

# Proceedings High Altitude Revegetation Workshop No. 13

Edited by  
Warren R. Keammerer  
Edward F. Redente

June 1999

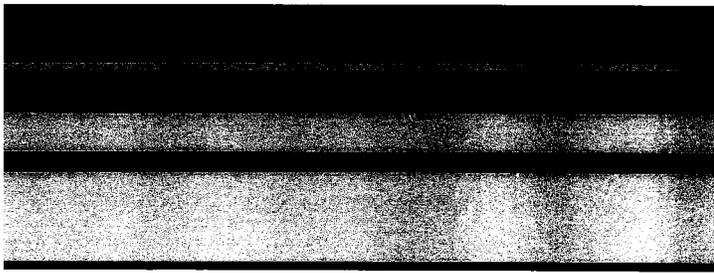
Information Series No. 89

# Colorado Water

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**Proceedings**

**HIGH ALTITUDE REVEGETATION WORKSHOP**

**NO. 13**

**Colorado State University  
Fort Collins, Colorado  
March 4-6, 1998**

**Edited by**

**Warren R. Keammerer  
Keammerer Ecological Consultants, Inc., Boulder, Colorado**

**Edward F. Redente  
Rangeland Ecosystem Science Department  
Colorado State University  
Fort Collins, Colorado**

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## PREFACE

The 13<sup>th</sup> biannual High Altitude Revegetation Conference was held at the University Park Holiday Inn, Ft. Collins, Colorado on March 4-6, 1998. The Conference was organized by the High Altitude Revegetation Committee in conjunction with the Colorado State University Department of Soil and Crop Science. The Conference was attended by 236 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 is a difficult task made relatively easy by the sharing of responsibilities among the member of the HAR Committee.

In addition to the invited papers and poster papers presented on March 4-5, a field tour of the Colorado State Forest Service Nurseries and Greenhouses was conducted on March 6, 1998. 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 15 papers grouped into seven conference sessions and four poster papers.

For current information on upcoming High Altitude Committee events, visit our website at [www.highaltitudereveg.com](http://www.highaltitudereveg.com).

Warren R. Keammerer  
Edward F. Redente  
Editors

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## SEEDIT

Paul Goodman  
John Galt Systems  
and  
William R. Beavers  
National Technical Advisor Plant Materials NPS

SeedIt was developed as a tool for calculating Pure Live Seeding rates (PLS) and is based on the number of seeds in a pound for an individual species. By using PLS rates, seed, with their widely varying size and numbers, are taken into account when developing specific seeding recommendations. Developing a seeding rate for various species based on weight can result in over-seeding a plant producing small seed relative to a large seeded plant.

For example, if you were to seed a site with 10 pounds of a mixture of Western wheat grass and Sand dropseed, and then allocated their ratios at 50% by weight, the site would be dominated by Sand dropseed. The reason is clear when you consider that a pound of Western wheat grass has 114,833 seeds and a pound of Sand dropseed has 5,399,333 seeds. The larger number of seeds for Sand dropseed will dominate the site if its size and number are not accounted for within the seeding specification.

Pure Live Seeding rate calculations take seed size into account by allocating the percentage of seed desired by species within the following formula:

$$\text{PLS} = \frac{(\text{Seeds ft}^2) \times (4356 \text{ ft}^2/\text{Ac.}) \times (\% \text{ of species desired in the mix})}{(\text{Seeds per pound by species})}$$

In the previous example if we want to develop a seed mix of Western wheatgrass and Sand dropseed with each species contributing 50% of the mix then SeedIt would calculate the seeding specification as follows:

$$\text{PLS for Western wheatgrass} = \frac{(40 \text{ seeds ft}^2) \times (4356 \text{ ft}^2/\text{Ac.}) \times (50\%)}{(114,833 \text{ seeds/lb.})} = 7.59 \text{ lb./Ac.}$$

$$\text{PLS for Sand dropseed} = \frac{(40 \text{ seeds ft}^2) \times (4356 \text{ ft}^2/\text{Ac.}) \times (50\%)}{(5,399,333 \text{ seeds/lb.})} = .20 \text{ lb./Ac.}$$

While references for seeds per pound exist and the mathematical formulas for these calculations are known, it is tedious and time-consuming and-after hours calculations for each seed application-one is not likely to want to repeat the work to justify a different mix.

SeedIt is designed to be easy to use with a minimum of training or effort. As a menu-driven system, SeedIt does not require memorization of a whole set of commands. The necessary

data from standard plant tables- seed per pound, etc.- are embedded in the program, saving you the step of looking up that information. You will find that you understand and are proficient in SeedIt in half the time it takes to perform by hand a single set of calculations for one revegetation specification.

An additional component to SeedIt is a work sheet that allows you to input the actual bulk seeding rates and compare the bulk seeding rates to the PLS specification and determine if the PLS revegetation specification was achieved. Bulk seeding rates differ from PLS rates because each bag or lot of seed will differ in percent purity and germination rates. If you have access to the seed tags listing purity and germination for each lot of seed before the actual seeding application commences then you can run the comparison with SeedIt and determine beforehand if the seeding specification will be achieved.

## **TWENTY FIVE YEARS OF TAILING RECLAMATION IN THE ARID SOUTHWEST**

S.A. Bengson

Agronomist, Mined Land Reclamation  
ASARCO Incorporated Copper Operations  
P. O. Box 5747  
Tucson, Arizona 85703

### **ABSTRACT**

ASARCO Incorporated has been working on tailing reclamation in the arid southwest for over 25-years. The experience gained has been instrumental in the development of sound and practical reclamation laws and regulations in Arizona. To date Asarco has reclaimed hundreds of acres of tailings in Arizona and New Mexico. The reclamation of some of these sites has achieved recognition and acclaim from state and federal agencies.

Tailings are unlike any other waste or by-product produced by mining or industry. Tailings are the finely ground inert rock residue from the milling process of the ore. Tailings have site specific chemical and physical properties that may require innovative treatment for reclamation. Each site must be evaluated before developing any reclamation plan. Standard "cook-book" reclamation techniques may not be the most appropriate for all sites. New innovative techniques developed by Asarco may be the best suited for ecologically sound reclamation.

If there is one outstanding lesson to be learned from Asarco's experience it is that each site is different. Although there may be many similarities in tailing sites, and some general reclamation practices which may be applicable, each site will require its own specific blend of reclamation techniques that have been proven successful. Asarco's objective in tailing reclamation is to achieve a viable, productive ecosystem. This requires a permanent, self-sustaining vegetative community. To achieve this objective there are 3-basic criteria that must be met. First, and foremost, is a productive soil, or growth medium. Secondly, the proper plant community must be established on the site. And lastly, a management program must be established to assure long-term objectives are maintained.

## TWENTY FIVE YEARS OF TAILING RECLAMATION IN THE ARID SOUTHWEST

Southern Arizona has been a major copper producing region of the U.S. for over a century. Today more than 60% of this nation's copper comes from Arizona. Despite the vast amount of copper mining that has, and is, taking place in Arizona, very little of the land is physically disturbed. Less than 0.11% of Arizona has been disturbed by copper mining (Arizona Mining Association 1992). South of Tucson, Arizona, near the rapidly growing retirement community of Green Valley, today there are two large open-pit copper mines and the associated tailing impoundments. In the mid-1960's the mining industry began to recognize the growing magnitude and responsibility of controlling blowing dust from these large tailing impoundments. In addition, efforts were begun to alter the viewshed by vegetative stabilization, or beautification, of the tailings. Vegetative stabilization of tailings became the focus of an industry wide initiative spearheaded by the "Solid Mineral Waste Stabilization Liaison Committee". This group was comprised of industry personnel and researchers from the U.S. Bureau of Mines. From the beginning, the group recognized the numerous site specific characteristics of the tailings.

There are numerous complex challenges that affect vegetative stabilization, or reclamation, of tailings in the arid southwest. Although the basic over-riding limiting factors involves aridity, plus each site will have its own site specific characteristics to evaluate in preparing and implementing a reclamation plan. Soil materials, aspect, slope, etc. can make major differences in the stabilization/reclamation techniques. Rainfall in this region can be as little as 3-6 inches/year, which coupled with annual evaporation often exceeding 100 inches, makes this region extremely arid. Other factors include pH extremes (both acidic and alkaline); complex soil textural variations; and the deficiencies of essential nutrients, organics, and necessary soil mycorrhizae (beneficial soil micro-organisms). Challenges include complex salinity, sulfide crusting problems and excessive concentrations of phytotoxic or growth inhibiting heavy metals and salts. Also, extreme surface temperatures and high albedos (or sunlight reflected from the surface) can literally bake emerging vegetation or cause plants to over-photosynthesize.

Recognizing these common similarities, the mines south of Tucson, began their tailing stabilization/reclamation work in the mid-1960's. This activity was strictly voluntary at the time. There were no laws or regulations mandating stabilization or reclamation, but the mines recognized their obligations. The close proximity of the growing urbanized areas near these large tailing impoundments called for action to control the blowing dust and visual aesthetics. Some of the mines used soil to cap the tailing to provide a seed bed conducive to plant establishment, while others incorporated organics directly into the tailing or used heavy applications of fertilizer to induce plant growth. Some used combinations of all three techniques. Each technique (soil, organics, and fertilizer) produced the desired result of vegetative stabilization of the tailings and hence final reclamation to productive future land use. It was this early development of successful techniques which helped the industry work with the Arizona State Legislature in the passage of the Arizona Mined Land Reclamation Act in 1995.

ASARCO Incorporated began developing techniques to stabilize and reclaim tailing in the mid-1960's. Beginning in 1973, Asarco increased its efforts by initiating an intensive professional reclamation program called Project GRASS (General Revegetation And Slope Stabilization) to investigate the problems and develop sound economic vegetative stabilization techniques. Concentrating on the vegetative stabilization, and working on tailing impoundments at three mine sites in southern Arizona, Asarco pioneered many of the tailing reclamation techniques presently

found in practice. Today, Asarco has successfully stabilized hundreds of acres of tailings in Arizona and New Mexico.

The U.S. Forest Service and the NM Environment Department have recognized Asarco's achievements and success in tailing reclamation.

Asarco's tailing stabilization usually begins by "capping" or surfacing the tailing with a thin cover of soil or rock. This "capping" of soil material serves two primary functions. It ameliorates the surface environment for better vegetative establishment, and it stabilizes the fine tailing from blowing. Asarco has found that a very thin veneer of minus 2 inch crushed rock on the flat surface and larger rip-rap rock on the slopes works very well to stabilize tailing. Soil capping for vegetative stabilization/reclamation of non-acidic tailing (pH's above 5) requires only a very thin "cap" of soil, perhaps 2 to 6 inches or less is actually necessary. Often, just mixing a small amount of soil into the tailing is sufficient for successful reclamation. For acidic tailing sites Asarco uses a heavier soil "cap" of several feet to establish vegetation. This is usually accomplished with a layer of 1-foot or more of calcareous rock material with a surface cap of 1-foot or more of soils. The alkalinity of most western soils will dictate the needed depth of soil. Through experience Asarco has found that the plant roots cannot grow down into the acidic tailing due to the presence of soluble phytotoxic heavy metals. The thicker acidic tailing "cap" is mounded to drain rainfall from the surface to eliminate ponding and control infiltration and seepage of water into acidic tailing. It's been Asarco's experience in arid environment that the limited rainfall can easily be drained away by the soil crown and the minimal amount of moisture that is absorbed by the soil "cap" can be easily removed by evapo-transpiration.

