposed natural soils, standing dead trees and shallow tailings. Where valleys occurred, there are only barren areas of tailings up to 24.38 meters (m) (80 ft) deep.

The areas of natural soils are islands of well-established native and introduced species. Within the areas of standing dead trees, some re-colonization has occurred. Where enough organic matter had fallen and decomposed, and sufficient protection from wind erosion was provided by the standing and fallen timber, some soil development and sparse vegetation had taken hold. These areas were relatively few, but provided evidence that under the right conditions, vegetation could survive.

Survey of Existing Vegetation In The Area

The existing vegetation in the area was surveyed to determine if there were species adapted to the local site conditions, which would survive on the tailings. A second purpose of the survey was to determine if any natural means of re-colonization were occurring which could be emulated for reclamation. Numerous species common to the *Tsuga-Pinus*-northern hardwoods ecotone, typical of the region, inhabit the undisturbed and disturbed clay soil areas around the tailings facilities. The timber immediately around the mine site has been harvested and a secondary forest of *Populus tremuloides* (Aspen) currently dominates most of this area. Reclamation seed mixtures used over the years have been very successful when sown on the native clay soils and growth from these mixtures is also present around the site.

Historic aerial photographs of the tailings indicated that the North Pond 1 tailings facility had been covered with vegetation to varying degrees over the past 20 years while the other two facilities had remained barren of vegetation. At different times, North Pond 1 had been totally barren, almost entirely covered, and at the time of the study, was approximately one third covered. The survey indicated that the vegetation was composed of just one species; *Agrostis alba* (Redtop). Apparently, this species had been introduced during the trials conducted in the 60s, or in past reclamation work around the facility, and had been able to spread across the site when conditions were favorable and died back when they were not. Further investigation into the operations of the facility pointed out that the water level and source had fluctuated over the years. When only precipitation water entered the facility the water level was low. However, during some periods mine dewatering was routed into North Pond 1 and the water level would increase dramatically. The mine water was saline and when flows were slowed or diverted elsewhere, a barren beach would develop. Repeated periods of this scenario have enabled the *Agrostis alba* present on-site to differentiate into a variety well adapted to the site conditions.

The only other species found growing on the tailings was *Equisetum arvense* (Field horsetail). This species was typically found on the lower slopes of the embankments and near permanently saturated areas.

Agricultural and Geochemical Soils Survey

A systematic survey of the tailings material was conducted by grid sampling each facility. Approximately 50 samples were collected and analyzed for agricultural and geochemical parameters. Based on the results, the tailings could be segregated into four different categories: Embankment sands; Saline tailings (only found in North Pond 1 barren areas); Typical tailings (all other tails within the impoundments); and, Slimes (located under the standing pools of water on each facility). The analysis confirmed the suspected results that the tailings were a relatively sterile, silty sand with little to no organic matter. A very neutral 7.0 to 7.5 pH was consistent with all samples. Calcium was relatively high and no acid generating capability was detected.

Unexpected results were that the barren areas within North Pond 1 were significantly more saline than any of the other areas, the surface few inches of tailings were consistently sand while a clay and silt fraction existed below, and almost all of the copper was plant available. The higher salinity may partially answer the question of why approximately one third of North Pond 1 was barren, while another third was supporting *Agrostis alba*. It was expected that sandier tailings would be found close to the points of deposition, while progressively finer sized tails would be found as you moved toward the standing pools on each facility. The results indicated this to be true for the tailings down more than a half meter below the surface. However, the surface several centimeters of tailings were consistently sand while finer particle sizes were found below. Wind action had most likely scoured the top several centimeters of clay and silt sized particles away as dust and deposited them elsewhere while the sands remained as dunes.

Elevated copper levels are to be expected in copper mine tailings. At the White Pine Mine the total copper levels vary from zero to about 1,300 parts per million (ppm). The ammonium bicarbonate diethylenetriaminepentaacetic acid (AB-DTPA) method was used to extract plant available copper from the tailings. The results indicated that virtually all of the copper was loosely held and could be available for uptake by plants.