This soil "capping" for reclamation is only practical at sites where adequate soil materials are readily available. To help alleviate some of these problems Asarco has successfully experimented with directly adding fertilizers and incorporating organics into the tailing. This ameliorates the tailing surface environment directly to initiate vegetation and to build the tailing into a suitable "soil". On basic tailing, application of a few hundred pounds of nitrogen/phosphorous fertilizer per acre with supplemental irrigation has proven successful. Also, we have incorporated several tons of sewage sludge, or biosolids, per acre into acidic tailing with successful vegetative results. The use of cattle, concentrated on small areas for a very short period of time, to incorporate organics (hay & manure) into the tailing has proven to be very successful for both acidic and basic tailing to initiate vegetative growth. The organics help to improve moisture regimes, develop soil structure, enhance the nutrient and mycorrhizae levels and can even moderate some acidic conditions. Ecologically speaking, these techniques can be quite advantageous. The impoverished tailing is not simply "buried" with soil. The site is actually stabilized by building its own soil. However, these techniques do have limitations. Organics may require several years of intensive cultivation and management to be successful. There are also the economics of finding suitable organic materials in sufficient quantity to be considered. Also, some sources of sewage sludge and other organics may not be desirable for use at some sites.

The next step in Asarco's professional vegetative stabilization or reclamation program is the selection of the plant species composition best suited for the specific site. This can be very critical to the success of the tailing reclamation project. Plant species are selected based upon their adaptability to the specific site conditions, physiological characteristics for stabilization, livestock forage or wildlife habitat values, and aesthetics. Where natural rainfall is sufficient the primary species for reclamation is a mixture of grass species with a scattered overstory of shrubs and trees. Where rainfall is restrictive, a desert shrub plant community dominates. Asarco has found that the

best grass species for reclamation in areas of 10-12 inches rainfall/year are Lehman's and "Cochise" lovegrass (*Eragrostis lehmanniana* & *trichophora*), blue panicgrass (*Panicum antidotale*) and buffleggrass (*Cenchrus ciliare*). In areas of sufficient rainfall (>12-inches/year) the grasses that have been proven successful are sideoats grama (*Bouteloua curtipendula*), yellow bluestem (*Bothriochloa ischaemum*) and weeping lovegrass (*Eragrostis curvula*). The best tree/shrub species include mesquite (*Prosopis* sp.), paloverde (*Cercidium* sp. and *Parkinsonia aculeata*), eucalyptus (*Eucalyptus* sp.), fairy duster (*Calliandra eriophylla*), hopseed (*Dondonea viscosa*), sheoak (*Casuarina cunninghamiana*), saltbush (*Atriplex* sp.) and rabbitbrush (*Chrysothamnus* sp.). Not all species used are indigenous to each site, but they are better adapted to the particular site environment, have a higher use or aesthetic value, or other desirable characteristics such as erosion control and wildlife values. Also many of the "native" species may not be the best suited to the specific site characteristics, nor available in sufficient quantities for large scale vegetative reclamation. Asarco's tailing reclamation program does take the natural ecosystem into account and develops a species composition that will blend in with, and complement, the adjacent natural plant community. The main objective is to stabilize the site. Once the site has been stabilized and is properly managed, then natural succession can occur and eventually the native ecosystem will become established.

ASARCO Incorporated's experience in southern Arizona has shown that a combination of both direct seeding and hand planting techniques is the most successful. Because of the steep slopes usually encountered (1.5:1), hydroseeding is the most practical technique for direct seeding. This technique involves mixing the seeds, any fertilizers or amendments deemed necessary, and a hydromulch material with water into a slurry that is then sprayed onto the slopes. Although hydroseeding may be more costly than simple broadcasting of seed, it is an exceptionally effective method to evenly disperse and hold the seed on steep slopes. In addition it is often the only way to mix a composition of complex seeds that would otherwise inhibit drill seeding. Asarco has developed several techniques to enhance its hydroseeding operations. To overcome the problem of poor germination and establishment of the seeded species, Asarco increases the recommended seeding rates considerably. To reduce damage to the seed by the hydroseeder or prolonged soaking, the seed is added to the slurry last. To alleviate the problems of small seed being suspended in a heavy hydromulch cover away from the soil surface, a "2-step" hydroseeding technique is used. This involves first hydroseeding the seed mix with a minimal amount of hydromulch material to help hold the seed on the slope while assuring good seed/soil contact; and then hydromulching a second, heavier application of hydromulch on top of the seed. There are many inexpensive and effective hydromulch substitutes that make a suitable slurry for the first step hydroseeding. These include seed screenings and chaff, sawdust, and other fine organic materials. Other mulch materials that have proven successful include the use of native grass, or prairie hay, with a tackifier to hold it to the slope.

Hand planting nursery grown trees and shrubs is especially advantageous to supplement the vegetative composition and provide for more biodiversity. Asarco has found that some species are hard to establish by seeding and hand planting is the only way to successfully establish these species. Also the seed of certain species may be difficult to obtain in large quantity for seeding. Past experience has also proven that bare-root transplants, small containerized seedlings, or trying to transplant native trees & shrubs from undisturbed natural areas are unsuccessful. Most desert species have extensive root systems or taproots that cannot withstand the shock of being bare-rooted or transplanted. Small immature seedlings simply haven't developed sufficient root systems

to survive. The most practical containerized plants are gallon-sized. An adaptation of the standard gallon-plant is a "tubling" container, approximately 3-4 inches square by 14-18 inches deep. The tube shape trains the deep taproots of desert species to grow downward and produce multiple taproots. Also, these containers are easier to handle on the steep slopes and can effectively reduce labor costs for planting.

In the arid southwest, the sporadic and undependable rainfall may not always be sufficient to assure successful establishment of vegetation. Supplemental irrigation for initial seed germination and plant establishment can be useful to enhance reclamation. The irrigation should be initiated and is most appropriate at the time of seeding or planting. There is a great deal of controversy over the use of irrigation, and there are many instances of successful reclamation without irrigation. Asarco experiments have used supplemental irrigation to provide the necessary moisture for the initial germination and for establishment of the plants only. Generally, the irrigation can be totally withdrawn after the first growing season and the plants will survive on the natural rainfall.

Asarco has utilized both sprinkler and drip irrigation techniques. Sprinkler irrigation is the dominant technique used to establish grasses and herbaceous ground cover on steep slopes. Sprinkler irrigation systems are operated to simulate approximately .25 inches of rainfall each day for the critical first few days of seed germination. This irrigation schedule is then gradually reduced as the plants grow to size and become established. The main drawback to sprinkler irrigation techniques is the volume of water used and the water system required to supply the water to the site and the inherent erosion hazards.

Research in establishment of trees and shrubs has utilized drip irrigation technology, which requires much less water than sprinkler irrigation. Drip irrigation is generally limited to establishing trees and shrubs. Drip irrigation delivers a very precise low volume of water over a prolonged period (usually 1 gallon/hour for an 8-hour period) to each individual plant. This technique provides very deep watering for optimum root development, but does not provide sufficient surface moisture for widespread seed germination. Although less expensive to install, the major drawback with drip irrigation, other than not being able to establish dense ground cover, is its labor intensive nature. It is essential that all water used in drip irrigation be filtered. Even then the drip emitters have a tendency to plug-up with algae, hard water deposits and other contaminants that get into the system beyond the filter. This requires daily maintenance. In addition wildlife find the plastic drip hose irresistible to chew on and cause numerous leaks requiring daily repair. Another drawback is that the spatial arrangement of the plantings provide a very unnatural linear appearance along the driplines. Also, because the plants are widely spaced, wildlife browsing on the plants can have dramatic impacts on the reclamation efforts.

Asarco has also successfully utilized micro-sprinklers. This incorporates the best of both sprinkler irrigation and drip irrigation. When properly designed micro-sprinklers can provide minimum surface moisture for seed germination with optimum water conservation. Asarco also recognizes the value of relatively new polyacrylamide water-holding "hydrogels" to help establish plants. One ounce of these "hydrogels" can hold as much as 5-10 gallons of water. By mixing "hydrogels" into the planting hole enough moisture may be stored near the roots to assure plant survival. One major drawback of this technique are the costs of the materials and application labor. Other problems to be aware of are that as the "hydrogel" hydrates and swells it could possibly lift the plant out of the ground, and as the gels dehydrate, they could leave a dry void around the plants

roots. There are also concerns over the ability of some of these “hydrogels” to re-hydrate after they have dried out. Salts in the soil, water, or fertilizers may greatly affect the hydration qualities of some of “hydrogels”.

A key component to successful tailing reclamation lies in the management of the site after reclamation activities have been successfully completed. Once the site has been soiled and seeded the site must be properly managed and maintained to perpetuate the ecosystem established. The management plan for each reclamation site will require periodic monitoring of conditions. Surface land uses such as grazing by domestic livestock or wildlife must be properly managed and controlled. While grazing can be very beneficial (i.e. stimulate vegetative growth & control erosion) it requires supervision. Other surface uses of reclaimed tailing sites such as recreation (especially off-highway vehicles) will require supervision as well.

Reclamation of tailing sites in the arid southwest can be successful. For over 25-years ASARCO Incorporated has been developing the necessary techniques needed for successful tailing reclamation. Developing innovative techniques to enhance the reclamation of tailings by utilizing biosolids and cattle, plant species selection, mycorrhizae development, and other new technologies as they become available have made Asarco a recognized leader in the reclamation of tailings in the Southwest for over a quarter of a century.

**REHABILITATION OF CUT SLOPES  
STATE HIGHWAY 40 WEST OF BERTHOUD PASS**

Wes Goff, P.E.

Colorado Department of Transportation  
PO Box 399  
Dumont, CO 80436

Inessa N. Zisman, P.E.

Colorado Department of Transportation  
18500 East Colfax Ave.  
Aurora, CO 80011

Michael P. Voxakis

Colorado Department of Transportation  
PO Box 399  
Dumont, CO 80436

Michael R. Banovich

Colorado Department of Transportation  
4201 East Arkansas Ave.  
Denver, CO 80222

**ABSTRACT**

Colorado Department of Transportation has recently completed an experimental erosion control project along state highway 40 west of Berthoud Pass. The purpose of this project was to test various cost effective erosion control materials and installation techniques, while providing data for future projects with similar features. Three sites were selected with 1:1 cut slopes, 25 to 35 meters high at an approximate elevation 3,150 meters. The slopes consisted of highly erodible sandy soils mixed with large quantities of rocks, some measuring to over two meters in diameter. Since this area experiences heavy snow accumulations during the winter months, the snow melt runoff combined with the severe thunderstorms of spring and summer wash away the top layer of soil preventing vegetation from establishing itself. Also, Colorado DOT sanding and ditch cleaning operations continually undermine the slopes, causing further erosion.

The project was located on Roosevelt National Forest land. Due to the steep mountainside above the cut slopes, right-of-way restrictions and Forest Service's requirements, laying back the slopes was not possible. In addition, the access to the top of the cut slopes was restricted to foot traffic and small equipment to prevent any additional disturbance of natural terrain.

All selected slopes were scaled of loose or unstable rocks. The scarp at the top of the cut slopes was removed. Various three-dimensional permanent geosynthetic erosion mats and cellular containment systems were installed at the top seven meters of the slopes to prevent future forming of the scarp and to help establish vegetation. Specific test sites were assigned to various products to provide the best comparison of the results. Most manufacturers supplied installation details and on-site assistance. At the toe of the slopes, a 1.25 m high concrete wall and 3.4 m wide concrete gutter were constructed to help to reduce the undermining, to allow for more efficient cleaning of the ditches and to reduce the amount of sand being washed into the river. Several different techniques and materials were tested during the seeding application. The project has been monitored for two years.

The goal of this and future similar projects is to rehabilitate and re-vegetate the eroded slopes, reduce the cost of maintenance and improve the water quality of the nearby streams.

## **GENERAL**

The project is located in Colorado, along State Highway 40, west of Berthoud Pass. This portion of the SH 40 as seen today was built in the early 60's. Standard practices for erosion control (in effect during the 60's) were applied to the cut and fill slopes. The disturbed areas were not seeded. The erosion of the cut slopes started almost immediately after construction was completed. The slopes consist of highly erodible and unstable sandy soils mixed with a large quantity of rocks. The rocks vary in size to over two meters in diameter. The snow melt runoff combined with the severe thunderstorms of spring and summer wash away the top layer of soil and thereby prevent vegetation from establishing itself.

Due to continuous erosion, rocks, previously deeply embedded into the slopes, have become exposed. These rocks roll down onto the roadway and create a major safety hazard in this area. A sediment control study of the Fraser River in the area identified these slopes as a major contributor to the sedimentation of the river. This requires extensive and expensive maintenance operations for rock removal and sand cleaning from the ditches.

Federal aid enhancement funds became available for the 1995 construction season to rehabilitate some of the eroded slopes. An experimental project was set up to establish effective methods of achieving this goal in this and similar areas. The job site became a test area for the variety of materials and erosion control techniques at 3,200 meters altitude and severe climate conditions. These techniques were refined on the erosion control project in the same area the following construction year.

## **SITE CONDITIONS**

### **Site Description**

The project site is located along State Highway 40, west of Berthoud Pass, within the Fraser River watershed on Roosevelt National Forest land at approximate elevation 3,150 meters (Figure 1). The cut slopes are between 25 and 35 meters high, approaching 1:1, and with no easy access to the top.

### **Climate**

The local climate at Berthoud Pass is influenced by the altitude and the Rocky Mountains. The climate conditions at Berthoud Pass weather station, elevation 3 439 meters are as follows:

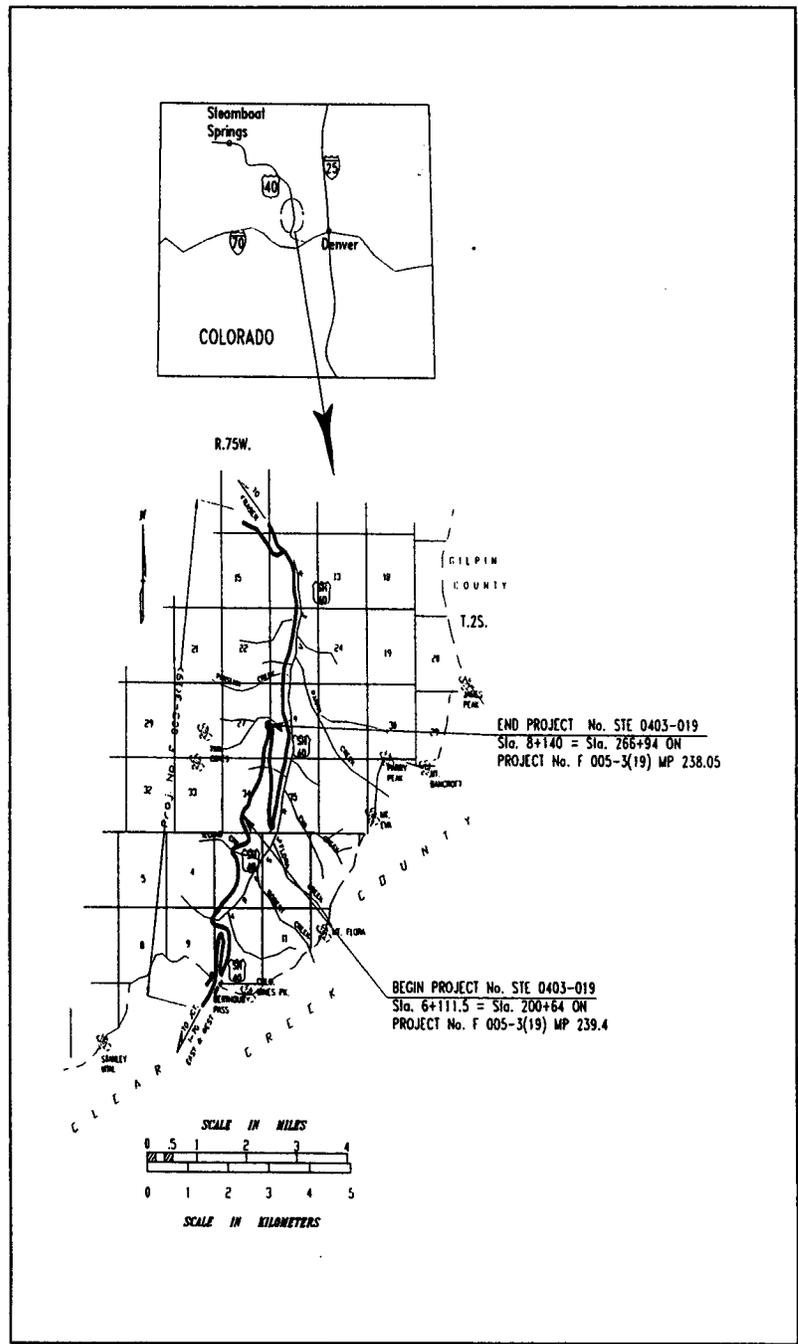


Figure 1. Project vicinity map.

- Average Temp: -1.9°C
- Average date of last frost in Spring - July 13.
- Average date of first frost in Fall, July 29.
- Average precipitation: 91.4 Centimeters.

### **Vegetation**

The roadside slopes were adjacent to a climax spruce/ lodgepole pine forest in the Rocky Mountains of Colorado. Existing roadway cut slope vegetation consisted of willows and wetland grass species in the areas of spring or seeps. In upland areas some forbs species are found. Most of the roadway slopes consisted of bare soil and rock outcrops with no vegetation.

### **Soils**

Well drained, moderately dense to very dense soils formed by glacial drift. Surface run off is rapid the erosion hazard is high. Slopes vary but are generally 1:1 and steeper. Slope length varies from 25 to 50 meters.

## **DESIGN AND CONSTRUCTION CONSIDERATIONS**

The engineer's approach to solving the erosion problem in the described area was:

- reinforce top of the cut slopes
- prevent undermining of the cut slopes at the toe
- improve drainage to minimize erosion of the fill slopes
- establish permanent vegetative cover

Only limited amount of clearing was allowed. To prevent any additional disturbance of natural terrain, access to the top of the cut slopes was restricted to the foot traffic and small stationary equipment.

For the initial experimental project three representative slopes were selected. They were designated as Work Zone No. 1, 2, and 3. The total length of three zones was 650 meters. All slopes were approaching 1:1, 32 meters average height, with a large quantity of rocks varying in size to over two meters in diameter (Figure 2). The slopes were located in the area classified as the tenth worst rockfall area in Colorado.

The prime contractor on the project was Kiewit Western, Inc.

### **Scaling**

Prior to commencing any erosion control work, the slopes had to be scaled of loose rocks and material. Specifications required that all loose rocks 100 mm in diameter and larger be removed from the slopes.

In the past Colorado DOT paid for this type of work per hour of labor and equipment using a Force Account (non-biddable) method of payment. To encourage contractors to come up with new and innovative



Figure 2. Work Zone No. 1 prior to the project.

methods of performing scaling operations, the decision was made to pay for this operation as a bid item per square meter of the scaled surface.

A mandatory job showing was held in the fall of 1994 for all potential bidders. This was done for two primary reasons. The first reason was that due to the severity of the slopes and the complexity of the work the contractors' input on constructability was desired to help finalize the design details. The second reason was that the job was being advertised for bid in the winter months. At 3,200 meters elevation, there would be nothing to see except a landscape under four to six feet of snow.

The rock scaling operations were performed during the night and roadway was closed to the traffic. The rock scaling work was initially attempted with a "walking excavator". This is a backhoe with extra stabilizing legs connected to it. These stabilizing legs permit it to maneuver up steep grades. The walking excavator proved unsuccessful. The slopes were too steep and too unstable. If either one of these factors were a little less severe, it might have been successful. A 120 ton crane with a 60 meter reach was then brought in to attempt the rock scaling. The crane came equipped with the proper fair-leads so a drag line bucket could be used. This was extremely important since the rock and debris had to be brought down at an angle to protect the crane. A concrete barrier was placed along the toe of the slope to contain the scaled rocks. A clamshell type bucket was also attached to the crane to bring down the debris and take off the overhanging scarp. The contractor also tried using the clamshell along the face of the slope to remove the large rock. The drag line bucket was more efficient for the face of the slope. Every time the clamshell took out a rock outcropping, another would appear behind it. This created some voids which had to be continually smoothed out.

Some unexpected springs surfaced during the scaling. This was in large part due to the incredibly wet spring and late summer (0.18 meters of snow on the fourth of July). The spring areas were successfully stabilized using an erosion mat called Super-Gro, manufactured by Amoco, supplied and donated by Vance Brothers Company of Denver, Colorado. The mat was pinned down with U-shaped staples. As rain water and spring water came in contact with the Super-Gro mat, the woven material broke down and penetrated the unstable soil. The broken down fibers of the mat mix with the unstable soil and a reinforcement occurred. This procedure stabilized the springs and halted the mud slides that were occurring in those areas. It was a temporary solution until vegetation was established. After the majority of material was brought down by the heavy equipment, a hand scaling operation consisting of an eight-man crew brought down the smaller rocks and sluff material. It was a time consuming operation essential to the success of establishing growth on the 32 meters cut slopes. All crews working on the slopes were provided with safety lines. The success of the erosion control mats at the scarp area was highly dependant on the mat making contact with the stable part of the slope. Once the slopes were hand scaled, with emphasis on the scarp area, the preparation for the erosion mats installation and seeding were completed. Approximately 22,900 square meters of slopes were scaled at the cost of \$91,600.

### **Top of Slope Reinforcement**

Following removal of the scarp material, a variety of turf reinforcement mats and cellular soil confinement systems were applied to the top seven meters of the slopes (Figure 3). Two of the applied products, Armature and Enkamat-S, were manufactured by Akzo Industrial Systems Co. and supplied by American Excelsior Company. The supplier in conjunction with the product manufacturer provided a complete site specific installation design and guide. The installation of the mats was performed with a manufacturer representative on-site. Five additional products were accepted from other manufacturers for experimental installation on this project. All of them were installed in accordance with each manufacturer's recommendations. Some manufacturer's had a representative on-site during installation of their products. The complete list of products and specific product site locations can be obtained from Colorado DOT