Although some heavy metals (Cu and Zn) are essential for plant growth, it is now well documented that when present at elevated levels in soils they are generally phytotoxic and can ultimately cause the death of plants (Antonovics, Bradshaw & Turner 1971, Smith & Bradshaw 1979). Generally the metals in soluble forms or adsorbed onto clays are most available for plants (Neuman, et. al 1987). In the presence of high levels of organic matter, humic materials and fulvic acids the plant availability of copper is reduced through the formation of strong complexes with organic matter and humates resulting in slow dissociation rates (McBride 1978, EPA 1992, and Davies et. al. 1978). Numerical thresholds for heavy metals in soils above which phytotoxicity is considered to be possible have been suggested. The copper levels promulgated by the United Kingdom are 140-280 mg/kg EDTA extractable (UK DOE 1980). J.J.M. Bowen (1979) suggested that soil concentrations above 250 mk/kg of total copper may result in phytotoxity. Neuman, et. al 1987 suggested that AB-DTPA extractable copper levels in mine soils from selected western coal mines between 50-210 mg/kg were phytotoxic to plants.

Elevated plant available copper levels cause shortening and excessive branching of the roots. Plants cope with high levels of copper in one of two ways: They can either exclude the copper at the root; or, they can take it up and partition it off in the leaves, stem, roots, or a combination of areas. These mechanisms work well for short periods when levels are low. When the levels are high and/or the plants are exposed for long periods of time, the protection mechanisms can be overwhelmed and the plants will be stunted, chlorotic, or eventually even die after a few years. In actual practice high copper levels can stress the plants to a point where they can no longer tolerate the environmental conditions. It is believed that this was the case with the earlier test plots done in the 60s. When the plants could no longer tolerate the heat, cold, dry periods and physical abrasion from the wind blown tailings, due to impacted rooting systems, they eventually died back.

Survey For Sources of Organic Matter

In almost any direct revegetation project, the organic matter (OM) component of the amendment mixture is generally the highest cost item. Therefore, a search for potential materials was conducted early in the process. In addition to cost, many other factors related to the material are important in making a decision on which material will, ultimately be the best value. The following is a list of factors used to make the decision on the OM for the White Pine Mine:

- Cost
- Availability
- Regulatory Restriction
- Quantities
- Quality
- Particle Size Distribution
- Labile and Recalcitrant Carbon Content
- Carbon: Nitrogen Ratio
- Moisture Content
- Handling Requirements/Restrictions

Initially, biosolids, waste from breweries, yard waste, sawdust, wood chips and paper mill sludge were considered. After careful comparison of all factors listed above, wood chips and wood pulp sludge, which are both waste products of the paper mill industry, were selected. Wood chips are sold in the winter as a fuel, but are disposed in landfills during the summer months. Paper mill sludge was previously being transported to a landfill for disposal. Wood chips provide larger particles, which will break down over time to provide a constant source of OM and carbon. Paper mill sludge has a small particle size and provides an almost immediate source of carbon. The combination of these two materials provided an adequate supply of OM, located within a few miles of the site, which had the desired chemical properties and acceptable regulatory restrictions.

Greenhouse Study

Following the acquisition and review of existing data, the vegetation and soil surveys, and the selection of an OM source, a greenhouse study was designed and conducted to test the initial levels of amendments and plant species response. The greenhouse study was a factorial design with the following variables:

- Organic Matter (dry weight) 0, 1, 3 & 5% (50% Woodchips - 50% Paper Mill Sludge)
- Standard Fertilizer:
  - Nitrogen = 44.82 kg/ha (40 lbs/ac)
  - Phosphorus (P_2O_5) = 67.25 kg/ha (60 lbs/ac)
  - Potassium (K_20) = 44.82 kg/ha (40 lbs/ac)
- Additional Nitrogen for Carbon - Nitrogen Balance = 2.5 kg/tonnes (5 lbs/Ton) Woodchips Applied.
- 14 Species Tested

The 14 plant species (Table 1) to be used were selected based on the following criteria:

- Species observed growing on or near tailings (forbs and grasses only)
- High potential to stabilize tailings
- Known capacity to stabilize sand dunes
- Commercial availability/quantity
- Adapted to tailings chemistry
- Adapted to climate

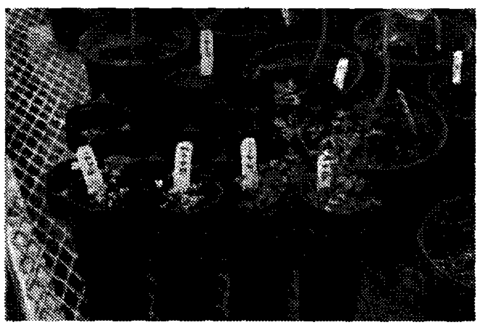
The following list of species was selected for use in the greenhouse study:

Table 1. Species Recommended For Inclusion In Greenhouse Trials

SCIENTIFIC NAME	COMMON NAME
Forbs	
Vicia villosa	hairy vetch
Vicia americana	American vetch
Medicago sativa	alfalfa
Lotus corniculatus	birdsfoot trefoil
Daucus carota	Queen Anne's Lace (wild carrot)
Graminoids	
Phleum pratensis	timothy
Dactylis glomerata	orchardgrass
Agrostis alba	redtop
Bromus inermes	smooth brome
Festuca rubra	red fescue
Ammophila breviligulata	American beachgrass
Elymus racemosa	Volga mammoth wild-rye
Agrostis tenuis	colonial bentgrass
Phragmitis australis	common reed

The initial results from the trial were not encouraging. Many of the plants were stunted and chlorotic and production was far below that believed necessary to stabilize the site. The data suggested that the more OM added, the worse the plants grew. Based on the symptoms displayed by the plants, a list of potential nutrient and micronutrients, which could be deficient was developed. Foliar applications of liquid forms of these nutrients were applied and the results indicated that a deficiency was present. Manganese (Mn), Boron (B), Nitrogen (N) and Phosphorus (P) were all found to be deficient. These nutrients are all easily bound to OM. Therefore, although possibly present in adequate quantities in the tailings, when the OM was added they may have been bound to a point where a deficiency occurred. Since the availability of N to plants is directly related to the Carbon (C):Nitrogen ratio, it was determined that our C:N ratio balance also needed further adjustment. When copper was added as a foliar nutrient, all of the plants died. Therefore, it was determined that copper was probably still present at just below phytotoxic levels.

Analyses of the AB-DTPA extractable metals levels in tailings before and after the greenhouse study indicated that only minor reductions in metals levels had occurred. This result was believed to be due to the limited (12 week) time for soil reactions to occur during the study. More positive results reported in the literature were from studies conducted over periods in excess of 180 days. Therefore, we believe metals reduction is occurring, but will take more time than could be simulated in the greenhouse.



A second round of greenhouse trials was run with fertilizer and amendment levels re-adjusted based on the findings of the first study. The results of this study were more promising and provided the expected results of a positive correlation of better plant growth with higher OM levels.

As can be seen from the following table, the mean mycorrhizal infection rate increased as OM was increased. It is believed that mycorrizal innoculum is being provided by the OM, and that conditions for growth of the microorganisms are being improved in the soil. The OM provides a food source and holds more moisture in the soil for consumption by microorganisms. It also allows better aeration of the soil and moderates temperature extremes. Although testing was not conducted to identify and categorize all microorganisms in the tailings, carbon decomposition rates have been monitored. A significantly higher decomposition rate occurs with the addition of OM. This may indicate that the generally improved conditions for mycorrhizal fungi also benefits other soil microorganisms such as bacteria and actinomycetes.

Effects of Organic Amendment Level on Mycorrhizal Infection Rates

Organic Matter Level (%)	Mean Infection Rate	Significance*
5	1.30	A
3	1.06	B
1	0.88	C
0	0.41	D

* Values with the same letter are not significantly different at the 0.05 confidence level.

Field Trial

Based on the results of the greenhouse study, a factorial design field trial was developed and installed with the following variables:

- **Organic Matter (dry weight) 0, 2, & 3%** (50% Woodchips - 50% Paper Mill Sludge)
- Standard Fertilizer:
  - Nitrogen = 44.82 kg/ha (40 lbs/ac)
  - **Phosphorus (P_2O_5) = 168 kg/ha (150 lbs/ac)**
  - Potassium (K_20) = 44.82 kg/ha (40 lbs/ac)
  - **Boron = 1.12 kg/ha (1 lbs/ac)**
  - **Manganese = 3.36 kg/ha (3 lbs/ac)**
- Additional Nitrogen for Carbon - **Nitrogen Balance = 5 kg/tonnes (10 lbs/Ton of Woodchips Applied.**)

Those elements shown in bold were changed based on results from the greenhouse study. The OM levels in the greenhouse were 0%, 3%, and 5%. The results indicated that adequate growth could be attained somewhere between 0% and 3%. Over 2,023 ha (5,000 ac) a reduction of 1% OM equates to a savings of approximately $2,000,000, therefore it was decided to test 2% in the field trial. Phosporus and Nitrogen were increased, and Boron and Manganese were added based on the identified deficiencies. Tilling of the applied organic material into the soil was also specified to bring about a better mixture of grain sizes for plant establishment and trafficability.

The seed mixture (Table 2) for the field trials was based on the results from the greenhouse and on commercial availability of the necessary quantities at economic prices. Species which were not available as seed, such as *Ammophila breviligulata* (American beachgrass), were eliminated from the trial due to the large scale of the site and expense of hand planting sprigs over an area this large. The final seed mixture used for the field trial is shown below:

Table 2. Standard Seed Mixture[1] 1998 Revegetation Field Trial Copper Range Company White Pine Mine White Pine, Michigan

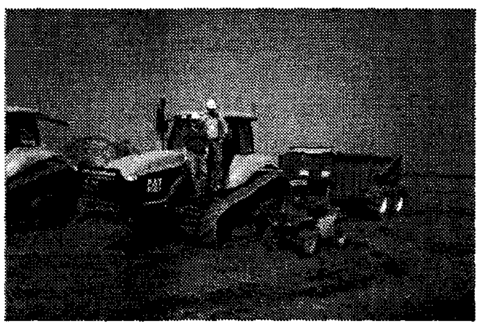
Scientific Name	Common Name	Variety	Origin	Meters	Centimeters	kg/ha
Forbs						
Medicago sativa	alfalfa	Vernal	Alberta, Canada	213 - 335	30.48 – 55.88	3.92
Vicia villosa	hairy vetch	VNS[3]	Hillsboro, Oregon	61 - 91	127	39.01
Graminoids						
Dactylis glomerata	orchardgrass	Potomac	Oregon	91 - 152	88.90 – 127	1.57
Bromopsis inermis	smooth bromegrass	Magna	Canada	213	40.64 – 50.80	8.25
Elymus racemosa	mammoth wild-rye	Volga	Powell, Wyoming	1,219	35.56 – 40.64	6.28
Phleum pratense	timothy	Climax	Alberta, Canada	335	55.88	0.45
Festuca rubra	creeping red fescue	VNS[3]	Alberta, Canada	335	55.88	0.45
Agrostis alba	redtop	Streaker	Idaho	701	55.88	0.45
Hordeum spp.	winter barley	Schuyler	Utah	1,372	38.10	0.11

[1]Seed was obtained from: Granite Seed Company
[2]PLS - Pure Live Seed. Pounds PLS/ac may vary depending upon actual seeds per pound for each seed lot.
[3]VNS - Variety Not Specified = Common

In addition to the variables shown above, ten different erosion control methods were tested in the field trial. Each method is briefly described below:

- Wind Fence: placed 1.22 m (4 ft) high wind fence 9.14 m (30 ft) upwind of each block of plots, and within plots
- Land Imprinting: used imprinter with 30.48 cm (12 in) wide X 45.72 cm (18 in) long X 10.16 cm (4 in) deep prints over entire plot
- Contour Furrowing: cut 1.22 m (4 ft) wide X 0.61 m (2 ft) high furrows across plot at 2.44 m (8 ft) intervals
- Dozer Basins: embankment slopes only, cut 3.35 m (11 ft) wide X 1.22 m (4 ft) long X 0.61 m (2 ft) deep basins at 3.05 m (10 ft) intervals
- Slag incorporation: 56 and 112 tonnes/ha (25 and 50 tonnes/ac) slag tilled into tailings 15.24 cm (6 in) deep
- Windrowing with Slag: slag placed in 0.91 m (3 ft) wide X 0.61 m (2 ft) high windrows
- Hardwood Bark Piles: 3.05 m (10 ft) long X 0.61 m (2 ft) wide X 0.30 m (1 ft) high (1 cu yd) piles placed at rate of 62/ha (25/ac)
- Soil Binder: M-BinderTM applied at rate of 112 kg/ha (100 lbs/ac)
- Surface Mulch: straw placed at 4.48 and 8.96 tonnes/ha (2 and 4 tonnes/ac)
- No erosion control method: control