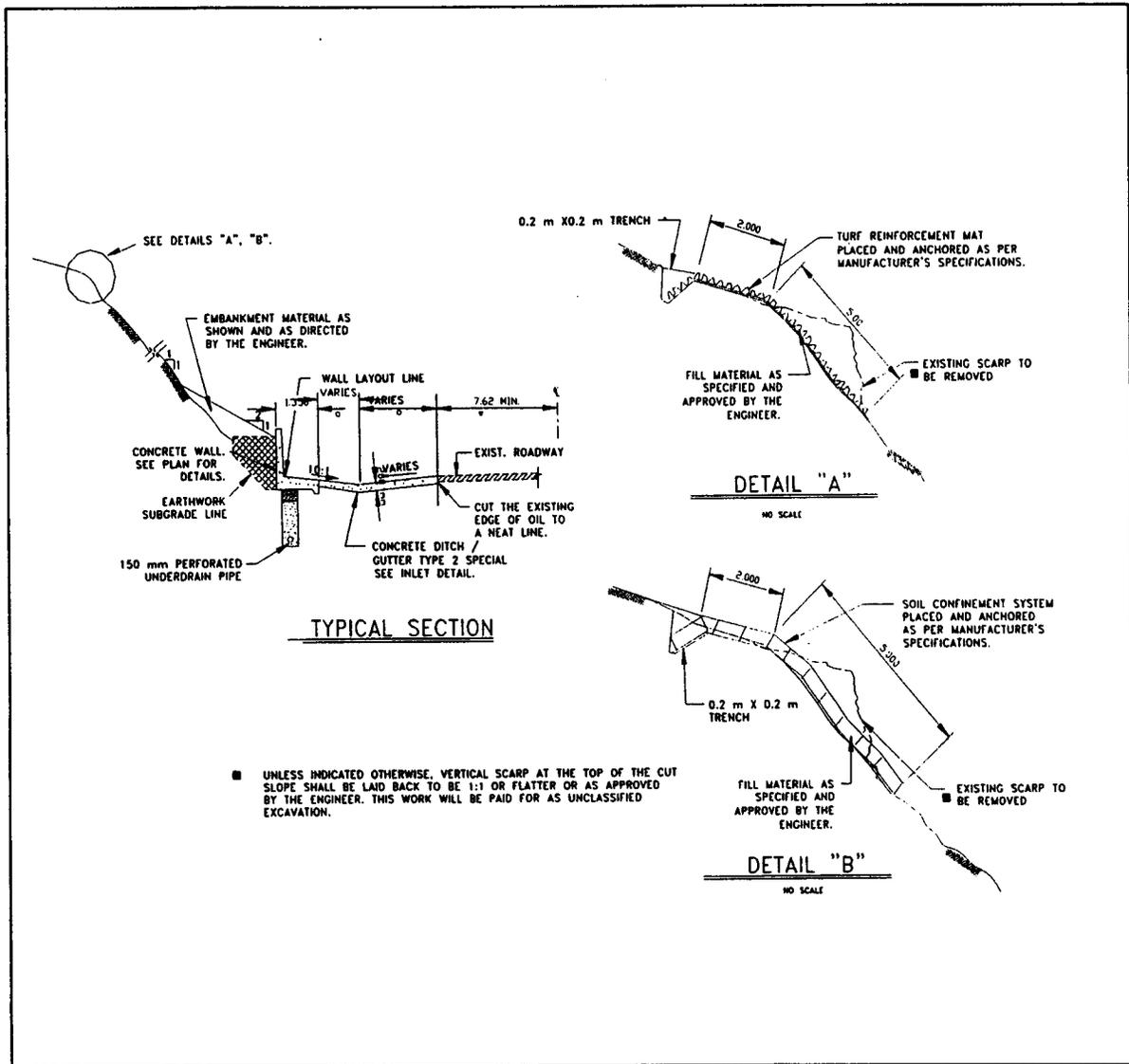


Figure 3. Typical slope treatment.

After the installation of the turf reinforcement mats and cellular soil confinement systems was completed, the fill material (not a top soil) was applied. The fill material was dropped down from the bucket of the crane. Approximately 50% of the material slid down the slope. This created a sluff layer below the erosion mats that needed to be removed prior to the seeding.

All turf reinforcement mats and cellular confinement systems greatly varied in price and in labor intensity of their installation.

### **Toe of Slope Protection**

Concrete walls, 1.25 meters high, were built at the toe of the slopes to prevent the road maintenance crews from cutting into the slopes during snow plowing and ditch cleaning operations and thus starting the whole erosion process again (Figure 3). Visual aesthetics was a consideration. Therefore, the wall was built using colored concrete and a random rock pattern was applied to the face of the wall. Colored concrete also helps to preserve the appearance of the wall even though snow plows chip away at it.

Concrete gutters, 3.4 meters wide, were placed in front of the wall to serve the following purposes: to improve roadway and slope drainage; to prevent ditch erosion along the steep roadway grades; to provide snow storage space; together with the walls to help to protect the slopes from the sand applied by the maintenance crews during winter; and to provide a settling place for the sediment. They also provide the roadway maintenance crews with the means to efficiently collect and remove the sand prior to it being washed away into the adjacent streams.

Approximately 650 meters of concrete wall and gutter were installed at the cost of \$422,000.00. A perforated pipe underdrain prevented ditch water from being a problem during foundation installation. It also provides foundation protection against ground water.

### **Slope Revegetation**

Propagation of grasses and forbs species was successfully performed on this project. Cool season grasses and forb species were selected for their ability to quickly stabilize the soil surface and produce a strong root system. Seeds were purchased from commercial seed growers producing cultivated named varieties. Slopes were seeded by mixing seed, tackifiers, humates, fertilizers and water, and spraying the mixture onto the soil surface. This application was followed by mulching. Figure 4 shows the specified Seeding Plan and rates of application. This and other various blends of seed mix, tackifiers, fertilizers, soil preparations, and mulching were applied in a hydraulic slurry by Western States Reclamation. Due to the extreme heights the specifications required the mix to be placed from a hose on the top half of the slope assuring uniform application of the seed and fertilizers. An initial application in the fall of 1995 was followed by a second application in the summer of 1996. The third application was placed on the rounded area at the top of some slopes.

Topsoil could not be used to help the revegetation. Due to the steepness of the slopes it would not remain in place and the scarcity of the material and application cost makes it prohibitive. All surfaces were seeded, fertilized, and mulched with native hay with a heavy application of tackifier to hold it in place.

## SEEDING PLAN

### NATIVE SEEDING

Soil preparation, fertilizer, seeding and mulching will be required for the disturbed and adjacent areas within the right-of-way limits which are not surfaced. The following types and rates shall be used:

COMMON NAME	BOTANICAL NAME	KILOGRAMS PLS/HECTARE
Slender wheatgrass v. primar	Elymus trachycaulus	8.9
Streambank wheatgrass v. sodar	Elymus lanceolatus	7.8
Western wheatgrass	Pascopyrum smithii	7.3
Mountain brome v. bromar	Bromus marginatus	5.6
Canada bluegrass v. reubens	Poa compressa	2.4
Alpine bluegrass	Poa alpinum	2.4
Timothy	Phleum pratense	2.4
Red fescue	Festuca rubra	4.5
Meadow foxtail v. garrison	Alopecurus pratensis	6.7
Rocky Mtn. Penstemon	Penstemon strictus v. bandera	1.1
Potentilla	Potentilla fruticosa	2.5
Alsike clover	Trifolium hybridum	4.5
Woods rose	Rosa woodsii	2.4
Strawberry clover	Trifolium fragiferum	3.3
Sheep fescue	Festuca ovina	5.6
Showy Goldeneye (scarified)	Viguiera multiflora	2.2
*Lodgepole Pine	Pinus contorta latifolia	1.1
<b>TOTAL</b>		<b>70.7</b>

\*Pine species shall be source identified within 300 meters+,- of project elevation and certified for elevation, state - CO,UT or WY, where collection was made. Pine seed shall be scarified.

At the completion of any area of 0.25 hectare or larger, soil preparation, seeding and mulching and other final slope treatment shall be completed within 7 days as directed by the Engineer. Additional adjacent areas may require revegetation as directed by the Engineer.

**SEEDING APPLICATION:** Seed, mulch tackifier, humate, Azo-cote and Biosol shall be applied in a single hydraulic slurry application per project special provision 212. Slurry application shall be limited to within 15 meters above the hydraulic pump, unless otherwise approved by the Engineer. A hand held wand shall be used to apply seed slurry mixture to wall areas as directed by the Engineer. Hand seed and rake top 5 meters of slope upon completion of scaling, and apply hydraulic slurry after placing soil retention blanket (plastic) and soil to same area. Azo-cote shall be pre-mixed with seed by supplier at a rate of .45 kg per 45 kg of seed mix or a 1:100 ratio. Azo-cote will be included in the price of the seed.

**MULCHING APPLICATION:** 4.5 m tons per hectare of certified weed free native hay shall be hand or mechanically placed as required on disturbed areas in combination with an approved mulch tackifier.

**MULCH TACKIFIER:** Material for mulch tackifier shall consist of a free-flowing, noncorrosive powder produced from the natural plant gum of Plantago Insularis (Desert Indianwheat), applied in a slurry with water and wood fiber. The rate of application shall be as follows:

	Seeding Application	Mulching Application
Powder / ha	170 kg	340 kg
Wood Fiber / ha	50 kg	250 kg
Water / ha	13,000 l	13,000 l

**SOIL PREPARATION:** Humate materials shall be added at the rate of 2 250 kg per hectare and Biosol shall be added at the rate of 2 250 kg per hectare.

85 kg / HA of potassium shall be incorporated as part of soil preparation. Potassium shall not be paid for separately but shall be included in the cost of the work.

Brush layer cuttings will be required in drainage areas between sta. 8+080 to 8+140 , 9+530 to 9+700 or as directed. Location for Salix Sp. (willows) material exists within the project in adjacent drainages within R.O.W. These areas shall be seeded using the provided seeding plan & covered with soil retention blanket per special provision 216- soil retention blanket (special). Water (landscaping) will be required on this project as directed by the Engineer.

**Figure 4. Seeding plan**



**Figure 5.**      **Work Zone No. 1 after the project.**

Despite the steep slopes and severe weather conditions this worked well.

A number of manufacturers and suppliers provided additional materials for experimental applications in the area. These included a variety of tackifiers, mulches, fertilizers, and erosion retardants. Two seeding and mulching applications were necessary for the following reasons:

1. Severity of the slopes and climate conditions
2. Some loose soil remained on the face of the slopes and slid down after snow melt in the first spring. This did not recur the in the following spring.

## CONCLUSIONS

Providing reinforcement to the scarp forming area of the cut slopes and protection from undermining to the toes of these slopes has successfully prevented surface erosion during plant establishment period. Figure 5 shows the same slope as shown on Figure 2 fourteen months after the final seeding. All turf reinforcing mats and cellular confinement systems applied on this project produced a successful end result -- green vegetation on the slope. However, the more flexible three-dimensional mats similar to Enkamat-S (Akzo Industrial Systems Co.) and Multimat-100 (Tenax Corp.) were lower priced, less labor intensive to install and better conformed to the ground.

The entire combination of seed, fertilizers, soil amendments, mulch, and tackifiers was key to the success of the revegetation.

The amount and size of the rocks and any other material coming down off the slopes is greatly reduced. Maintenance crews report that there is more than an 85% reduction in the quantity of rocks and erosion off the slopes in the areas where slope treatments were applied. The concrete wall and gutter provide roadway maintenance crews with the means to remove the roadway sand before it gets washed into the adjacent streams.

The overall end results of this project are slopes with vegetation and a major reduction in the sediments contaminating the Fraser River watershed.

## REFERENCES

Siemer 1977. *Colorado Climate*

Price, D.A. 1996 *Evaluation of Slope Stabilization Methods (US-40 West of Berthoud Pass)*  
Colorado Department of Transportation Report No. CDOT-DTD-96-6.

## **USE OF THE EDYS ECOLOGICAL DYNAMICS SIMULATION MODEL IN REVEGETATION AND ECOLOGICAL RESTORATION PLANNING**

Terry McLendon,

Department of Biological Sciences  
University of Texas  
El Paso, Texas

### **ABSTRACT**

The EDYS (Ecological DYNAMIC Simulation) model is a PC-based model that can be applied to a wide variety of ecological scenarios. It contains climate, soil, plant, animal, stressor, and landscape modules, each of which can be parameterized for specific applications. The stressor module contains drought, competition, nutrient availability, herbivory, fire, contaminant, non-native plant, trampling and vehicle impacts. EDYS provides multi-scale options at quadrat (e.g., 1.0 square meter), community (e.g., 100-10,000 square meters), and landscape (e.g. 1-10 square kilometers) levels. Outputs include changes in species composition, aboveground biomass by species and by plant part, root biomass by species and by depth, soil moisture by depth, animal diets by species, fire patterns, and changes in Threatened and Endangered species habitat. EDYS is being applied in six national parks, five military installations, the Air Force Academy and several non-agency projects (ranches, conservation groups, mining companies). These scenarios include roadway revegetation, slope stabilization, fire management, training impacts, foot traffic impacts, non-native plant control, grazing (bison, elk, cattle), successional pathways, and vegetation effects on watershed yields. Associated ecosystems range from Maine wetlands to Chihuahuan and Mojave Desert creosotebush shrubland, and from little bluestem prairie in Texas to subalpine tundra in Montana.

**RECLAMATION IN THE HIGH COUNTRY:  
IDARADO MINE REMEDIATION**

Camille M. Farrell

Environmental Protection Specialist  
Colorado Department of Public Health and Environment  
Telluride, Colorado

**ABSTRACT**

After ten years of litigation, the State of Colorado and Idarado Mine Company settled on a remedy to stabilize metal-mine tailings and implement hydrologic controls to improve water quality in the upper San Miguel River and Uncompahgre River basins. The Idarado site, ranging in elevation from 8,500 to 12,400 feet above mean sea level, encompasses approximately 45 square miles, near the San Juan Mountain towns of Telluride and Ouray, in southwest Colorado.

The method employed to stabilize mine tailings using direct revegetation is presented. The results of directly revegetation 200 acres of tailing piles, incorporating organic matter, limestone and fertilizer amendments indicate that vegetation cover meets the performance objectives of 80 percent total cover and 60 percent live cover on the top surfaces and 70 percent total cover and 60 percent live cover on the slope segments, except for two instances. The first year of monitoring revegetation test plots on tailings, using various amendment applications, soil depths and the incorporation of trees and shrubs, indicates that vegetation cover of test plots utilizing organic amendments followed by direct revegetation of tailings exceeded those test plots covered with varying depths of soil.

Hydrologic controls constructed above mine tailings and waste rock piles, through high mountain stream channels, and in the underground mine workings area presented. An improving trend in water quality in both basins is presented.

**RECLAMATION OF THE SAWPIT WASTE ROCK FACILITY  
HOMESTAKE MINE, LEAD, SOUTH DAKOTA**

John W. Scheetz

Homestake Mining Company  
Lead, South Dakota

**ABSTRACT**

Reclamation of the Sawpit Waste Rock Facility (SWRF) is an example of improving a permitted reclamation plan through learned reclamation practices. The original permitted SWRF design specified a 33 million ton, flat-topped, trapezoidal shaped rock fill that included benches every 80 feet with an overall slope of 28 degrees. Reclamation work at the Homestake Mine indicated that this design should be improved to better meet company standards. A voluntary permit technical revision was submitted to the state with the following underlying objectives: create a landform that is functionally compatible with the surrounding undisturbed land form and provide for drainage control, slope stability, vegetation and wildlife; integrate this landform into the permitted post-mining land uses; and perform the reclamation in a cost efficient manner.

The above reclamation goals have been achieved by: redistributing the Sawpit waste rock; recontouring the SWRF to achieve an overall 3.8:1 slope; installing a wide range of specific wildlife habitats; and establishing a practical, cost effective vegetation management plan. All of these goals, accomplished with the state's support, help to achieve better reclamation.

## **REVEGETATION AT THE RICHMOND HILL MINE**

Lawrence County, South Dakota

by

Todd A. Duex  
General Manager  
LAC Minerals (USA) Inc.  
Richmond Hill Mine  
P.O. Box 892  
Lead, SD 57783

### **ABSTRACT**

The Richmond Hill Mine has recently completed a reclamation plan to mitigate Acid Rock Drainage (ARD) which was identified at the site in 1992. ARD material was isolated from the near surface environment by a low permeability capping system designed to minimize water and oxygen flow into the material, in both the former pit and leach pad areas. This plan has been successful in isolating the material and minimizing the effects on the environment.

The primary reclamation goal at the Richmond Hill Mine Site is to provide for wildlife habitat. Because of concerns of maintaining the integrity of the clay cap, revegetation of these areas is limited to the establishment of an aggressive grass species. In areas away from the clay caps, revegetation consisted of the development of six habitat zones in the disturbed area. These habitat zones were established using a varied composition of shrubs and plants to create habitat diversity in the reclaimed areas. In addition, large scale tree transplants were conducted from areas of natural vegetation to the reclaimed sites in order to introduce potential seed source of trees, shrubs, forbs, and grasses. Additional benefit of these transplants is believed to be the introduction of native microbes to assist in the revegetation of the site.

### **INTRODUCTION**

The Richmond Hill mine is located in western Lawrence County, South Dakota, about five miles northwest of the city of Lead. It is located in the northern part of the Black Hills, and lies within the Lead gold mining district. Topography at the site is moderate to steep ranges with elevations ranging from 5400 to over 6000 feet. Average annual precipitation at the site is about 30 inches. The Richmond Hill mine began operation in 1988 and mining operations continued into 1993. The last gold was produced from the mine in June 1995. The Richmond Hill operation consisted of a single open pit, approximately 35 acres in size, and an associated heap leaching facility located one mile to the north. In all, three leach pads were constructed in the processing area. Over the life of the Richmond Hill mine, approximately 9 million tons of material was mined, with about 3.75 million tons being placed in the Spruce Gulch waste rock pile.

In 1992, Acid Rock Drainage (ARD) was identified at the toe of the waste rock pile in Spruce Gulch drainage, a historically dry drainage. Shortly after the identification of the ARD, the pH of the effluent dropped to 3.5, where it remained until the completion of the reclamation activities. In February 1994, the State of South Dakota approved a Permit Amendment to mitigate the Acid Rock Drainage.

Reclamation activities began at the site in April 1994. The primary goal of the reclamation activities was to isolate the acid generating waste rock from the near surface environment with a multi-layer capping system. The capping system was designed to minimize water infiltration into the underlying waste rock. Because of the problems with isolation of the waste material in the Spruce Gulch area along with exposures of sulfide bearing rock in the Richmond Hill pit area, the reclamation plan called for the complete removal of the waste rock in Spruce Gulch and placement into the pit area.

The capping system for the Richmond Hill Pit Impoundment consists of, from bottom to top, six inches of limestone, eighteen inches of low permeability clay, four and one-half feet of thermal barrier/drain layer, and six inches of topsoil. In order to protect the capping system from differential settlement, the backfilled waste rock was compacted in three foot lifts with vehicle traffic. The low permeability clay layer consists of crushed rock amended with about 13 percent bentonite to achieve an in field permeability of less than  $1 \times 10^{-7}$  cm/sec.

Construction of the Richmond Hill Pit Impoundment continued until September 1995. Revegetation of the site was started at this time and was completed in October. At the same time, revegetation of the former waste dump area in Spruce Gulch was accomplished. The primary post mining land use for the Richmond Hill property is wildlife habitat, with a secondary use of recreation. The revegetation plan accounts for these land uses in both the Richmond Hill Pit Impoundment and the Spruce Gulch area.

## REVEGETATION

### Introduction

In order to meet the post mining land use and to meet the special needs of the Richmond Hill Pit Impoundment, two separate revegetation plans were developed at the site. In areas away from the clay cap, revegetation concentrated upon the establishment of grasses, forbs, shrubs, and trees to provide a stable setting with minimal erosion potential. Within the Spruce Gulch area, the removal of nearly all of the waste material resulted in approximately original contours up to a 1.5 to 1 slope. Therefore, the first priority in revegetation was to ensure the stabilization of the site. The use of a variety of grass species and topsoil preparation allowed for the stabilization as quickly as possible. The use of native species of shrubs and trees will provide forage and cover for wildlife use while allowing the disturbed site to return to an approximate natural area as soon as possible.

In the clay capped areas of the Richmond Hill Pit Impoundment, the first priority was site stabilization. The longer term reclamation goal was to establish a cover that would not only provide erosion protection for the capping system, but also retard the establishment of deep rooted

plants which could threaten the integrity of the clay cap. Therefore, the revegetation of the Richmond Hill Pit Impoundment aimed to establish an aggressive grass cover, which includes the use of smooth brome grass.

### Reclamation Activities

Reclamation activities varied according to site conditions. Within the Richmond Hill Pit Impoundment Structure, the design of the capping system included extensive stormwater management features, including diversion benches at 100 foot intervals down slope. These diversion benches drained towards tri-lock lined down-shoots which carries the water for off site discharge. Because of the extensive water management plan along with shallow slopes, normally 3:1, the only additional preparation was cross ripping of the topsoil prior to seeding. As closely as possible, hand seeding of the grass mixture (Table 1) followed the ripping.

In the Spruce Gulch area, additional measures were taken after the removal of the waste rock pile. Since active Acid Rock Drainage was occurring in this area for at least two years, neutralization of acid by-products in the underlying sub soil was done using crushed limestone. A nominal four inches of limestone was placed on the excavated surface, and subsequently ripped into the subsoil. Six inches of topsoil was then placed over the entire area. Because of the steep slopes in Spruce Gulch, up to 1.5:1, extensive stormwater diversion structures were planned in the area to channel water into the natural drainages. Ripping of the topsoil was limited in aerial extent because of the steep slopes and was only completed in areas with a less than 2:1 side slope.

Hand seeding of the grass mixture (Table 2), the wildflower/forb mixture (Table 3), and the shrub mixture followed topsoil preparation. The shrub mixture was altered along with the tree transplanting composition to diversify the Spruce Gulch area. Six habitat zones were developed in the Spruce Gulch area to achieve this diversity (Table 4). In general these habitat zones were developed to match the aspect of the Spruce Gulch area, with the mesic species being planted on the north facing slopes and valleys bottoms, while the zeric species being planted on the south facing slopes.

After hand seeding of the grasses, forbs, and shrubs, the area was hydromulched at a rate of approximately 1500 pounds per acre. During hydromulching, fertilizer and tactifier was applied. The fertilizer application rate was about 100 pounds per acre of 40:40:10 (N-P-K), and the tactifier rate was 75 pounds per acre. Lastly, tree were transplanted according to the scheduled outlined in Table 4. These trees were grown by Bitterroot Restoration, Inc. from seeds collected in the Black Hills under a program initiated by the South Dakota Mining Association.

The last phase of revegetation involved the transplanting of large sized trees with a tree spade. These trees were selected from an on site source and reflect the natural vegetation of the area. A total of 49 trees and associated understory components were transplanted into the Spruce Gulch area. In addition, Twenty-eight 5-year old spruce trees were transplanted from an on site tree farm into Spruce Gulch.

**Table 1. Pit Impoundment Grass Seed Mixture.**

Green Needlegrass	2.4 PLS
Sideoats Grama	1.0 PLS
Western Wheatgrass	4.0 PLS
Slender Wheatgrass	2.0 PLS
Timothy	0.5 PLS
Dutch White Clover	1.0 PLS
Kentucky Bluegrass	1.0 PLS
Smooth Bromegrass	3.0 PLS
'Durar' Hard Fescue	1.0 PLS

**Table 2. Spruce Gulch Grass Mixture.**

Western Wheatgrass	8 PLS
Thickspike Wheatgrass	6 PLS
Slender Wheatgrass	4 PLS
'Durar' Hard Fescue	2 PLS
Kentucky Bluegrass	4 PLS
Timothy	4 PLS
White Dutch Clover	4 PLS
Nurse Crop (Winter Wheat)	6 PLS

**Table 3. Wildflower/Forb Mixture in Spruce Gulch**

Blue Thimble Flower
Lance-Leaved Coreopsis
Plains Coreopsis
Blanket Flower
Blue Flax
Rocky Mountain Penstemon
Prairie Coneflower
Yellow Upright Prairie Coneflower
Black Eyed Susan

Table 4. Spruce Gulch Habitat Zones.