Field Trial Results



The trial was intended to test not only the effectiveness of each variable and method, but also the practicality and cost of actual implementation. Therefore, large scale test plots of one half acre or more were used so that full sized equipment could be used. It was discovered very early that accessing the tailings with typical heavy equipment would not be practical. Front-end loaders, over the highway dump trucks, standard tracked dozers, and rubber tired farm equipment could not safely access all areas of the tailings. Ultimately, Caterpillar™ "Challenger" tractors, which are equipped with wide rubber tracks, and tandem axle trailers with tracks over the wheels, were required to access the site. All-terrain vehicles (ATVs) were used for personnel and light duty work. A snow cat, which was used to transport seed and other light materials, could access all areas right up to the waters edge, while most of the other equipment had to avoid these areas. In some cases, equipment could travel over an area once, but could not travel over the same area twice without sinking.

Even utilizing the low ground pressure equipment described above, equipment was stuck quite often. For safety reasons, it was imperative that cable be used to pull stuck equipment out. Chains and especially nylon ropes, have been known to cause fatal accidents when they break and snap back, throwing metal hooks at the operators. Slow, constant pulling pressure, with a cable was the most effective method of freeing equipment from the tailings when stuck. Any method of breaking the suction between the equipment and the tailings, helped immensely.

On-going agronomic monitoring of the test plots has indicated that approximately 2% OM incorporation, accompanied with the fertilizer application described above, produces adequate growth to control erosion. The 3% plots produced more vegetative growth, but did not contain the diversity that the 2% plots exhibited. Therefore, 2% OM was selected as the soil amendment specification for the full-scale work.

Plant species selection is an on-going process due to the differing availability of each species each year. The goal is to have a wide enough variety of commercially available species identified that work well at the site to be able to adjust the seed mixture as the seed market changes.

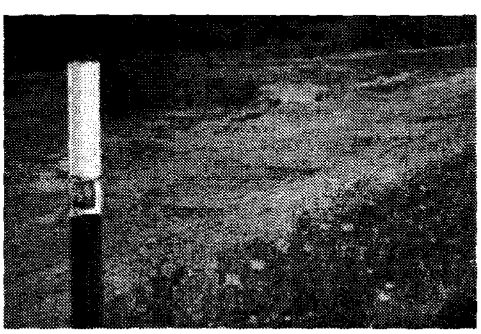
One interesting note was that the *Agrostis alba* variety used in the trials did not perform very well. Apparently, the *Agrostis alba* on-site has become ecotypically differentiated sufficiently to survive, while commercial varieties, developed in other locations, cannot. If this has indeed occurred in the span of approximately 20 years, further investigation could be warranted since it is generally believed that this process takes many more years than this.

Wind fence was found to be effective on a short-term basis in causing entrained sand to drop out of the wind stream. Placing the wind fence approximately 2.89 m (7.5 ft) up wind for every 0.30 m (1 ft) of of vertical height worked well for preventing the plots from being buried by tailings. However, the cost of the fence, and effort required to install it, limits its applicability to the most critical areas. In the future, it will only be used to protect new reclamation areas from burial by tailings up wind which have not yet been stabilized, and possibly on the embankments where wind erosion is the most severe.

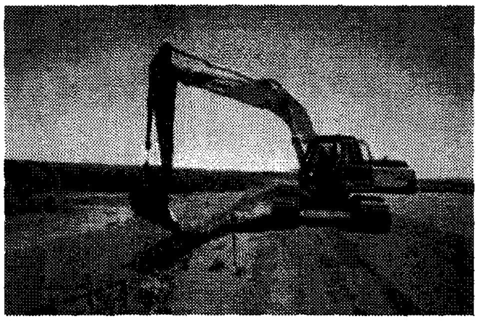
The trial involving pock-marking the surface with a roller similar to a sheepfoot, referred to as surface imprinting, was not conclusive. As tested here with a relatively small 1.83 m (6 ft wide) imprinter, it was not considered to be practical over the entire site. Although there was evidence that it provided adequate protection to aid establishment, the tailings were mobile enough to quickly fill in the prints. Therefore, imprinting was not selected for final use, but may be considered in the future, if a larger device is identified.

Contour, or tillage, furrowing was not found to be an effective means of stabilizing the tailings. The furrowing provided both a cut area which ponded water and prevented establishment, and a peak or crest which was not stable enough for plants to take hold. Since small areas without plant establishment can "blow out" and grow into larger areas, which are sources of dust generation, this method was not considered for further trial.

Dozer basins were tested on the slopes of the tailings facility embankments. Although relatively effective in slowing and dispersing water flow over large slopes, they did not appear to be very effective when used on loose, sandy textured soils. The logistics of building the dozer basins and maintaining them while revegetation takes place was complicated and would be easier in more competent soils. Dozer basins did not provide significantly better stabilization than other means, and therefore, were not selected for further study or use.

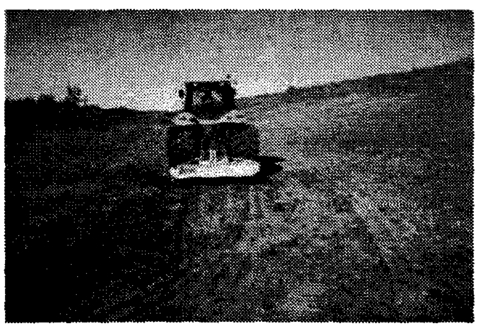


Slag from the smelting process had been stored at the site and was available for use in reclamation. The slag is a dark, glassy material of approximately 2.54 cm (1 in) diameter. Since it was available on-site, and the erodability of the tailings could be reduced by adding a coarse fraction component, slag was included in the trial. However, for any of the slag methods,

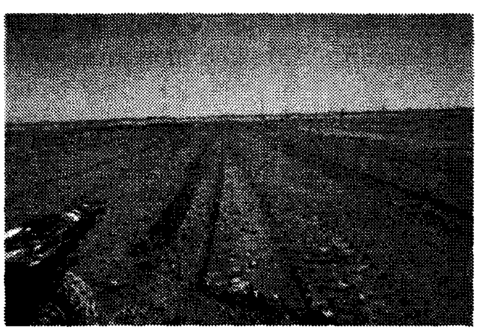


including incorporation, or placement in windrows, it was found to be very difficult to transport and apply. It is a very heavy material and trucks or loaders with full loads could not access the tailings without becoming stuck. Smaller loads were used to construct the trials, but methods adequate for the large scale project have not been identified. Therefore, slag was not considered for further trial at this time.

Hardwood bark was available as a waste product from the paper industry in the area. Piles of the bark were tested as a means of directing wind above the surface similarly to the slag piles discussed above. The bark was easier to transport out onto the tailings because it was less dense. However, the piles were not found to be any more effective at preventing wind erosion than other means and were more difficult to construct. Hardwood bark has and is still being considered for multiple purposes in the reclamation of the site, such as a replacement for the wood chips in the amendment mixture. However, hardwood bark was not considered for further use as an erosion control method.



Soil binders, tackifiers and soil cements have been used for dust control on tailings for some time. The drawbacks associated with them are related to their longevity and need for repeated applications. They bind the surface soil and are effective until washed out or broken up by traffic. The stronger and longer lasting formulas tend to inhibit vegetation establishment, especially in an already harsh environment. Therefore, in this trial, soil binder was tested as a potential replacement for crimping the straw mulch on plots, which were imprinted or had furrowing installed. This eliminated the need to run a crimper over and possibly destroy the rather fragile erosion control features. In this regard it worked quite well. However, as described above, the imprinting and furrowing were not selected as methods to use in further work. Should a larger scale imprinter be used in the future, soil binder is likely to be used as well.



Straw mulch was applied at a rate of 4.48 tonnes/ha (2 tons/ac) and crimped in as a standard application on all of the plots that were accessible by heavy equipment. A second level of straw mulch, 8.96 tonnes/ha (4 tons/ac), was tested as another erosion control method. The higher rate of straw mulch performed the best of all erosion control treatments. However, straw mulch at 4.48 tonnes/ha (2 tons/ac) worked second best and controlled wind and water erosion sufficiently for vegetation to become established. Therefore, straw mulch at a rate of 4.48 tonnes/ha (2 tons/ac), crimped in, was selected for use in the full-scale revegetation work. In order to prevent dust events from occurring, it is only necessary to direct the wind a few inches above the tailings surface. As shown below, the straw mulch, crimped perpendicular to the direction of the wind, is capable of accomplishing this.

It is possible that a more robust means of controlling erosion may be required for the tailings embankments. The higher rate of straw application, or the addition of a soil binder may be applicable. However, on the practically flat areas of the tailings, the 4.48 tonnes/ha (2 tons/ac) rate has worked adequately, and is the lowest cost alternative identified to date.