HABITAT TYPE	ACRES	SHRUB MIXTURE	TREE MIXTURE	DENSITY
<b>Spruce Zone</b>	5.4	Service Berry	0.7 PLS/acre Spruce	129 trees/acre
		Woods Rose	0.7 PLS/acre Birch	37 trees/acre
		Choke Cherry	0.5 PLS/acre Aspen	18 trees/acre
<b>Birch Zone</b>	12.0	Service Berry	0.7 PLS/acre Birch	126 trees/acre
		Woods Rose	0.7 PLS/acre Spruce	42 trees/acre
		Choke Cherry	0.5 PLS/acre Aspen	33 trees/acre
		Snow Berry	0.3 PLS/acre	
		Currant	0.3 PLS/acre	Choke Cherry Woods Rose
<b>Transition Zone</b>	11.7	Service Berry	0.7 PLS/acre Birch	94 trees/acre
		Woods Rose	0.7 PLS/acre Aspen	77 trees/acre
		Choke Cherry	0.5 PLS/acre Spruce	17 trees/acre
		Snow Berry	0.3 PLS/acre	
		Currant	0.3 PLS/acre	Choke Cherry Woods Rose
<b>Burr Oak Zone</b>	16.9	Ceanothus	1.0 PLS/acre Burr Oak	118 trees/acre
		Kinnikinnick	1.3 PLS/acre Aspen	83 trees/acre
		Choke Cherry	0.5 PLS/acre	Choke Cherry
<b>Open Zone</b>	3.6	Service Berry	0.7 PLS/acre	No Trees Planted
		Woods Rose	0.7 PLS/acre	
		Choke Cherry	0.5 PLS/acre	
		Snow Berry	0.3 PLS/acre	
		Currant	0.3 PLS/acre	
<b>Ponderosa Pine Zone</b>	2.1	Ceanothus	1.0 PLS/acre	No Trees Planted
		Kinnikinnick	1.3 PLS/acre	Pine Cones Scattered
		Choke Cherry	0.5 PLS/acre	Around The Area

## MONITORING RESULTS

### Monitoring Plan

A Reclamation Success Monitoring Plan was submitted to and approved by the South Dakota Department of Environment and Natural Resources and the Department of Game Fish and Parks in June 1997. The plan provides for surveys of vegetation and wildlife components of the revegetation and includes surveys for herbaceous cover and composition, woody species densities and survival, along with big game pellet transects.

Cover values are obtained along defined 100 foot transects, and results are gathered by the point intercept method described by Buckner, 1985. Species composition is obtained along these same transects at ten foot intervals using a quarter meter square frame. Data are gathered on Perennial and annual grasses, perennial and annual forbs, shrubs, legumes, trees, and other species as noted. Cover is reported as relative cover where all categories total 100 percent. Species composition data are presented as plants/ square meter and life form category.

Data is also gathered on the survival rate of the containerized trees and shrubs planted throughout the area. In Spruce Gulch, 21 tree survival transects are monitored on a yearly basis in four of the established habitat zones. The zones that area monitored are the Birch, Spruce, Transition, and Oak zones. Each of the large and medium scale tree transplants are also monitored annually.

### Monitoring Results

Total cover results for four transects in the Pit Impoundment area are reported in Table 5. Live cover values for this area range from 40 to 58 percent, with herbaceous cover values ranging from 40 to 89 percent. It is important to note that the highest results are due to that fact that this area was planted in 1994 resulting in higher live cover and litter values contributing to the high result. Corresponding composition values for this area are shown in Table 6, and show that a wide variety of species have been established in the area. Within the surveyed areas, eight of the nine species seeded have been identified, resulting in a success rate of 89 percent. Plant densities in this area range from 125 plants to 278 plants per meter<sup>2</sup>.

Within the Spruce Gulch area, live cover values (Table 7) range from 45 to 82 percent with corresponding herbaceous cover values ranging from 57 to 84 percent. Plant densities range from 184 to 263 plants per meter<sup>2</sup> in the Spruce Gulch area, with a wide diversity of species present (Table 8). Overall, 7 of 8 species in the grass mixture have been identified in the surveys.

Two 50 by 50 foot macroplots have been established in the Spruce Gulch area to monitor the success of the shrub seeding. One plot is within the Birch Zone on the north facing slope, and the second is within the Oak Zone on the south facing slope. Shrub seedlings have only been identified within the Birch Zone to date, but observations throughout the Spruce Gulch area indicate that shrubs are well represented in the area. Within the Birch Zone macroplot a series of 1 meter wide transects were surveyed to provide the actual numbers in Table 9. These numbers of plants were obtained from a 45.72 square meter (492 square feet) area. As shown, total number of

Table 5. Cover Values from the Richmond Hill Pit Impoundment

	PI-#1	PI-#2	PI-#3	PI-#4	Mean
Perennial Grasses	28	54	31	39	37.8
Perennial Forbs	1	1	0	0	1.0
Legumes	22	3	13	0	7.8
Bare Ground	6	31	41	48	34.4
Litter	38	1	6	0	9.6
Rocks > 3/4"	4	10	9	10	8.0
Live Cover	51	58	44	40	46.8
Herbaceous Cover	89	59	50	42	57.0

Table 6. Plant Densities (number per square meter) from the Richmond Hill Pit Impoundment

Species	PI-#1	PI-#2	PI-#3	PI-#4	Mean
Timothy	47.20	38.80	47.20	20.40	36.08
Kentucky Bluegrass	67.20	30.00	22.40	25.60	33.28
Smooth Bromegrass	51.20	24.80	3.20	26.40	24.40
Slender Wheatgrass	45.60	18.40	29.60	29.20	35.28
Western Wheatgrass	0.80	3.60	7.20	8.80	5.92
Hard Fescue	20.40	38.00	8.40	7.60	19.12
Green Needlegrass	0.00	0.40	0.40	0.40	0.24
Canada Bluegrass	0.00	22.80	1.60	0.00	4.96
Total Perennial Grasses	232.40	176.80	120.00	118.40	159.28
White Clover	45.60	0.40	19.60	5.20	14.72
Yellow Sweetclover	0.00	0.00	0.00	0.00	0.00
Total Legumes	45.60	0.40	19.60	5.20	14.72
Perennial Forbs	0.00	0.40	3.60	0.80	1.76
Biennial Forbs	0.00	0.00	0.00	0.80	0.40
Total Species Count	278.00	177.60	143.20	125.20	176.16

Table 7. Cover Values from Spruce Gulch.

	SGHER#1	SGHER#2	SGHER#3	SGHER#4	Mean
Perennial Grasses	30	16	32	21	24.8
Perennial Forbs	17	2	6	5	7.5
Legumes	11	64	4	32	27.8
Bare Ground	34	11	34	30	27.3
Litter	2	2	12	5	5.3
Rocks > 3/4"	5	5	10	6	6.5
Live Cover	58	82	45	59	61.0
Herbaceous Cover	61	84	57	64	66.5

Table 8. Plant Densities (number per square meter) from Spruce Gulch.

Species	SGHER#1	SGHER#2	SGHER#3	SGHER#4	Mean
Timothy	28.80	35.60	47.20	59.20	42.70
Kentucky Bluegrass	38.00	99.20	51.20	51.20	59.90
Slender Wheatgrass	38.00	29.60	49.20	36.00	38.20
Western Wheatgrass	12.80	6.40	15.20	6.00	10.10
Hard Fescue	7.20	5.60	10.00	13.60	9.10
Canada Bluegrass	0.00	0.00	0.80	0.00	0.20
Total Perennial Grasses	124.80	176.40	173.60	166.00	160.20
White Clover	8.40	71.60	17.60	7.20	26.20
Yellow Sweetclover	0.00	0.00	0.40	0.00	0.10
Total Legumes	8.40	71.60	18.00	7.20	26.30
Perennial Forbs	56.80	14.80	16.80	11.20	24.90
Biennial Forbs	0.00	0.40	0.40	0.40	0.30
Total Species Count	190.00	263.20	208.80	184.80	211.70

Table 9. Results from Birch Zone Macroplot.

Species	1996	1997
Serviceberry	15	8
Woods Rose	0	3
Chokecherry	0	0
Snowberry	0	0
Currant	59	54
Ceanothus	1	0
Birch Transplant	3	2
Chokecherry	2	1
Totals	80	68

individual plants decreased between 1996 and 1997, with the largest percent decrease being seen in the number of serviceberry plants. This was partially offset by the germination of woods rose in 1997. However, the overall survival rate from 1996 to 1997 is 85 percent for the plants in this survey area.

Within the Spruce Gulch area, excellent success has been noted with the shrub seeding for serviceberry, woods rose, and currant. Moderate success has been seen with ceanothus and chokecherry, but little or no success has been noted with either snowberry or kinnikinnick. Monitoring of the area will continue in the future.

The containerized tree survival transect results are shown in Table 9. The results shown are difficult to interpret for several reasons. The large decline in the number of spruce trees within the transects is primarily due to extensive erosion which washed out the trees and do not necessarily indicate a low survival rate. Meanwhile, the increase in the number of chokecherry plants in the transects is possibly explained by the seeding of chokecherry and subsequent germination of these seeds. For the other species surveyed, there appears to be a survival rate of nearly 100 percent. Since two growth seasons have been monitored since the transplanting has occurred, there is reason to believe that a large number of the trees will survive in the long term and grow to maturity.

Two types of survey results have been gathered for the larger scale tree transplants. For the largest tree transplants, data has been gathered on the understory components which have been introduced into the site. The list of the species identified is shown in Table 10. In addition, each transplant is examined each year and notes are taken to estimate the health of the tree and any other information is gathered such as tree height, growth, or evidence of seed pods. This data shows that 69 percent of the largest transplanted trees exhibit healthy growth and 52 percent of the smaller transplants showed healthy growth. In regard to the smaller transplants, the data is somewhat skewed because erosion has washed away some of the transplants. Of the trees which are stressed, basal re-growth has been noted in several cases. Also, monitoring between 1996 and 1997 show that a few trees which showed stress in 1996, improved and did not exhibit stress in 1997. Overall, a significant percent of the tree transplants are adapting to the Spruce Gulch area, and even where trees have died, there remains an introduction of the understory component to the area.

## SUMMARY

Revegetation at the Richmond Hill Mine Site has been successful in stabilizing both the Pit Impoundment and the Spruce Gulch area in the two years since the initial seeding. Only very minimal erosion has been noted in the Richmond Hill Pit Impoundment area, and this erosion has been stopped. In the Spruce Gulch area, where extremely steep slopes are present, erosion was quite evident in 1996. Extensive repairs were under taken in 1996, and has significantly reduced the erosion problems seen in 1997. In July 1997, a major rain storm occurred at the site, which dropped about 2 inches of precipitation in one-half hour. Inspections after this storm event found erosion limited to the stream channel areas, with the side slopes showing no major erosion problems. Much of the success in stabilizing the Spruce Gulch site is attributed to the stormwater diversion structures which were placed in the area along with the ripping of the topsoil prior to

seeding. With live cover values of over 40 percent and plant densities of well over 100 plants per square meter, it appears that the short term goal of the revegetation plan has been met.

Revegetation at the site has also been successful in establishing a diverse community of plants, with the vast majority of the species planted being found during the monitoring of the site. Monitoring is on-going to determine the long term rates of survival, but preliminary data indicates a high survival rate. The success of the planting along with the introduction of native species with the tree transplanting program is allowing wildlife utilization of the area for foraging, and will in my opinion speed up the return of this area to natural vegetation.

#### ACKNOWLEDGMENTS

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## **RED PLACER RECLAMATION AND STREAM REHABILITATION**

**Philip C. Barnes**

**and**

**David G. McDowall**

**Homestake Mining Company  
Lead, South Dakota**

### **ABSTRACT**

A turn of the century placer goal claim, mined by companies other than Homestake Mining for over one hundred years is reclaimed. Whitewood Creek had been pushed into a channel and the flood plain drastically disturbed by placer mining, dredging and sand and gravel production. Reclamation planning began with baseline inventories of plants, wildlife, aquatic life and collection of geomorphic and hydrologic data. Reclamation included creation of a new creek channel following extensive geomorphic and engineering analyses. Design criteria were for dynamic stability during a 50-year flood event using spur dikes to control creek movement into the flood plain. Protection of an adjacent railroad grade was achieved through use of concrete T-walls. Trout habitat was created using engineered step-drop pools. The overbank land form was constructed using locally available material, and revegetation within the flood plain was accomplished using indigenous species of grasses, shrubs and trees. The site is now a walk-in trout fishery.

# PLANT GROWTH AND SOIL MICROBIAL COMMUNITY STRUCTURE AS AFFECTED BY AMENDMENTS TO MOLYBDENUM TAILING

K. L. Prentice, R. D. Child, and M. J. Trlica

Rangeland Ecosystem Science Dept., Colorado State Univ., Ft. Collins, CO 80523

## ABSTRACT

Stabilization of tailing with vegetation can be a cost effective management technique even though surfaces of tailing dams and disposal areas usually lack typical soil features and are poor plant growth media. Establishment of self-regulating vegetation communities directly on tailing is dependent on the development of soil features in tailing. A greenhouse study was conducted to address short-term effects of organic and inorganic amendments to tailing and the efficacy of amended tailing under cover soil as a replacement for increased soil depth. Amendments included NPK fertilizer, a combination of cow manure compost and hay, sewage sludge, soil, and lime. Two randomized, complete block experiments were used. The first experiment included pots filled entirely with homogeneous mixtures of tailing and amendments. The second experiment included two major groups of amended tailing under either 0-, 15- or 30-cm of cover soil. Red fescue, *Festuca rubra*, was seeded in both experiments. The incorporation of organic amendments and lime with tailing increased shoot and root biomass, organic C, and pH as compared with control and NPK treatments. Nematode frequencies, FDA-active bacteria, and total N were greater in organically amended treatments than in tailing that received mineral fertilizer or no nutrient amendment. Soil addition increased nematodes and decreased FDA-active fungi. These results indicated that tailing amended with organic materials and lime adequately replaced soil function in this short-term, greenhouse trial.

## INTRODUCTION

Tailing is a waste product of hardrock mining and milling. The surfaces of tailing disposal piles are usually erosive. Stabilization of tailing surfaces with vegetation reduces fugitive dust and acid rock drainage, facilitates beneficial uses of reclaimed sites by humans and wildlife, permits future utilization or re-mining of tailing, is aesthetically pleasing, and can be cost effective. Without treatment, tailing may have characteristics that limit plant and microbial growth and complicate reclamation efforts. Specific characteristics include high concentrations of acids, soluble salts and other phytotoxins; lack of aggregate stability, limited (or excessive) moisture holding capacity, low cation exchange capacity, and low levels of essential nutrients and organic matter. Mineral fertilizers, organic amendments, and lime can be used to modify the physical, chemical, and biological properties of tailing and create a soil substitute. The amendment of tailing

to create a soil substitute can be a cost-effective alternative for reclamation on sites for which inadequate quantities of stored soil are available (e.g. Daniels and Zipper 1995; Redente and Baker 1996).

Soil consists of mineral particles, plant roots, microorganisms, and organic solids in various stages of decomposition. In contrast, tailing is comprised largely of mineral materials and is deficient in organic materials and biologic activity. Soil substitutes capable of sustaining permanent vegetation must mimic the structure and function of natural soils. Establishment of processes of nutrient retention, decomposition and cycling in soil substitutes is essential (e.g. Lindemann *et al.* 1984; Allen 1988; Zak *et al.* 1992; Redente and Baker 1996) and may depend on development of both faunal (i.e. nematodes) and microbial (i.e. bacteria and fungi) communities. Soil microbial and mesofaunal communities are intimately associated with the processes of nutrient retention, decomposition and cycling (Anderson 1988; Coleman *et al.* 1990; Shetty *et al.* 1994). Microbes immobilize soil N and retain it in their biomass. Soil fauna graze on bacteria or fungi, thereby mineralizing N and increasing the quantity of plant available N (Hunt *et al.* 1988). Ingham *et al.* (1985) demonstrated that plants grown in the presence of bacteria and bacterial-feeding nematodes grew more quickly than plants in soil without nematodes.

Proper management techniques can accelerate the establishment of microbes on previously sterile sites; their presence ensures the availability of carbon and nitrogen, and improves soil physio-chemical conditions. Also, applications of fertilizer-N to soil can accelerate the rate of nutrient accumulation in tailing. Unamended surface soil (Lindemann *et al.* 1984; Barnhisel 1988; Scullion 1992), straw contaminated with soil (Gemmell and Goodman 1978; Peters 1995), sewage sludge (Mitchell *et al.* 1978; Lindemann *et al.* 1984) and commercial inocula can be used to introduce bacteria, fungi, and other soil organisms to sterile or biologically deficient media such as tailing. Additionally, organic materials such as sewage sludge and cow manure increase C availability, improve aggregate stability (Avnimelch and Cohen 1989; Sun *et al.* 1995), reduce metal availability (Gemmell and Goodman 1978), and decrease surface crusting (Barth 1986).

It has been reported in several studies that soil biota in mine wastes and agricultural soils respond strongly to organic amendments and mulches (e.g. Elkins *et al.* 1984; Lindemann *et al.* 1984; Steinberger *et al.* 1984; Aescht and Foissner 1992; Martens *et al.* 1992; Noyd *et al.* 1995). Mineral fertilizers are reported to have smaller, and possibly negative, effects on soil biota (Berger *et al.* 1986; Klein *et al.* 1989; Aescht and Foissner 1992; Noyd *et al.* 1995; Hart and Stark 1997). The effects of lime on microbial populations in soil appear to be variable. Witter *et al.* (1993) showed significant lime-related increases in microbial biomass in ammonium sulfate-, straw-, and farmyard manure- amended soils, but reported insignificant increases in microbial biomass for limed soils that were amended with sewage sludge or peat. Soil incorporated into mine wastes without the use of other amendments has been shown to have little or no effect on

microbial parameters (Fresquez and Lindemann 1982; Lindemann *et al.* 1984) but soil combined with organic amendments was shown to increase the distribution of fungal genera in a greenhouse experiment (Fresquez and Lindemann 1982).

Tailing from the Climax Molybdenum Company's Henderson Mill is a poor plant growth media and exemplifies this problem. Henderson tailing is acidic, sandy textured, and deficient in plant essential nutrients. Without amendment, this tailing is a poor soil substitute. Following an 11-year field study (Trlica *et al.* 1994), investigators found that vegetation grown on untreated tailing failed to thrive and persisted for only a few seasons and that 15-cm of soil over tailing resulted in low production, cover, and diversity. A 30-cm depth of cover soil over tailing was found to be sufficient to maintain a naturally-functioning, sustainable herbaceous plant community that was significantly better than communities grown on 0-cm or 15-cm soil caps. Few differences existed between measured variables for 30- and 45- cm depths of soil over tailing. Plant roots that became established in the soil caps did not enter into the tailing. Although lime was shown to be effective in this tailing, no mineral fertilizer or organic amendments were used to encourage plant growth after seeding directly on the tailing. These investigators made no evaluations of biological characteristics in the soil caps or underlying tailing. Similar results have been obtained for grass and shrub communities grown on retorted oil shale (e.g. Terwilliger *et al.* 1974) and coal spoil (e.g. Power *et al.* 1979; Pinchak *et al.* 1985). Based on these information needs, the present study was conducted to examine short-term changes in certain chemical and biological parameters of organically and inorganically amended molybdenum tailing and to examine the efficacy of amended tailing under cover soil as a replacement for increased soil depth.

The specific objectives of this greenhouse study were to determine the effects of lime, incorporated soil, sewage sludge, a combination of cow manure compost and hay, and NPK fertilizer amendment on microbial and mesofaunal community structure and plant biomass in amended molybdenum mill tailing. The effects of these amendments on total organic C, total N, and pH in the growth medium were investigated. Additional objectives were to compare rooting depth, shoot and root biomass, nematode frequency, and microbial community structure, in treatments with 0-, 15-, and 30-cm of cover soil over amended tailing.

## METHODS AND PROCEDURES

This research was designed to address two broad questions. First, a comparison of the effects of organic and inorganic amendments to molybdenum tailing on chemical properties, nematode frequency, microbial community structure and plant biomass was made without the use of cover soil. Second, amended tailing was evaluated under cover soil as a replacement for increased soil depth. Two randomized, complete block experimental designs in four replications were conducted to address these questions. Both experiments were conducted simultaneously, on the same greenhouse bench, in similar 15-L, 40-cm tall pots. *Festuca rubra*, red fescue, a grass species commonly

Table 1. Greenhouse amendments to molybdenum mill tailing with no soil cap. A randomized complete block design in four replications was used in this experiment. Four types of nutrient treatment, two levels of lime amendment, and two levels of soil incorporation are indicated in this table. Amendment application rates: Agricultural lime (145 Mg ha<sup>-1</sup>), check (no nutrient amendment), cow manure compost (145 Mg ha<sup>-1</sup>) and hay (5 Mg ha<sup>-1</sup>), sewage sludge (145 Mg ha<sup>-1</sup>), and soil (8 Mg ha<sup>-1</sup>).

	<i>Nutrient Amendment</i>							
	<b>Check</b>		<b>NPK</b>		<b>Manure-Hay</b>		<b>Sludge</b>	
<b><i>LIME</i></b>	Lime	No lime	Lime	No lime	Lime	No lime	Lime	No lime
<b>Incorporated Soil</b>	4	4	4	4	4	4	4	4
<b>No Incorporated Soil</b>	4	4	4	4	4	4	4	4

Table 2. Greenhouse amendments to molybdenum mill tailing with soil caps. A randomized complete block design in four replications was used in this experiment. Two types of nutrient treatment, two levels of soil incorporation, and three soil cap depths are indicated in this table. All treatment combinations included lime. Amendment application rates: Agricultural lime (145 Mg ha<sup>-1</sup>), 11-15-11 NPK fertilizer (1 Mg ha<sup>-1</sup>), cow manure compost (145 Mg ha<sup>-1</sup>) and hay (5 Mg ha<sup>-1</sup>), sewage sludge (145 Mg ha<sup>-1</sup>), and soil (8 Mg ha<sup>-1</sup>).

	<i>Nutrient Amendment</i>					
	<b>Manure-Hay</b>			<b>Sludge</b>		
<b><i>Depth of Soil Cap (cm)</i></b>	0	15	30	0	15	30
<b>Incorporated Soil</b>	4	4	4	4	4	4
<b>No Incorporated Soil</b>	4	4	4	4	4	4

included in seed mixes was grown in both experiments. *F. rubra* is known to be successful on metal-contaminated sites (Gemmell and Goodman 1978; Smith and Bradshaw 1979; Johnson and Munshower 1984) and has shown marked long-term persistence on some seeded high altitude sites (Buckner, *personal communication*).

The first experiment, Experiment 1, included pots filled to a depth of 38 cm with homogeneous mixtures of growth medium. Growth media were composed of four sources of nutrient amendment (Check [no nutrient amendment], NPK Fertilizer, Manure-Hay, Sewage Sludge), two types of lime treatment (present/absent), and two types of incorporated soil treatment (present/absent) (Table 1). Experiment 2, included two sources of nutrient amendment (Manure-Hay, Sewage Sludge), and two types of incorporated soil treatment (present/absent) under 0-, 15- or 30-cm of cover soil (Table 2). In Experiment 2, all growth media included lime as an amendment.