Full Scale Implementation

Full scale implementation of the revegetation specifications was initiated in the summer of 1999. Approximately 202 ha (500 ac) of North Pond 2 received the "full treatment" specification of the incorporation of 2% OM, consisting of 50% woodchips and 50% paper mill sludge. Another 486 ha (1,200 ac) received a "green manuring treatment" of seed and fertilizer, of which 202 ha (500 ac) also received crimped straw. The green manuring treatment was used to stabilize the tailings until sufficient paper mill sludge could be obtained for the full treatment. When the full treatment is applied to these areas, the application of OM can be reduced by the amount of OM already applied. In 2000, another 81 ha (200 ac) was fully treated on North Pond 2, and 190 ha (470 ac) on North Pond 1 and 53 ha (130 ac) on South Dam were aerially seeded and fertilized.

The test plots and the newly installed full scale implementation areas were monitored in the fall of 1999 and the summer of 2000. Although it is early to obtain useful results from the full scale implementation areas, useful data was collected from the test plots. The data has allowed the fertilization rates and seed mixtures to be modified for improved economics and success. Most of the treatments on the tailings embankments have not shown adequate plant establishment to control erosion. Supplemental applications of fertilizer and possibly, more intensive erosion control treatments may be required in these areas. However, further monitoring will be conducted prior to any changes.

Accessing the tailings has been extremely variable each year and is closely tied to the severity of the winter and spring precipitation. Therefore, initiation of work each year will be based on the preceding seasons weather patterns. Ultimately, it will take many years to determine if the vegetation is totally self sustaining. However, the site has not experienced severe dusting since implementation of the revegetation program. This is partially due to more favorable weather patterns, and to raising the water level in the facilities to keep more of the tailings wet longer into the summer months. However, it is primarily due to the stabilization of the tailings by revegetation. The fully treated areas appear to be self sustaining and the green manured areas appear to be controlling erosion for, in some areas, going on two years now. Although monitoring will continue in order to allow advance warning of any difficulties and to allow maintenance plans to be developed, the tailings are now stabilized to a point where severe dusting is not believed to be the major issue it once was.

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We were pleased to have a total of 264 participants at the Fifteenth High Altitude Revegetation Conference. Representatives from two foreign countries and 16 states and the District of Columbia attended the conference (Table 1). As can be seen from the data presented in Table 1, most of the participants came from Colorado, however, people from both coasts and from as far away as Switzerland were present.

For all of you that came, thank you for your participation. Make plans for attending in 2004. The High Altitude Revegetation Conference will be held in March, 2004 in Ft. Collins, Colorado. Pass the word to your colleagues, so that the 2004 conference will be a great success.

For current information on upcoming High Altitude Committee events, visit our website at www.highaltitudereveg.com.

Warren R. Keammerer

Table 1. Geographical distribution of participants at the Fifteenth High Altitude Revegetation Conference (March 6-8, 2002).

Geographic Entity	Number of Participants	Percent of Total Participants
CANADA		
Alberta	3	1.14
SWITZERLAND	1	0.38
UNITED STATES		
California	8	3.03
Colorado	200	75.76
Florida	1	0.38
Idaho	2	0.76
Indiana	1	0.38
Kansas	3	1.14
Montana	10	3.79
Nebraska	1	0.38
Nevada	3	1.14
New Mexico	2	0.76
North Carolina	1	0.38
South Dakota	1	0.38
Tennessee	1	0.38
Utah	10	3.79
Washington	1	0.38
Washington, D. C.	1	0.38
Wyoming	14	5.30
Total	264	100.00

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SUMMARY OF SUMMER TOURS 1974-2002

Assembled by Wendell Hassell

Since 1974, the HAR Committee has sponsored biannual conferences and annual field trips to unique mountainous revegetation project and research sites. All Conferences have been held at Fort Collins, Colorado, in conjunction with CSU, except the 1980 conference, which was held at the Colorado School of Mines in Golden, Colorado. Summer Field Tours have been conducted at the following sites:

YEAR	AREA TOURED	SITES TOURED
1974	Vail/Climax, CO	Vail Ski Area, AMAX Climax Molybdenum Mine
1975	Empire, CO	AMAX Urad Molybenum Mine, Winter Park Ski Area, Rollins Pass Gas Pipeline
1976	Idaho Springs/ Silverthorne, CO	US Highway 40 Construction, Keystone Ski Area
1977	Aspen/Redstone, CO	Snowmass Ski Area, CF&I Pitkin Iron Mine, Mid-Continent Coal Redstone Mine
1978	Estes Park, CO	Rocky Mountain National Park
1979	Silverton/ Durango, CO	Purgatory Ski Area, Standard Metals Sunnyside Mine Bayfield Range Experiment Program
1980	Vail/Climax, CO	I-70 Vail Pass Highway Construction Revegetation Ten Mile Creek Channelization, Copper Mountain Ski Area, AMAX Climax Molybdenum Mine
1981	Crested Butte/ Gunnison, CO	AMAX Mt. Emmons Molybdenum Project, Western State College, Homestake Pitch (Uranium) Mine, CF&I Monarch Limestone Quarry
1982	Steamboat Springs, CO	Mt. Werner Ski Area, Howelson Hill Ski Jump, Colorado Yampa Energy Coal Mine, P&M Edna Coal Mine
1983	Rifle/Meeker, CO	CSU Intensive Test Plots, C-b Oil Shale Project Upper Colorado Environmental Plant Center, Colony Oil Shale Project
1984	Salida, CO Questa, NM	Domtar Gypsum Coaldale Quarry, ARCO CO_2 Gas Project Molycorp Molybdenum Mine, Red River Ski Area
1985	Cooke City, MT	USFS Beartooth Plateau Research Sites Bridger Plant Materials Center
1986	Leadville, CO	Peru Creek Passive Mine Drainage Treatment, California Gulch/Yak Tunnel Superfund Site, Colorado Mountain College
1987	Glenwood Springs/ Aspen, CO	I-70 Glenwood Canyon Construction, Aspen Ski Area
1988	Telluride/Ouray/ Silverton, CO	Ridgeway Reservoir, Telluride Mt. Village Resort, Idarado Mine, Sunnyside Mine
1989	Lead, SD	Terry Peak Ski Area, Glory Hole and Processing Facilities of Homestake Mining Co., Wharf Resources Surface Gold Mines Using Cyanide Heap Leach
1990	Colorado Springs/ Denver, CO	Castle Concrete's Limestone Quarry, Cooley Gravel Quarry (Morrison), E-470 Bridge and Wetland near Cherry Creek. Littleton Gravel Pit Restoration to Parkland

YEAR	AREA TOURED	SITES TOURED
1991	Central Colorado	Alice Mine, Urad Tailings, Pennsylvania Mine at Peru Creek, Yule Marble Quarry near Marble, and Eagle Mine Tailings and Superfund Clean Up near Minturn and Gilman
1992	Northern Colorado	Rocky Mountain National Park, Harbison Meadow Borrow Pit, Alpine Meadow Visitor Center, Medicine Bow Curve Revegetation, Hallow Well Park
1993	Central and Southern Colorado	Mary Murphy Mine, Summitville Mine, Wolf Creek Pass, Crystal Hill Project
1994	Northeastern Utah	Utah Skyline Mine, Burnout Canyon, Huntington Reservoir Hardscrabble Mine, Royal Coal, Horse Canyon Mine
1995	North Central Colorado	Eisenhower Tunnel Test Plots, Henderson Tailing Test Plots, Wolford Mountain Reservoir, Osage and McGregor IML Site Seneca II and 20 Mile Coal Mines (Steamboat Springs)
1996	Southwest Colorado	UMTRA Site (Durango), Sunnyside Mine (Silverton), Idarado Mine (Telluride), Southwest Seed Co. (Dolores)
1997	Southwest Colorado	Cresson Mine (Cripple Creek), San Luis Mine, Bulldog Mine (Creede)
1998	Lead, SD	Richmond Hill Mine, Wharf Resources, Homestake's Red Placer, Sawpit Gulch, WASP Reclamation Project
1999	Northern New Mexico	Molycorp's Questa Mine, Hondo Fire Revegetation Work, Pecos National Monument, El Molino Site, Cunningham Hill Mine
2000	Central Colorado	Boardwalk at Breckenridge, Eagle Mine, Independence Pass, and Climax Mine
2001	Estes Park, Colorado	Rocky Mountain National Park
2002	Western Colorado	I-70 Glenwood Canyon, CSU Intensive Test Plots, Upper Colorado Environmental Plant Center, Rocky Mountain Native Plants, Union Oil Shale Project

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