Unamended molybdenum tailing and tailing amended with mineral fertilizer do not support permanent and self-sustaining plant communities in the field (Barrau and Berg 1977; Trlica *et al.* 1994). In contrast, organic material amendments to tailing appear to create permanent and self-sustaining vegetation communities (Redente and Baker 1996; Wheeler 1996). Unamended tailing and tailing amended with mineral fertilizer were included in this design as a control and for purposes of comparison with treatments that received organic amendments and are hypothesized to support permanent and self-sustaining vegetation communities. Sewage sludge and a combination of cow manure compost and hay were used as organic amendments. Sewage sludge was selected because it is a commonly available, inexpensive material that can be applied to acidic mine spoils to increase pH, to provide organic matter and nutrients, and to improve the physical characteristics of the media (Barnhisel 1988). The cow manure compost and grass hay treatment was selected to approximate the effects of the holistic reclamation technique described by Wheeler (1996).

Soil was used in two circumstances in this project. Soil was incorporated into tailing as a possible source of microbial inoculum in both experiments. In Experiment 2, amended tailing was covered with 0-, 15- or 30-cm of soil. Therefore, soil was used both as a surface dressing and as an incorporated amendment. Although the use of additional organic amendments may also be required, soil that is applied to the surface of a sterile medium or that is incorporated into the medium can serve as an effective source of microbial inoculum (Lindemann *et al.* 1984; Scullion 1992). Also, surface applications of cover soil increase plant production (Pinchak *et al.* 1985; Munshower 1994; Trlica *et al.* 1994). It was hypothesized that incorporated soil would serve as a source of microbial inoculum, and that surface-dressed soil would serve as a plant root zone and as a source of inoculum.

## Experimental Methods

Soil for this experiment was gathered from a location in lodgepole pine (*Pinus contorta* Douglas subsp. *latifolia* (Engelmann)) forest located near the Henderson Mill in October of 1996. Organic litter was removed from the surface and soil excavated to a depth of 45 cm. Prior to use, soil was stored indoors under aerobic conditions in 110-L plastic containers. Soil was mixed until homogeneous and sieved through a 4-mm mesh screen. All application rates are reported in megagrams amendment per hectare,

(Mg ha<sup>-1</sup>), and were adjusted to reflect the depth of incorporation used. The multiplication factor "0.446" can be used to express these values in "tons per acre". Soil was incorporated into one half of the pots in Experiments 1 and 2 at an application rate of 8 Mg ha<sup>-1</sup>. Soil of caps 0-, 15-, or 30-cm in depth were used in Experiment 2.

Sewage sludge, cow manure compost, and agricultural lime were each applied at a rate of 145-Mg ha<sup>-1</sup>. The City of Fort Collins, Colorado provided sewage sludge, which contained approximately 20% solids and was applied wet. Grass hay was applied at 5 Mg ha<sup>-1</sup>. To prevent the introduction of undesirable species, seed heads were removed from the hay, which was cut to lengths of between 5 and 10 cm to facilitate homogeneous distribution throughout the pots. NPK fertilizer (11-15-11) was applied at a rate of 1 Mg ha<sup>-1</sup>. Nitrogen was supplied as 4% ammoniacal-N and 7% urea-N. Amendments and tilling were thoroughly mixed and pots filled to volume with amended tilling (Experiment 1) or with amended tilling and cover soil (Experiment 2). The pots with 15-cm cover soil were filled to a depth of 23 cm with the experimental growth medium; the remaining depth was filled with soil to a total depth of 38 cm. The pots with 30-cm cover soil were filled to a depth of 8 cm with the experimental growth medium; the remaining depth was filled with soil to a total depth of 38 cm. All pots were saturated with water and allowed to stand for one week prior to seeding. Experiment 1 pots that settled were filled again with the same material to 38 cm of depth. Experiment 2 pots that settled were filled to 38 cm with soil.

*Festuca rubra* was broadcast seeded directly into the pots on April 20, 1997. Because of poor germination and plant establishment, all plants were removed and all pots were reseeded at a depth of 1.5 cm on May 8, 1997. If necessary, pots were reseeded one additional time. Later, all pots were thinned to five plants per pot. Plants were allowed to grow under conditions of natural light and did not receive additional fertilization during the 120-123 day experiment. Tapwater was used to maintain pots near field capacity. Undesirable plants and herbivores were removed by hand.

### Sampling Method

Three soil cores were removed from the entire depth of each pot in Experiment 1 prior to destructive sampling that occurred September 5 through 7, 1997. These cores were consolidated and mixed. Subsamples of core materials were removed for nematode extraction, and for active bacterial, active fungal, total fungal, and soil chemistry analyses. Root subsamples were removed from soil cores for assessment of arbuscular mycorrhizal infection. All samples used for microbiological analyses were placed on ice for transport and then kept refrigerated at 4 °C. Roots and shoots were removed from the pots and separated at the crown.

Destructive sampling of Experiment 2 materials was carried out September 7 and 8, 1997. Shoots were separated at the crown. The pots were cut open and divided into three sections, soil only, a mixed zone of soil and amended tilling, and amended tilling only. This process ensured that materials from the soil caps did not contaminate samples

used for soil microbiological analyses. The amended tailing was mixed by hand and subsamples of amended tailing were removed for nematode extraction, active bacterial, and active and total fungal analyses. Root subsamples were removed from this mixture for assessment of arbuscular mycorrhizal infection. All materials used for microbiological analyses were placed on ice for transport and then kept refrigerated at 4 °C. Roots were removed from each section of growth media.

### Laboratory Methods

Shoots were oven dried at 50 °C for 72 hours. Roots and surrounding growth media were placed in a nylon stocking and agitated in water to loosen organic materials and then washed over an 18-mesh screen. All roots were oven dried at 50 °C for 72 hours. Root subsamples were cleared and stained according to the method described by Phillips and Hayman (1970) for non-pigmented roots. The proportion of host tissue infected by arbuscular mycorrhiza was assessed with the gridline intersect method described by Giovannetti and Mosse (1980).

Nematodes were extracted from 50 g samples of amended tailing using the Baermann technique (Gundy 1982). Solutions containing nematodes were collected daily for 5 days. Nematodes were identified, counted and identified to genera and trophic group.

All materials analyzed for pH, organic C, and total N were ground in a ball mill prior to analysis. Hydrogen-ion activity (pH) was determined with a 2:1 paste of amended tailing and 0.01 M CaCl<sub>2</sub> in distilled, deionized water. A LECO® CHN-1000 Carbon Hydrogen and Nitrogen Analyzer was used to measure total organic C and total N. Samples which contained lime were analyzed once and then acidified with 0.1 M HCl for 24 hours and analyzed a second time to isolate the effects of lime addition.

Bacteria and fungi both play significant roles in the immobilization of minerals and the creation of soil structure (e.g. Paul and Clark 1996) and can encounter conditions of nutrient and energy deprivation within the heterogeneous soil environment. At these times, metabolic activities decrease but the microorganisms persist and continue to immobilize nutrients (Morita 1997). Metabolizable dyes such as FDA (fluorescein diacetate) can be used to identify metabolically active bacteria and fungi (Ingham and Klein 1982; Stamatiadis *et al.* 1990; Lodge and Ingham 1991). In this study, metabolically active (FDA-active) lengths of fungal hyphae and numbers of FDA-active bacteria were determined using phosphate buffer and the coverslip well technique described by Lodge and Ingham (1991). Metabolically inactive (total) lengths of fungal hyphae were estimated using phase contrast/DIC microscopy (Lodge and Ingham 1991).

## Data Analysis

All data were subjected to a factorial analysis of variance (Steel, Torrie, and Dickey, 1997) using the General Linear Model Procedure in SPSS version 7.5 for Windows (SPSS Inc. 1989-1996). When significant ( $p < 0.05$ ) main effects were detected for source of nutrient amendment or depth of soil cap, then Tukey's HSD (Steel, Torrie, and Dickey 1997) test was utilized to separate significant ( $p < 0.05$ ) means. When significant main effects were detected for presence or absence of lime, or presence or absence of incorporated soil, then independent t-tests were used for separation of significant ( $p < 0.05$ ) means (Steel, Torrie, and Dickey 1997). When meaningful significant ( $p < 0.05$ ) interactions were found among variables, these are discussed rather than main effects. Numbers of FDA-active bacteria were normalized using a  $\log(X + 1)$  transformation (Steel, Torrie, and Dickey 1997) to meet the assumptions of analysis of variance procedures.

## RESULTS AND DISCUSSION

### Anecdotal Observations

Mineral fertilizers distribute nutrients evenly throughout soil and have no immediate effect on soil structure (Gross *et al.* 1993). Organic amendments, in contrast, are distributed more heterogeneously and cause two immediate changes. First, organic amendments change the physical structure of the growth environment thereby altering water relations and creating microsites that influence trophic relationships and microbial activity (Paul and Clark 1996). Second, organic amendments are localized "hotspots" of relative nutrient abundance that may stimulate root proliferation (Robinson 1994) and microbial activity (Lindemann *et al.* 1984; Goyal *et al.* 1992). The duration of this effect is related to the quantity and quality of material added (Persson and Kirchmann 1994). At the termination of these experiments, tailing that received no nutrient amendment (check) and NPK amended tailing had similar, sandlike, appearances. The manure-hay amendment had undergone significant decomposition resulting in dispersion of organic material throughout the growth media. Irregularly sized masses of sludge up to 1 cm in diameter were distributed throughout the sludge-amended tailing.

### Plant Biomass

Plants grown in tailing that received no amendments did not survive the 120 day growth trial and were considered to have no shoot or root biomass (Fig. 1A). This result is consistent with previous observations that this tailing does not support permanent vegetation without amendment (Trlica *et al.* 1994). The addition of NPK fertilizer increased plant survival but mean shoot biomass was low and not significantly ( $p > 0.05$ ) different than the check treatment. Elevated pH and nutrient availability have both been

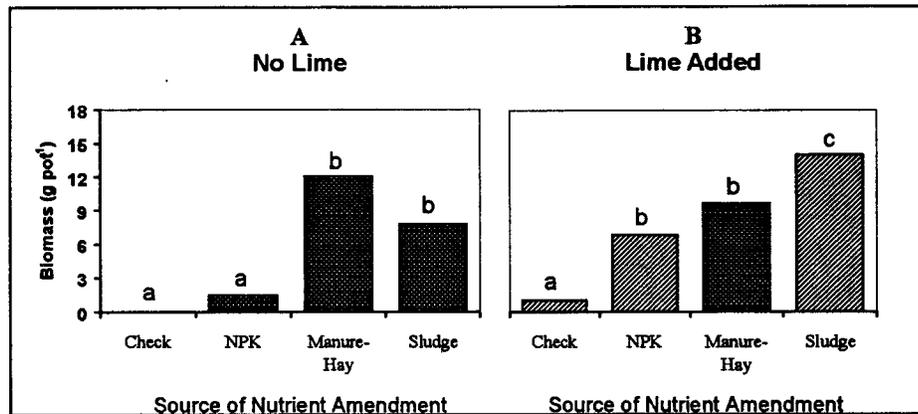


Figure 1. Shoot biomass in molybdenum tailing with no added lime (A) or with the addition of lime (B) as influenced by nutrient amendment\*. Similar letter above bars indicate no significant differences ( $P>0.05$ ) among those nutrient treatments. If the bar for a single nutrient treatment is black in Fig. A and gray in Fig. B, then those two means are significantly different ( $P<0.05$ ). \*Application rates: Agricultural lime ( $145 \text{ Mg ha}^{-1}$ ), check (no nutrient amendment), 11-15-11 NPK fertilizer ( $1 \text{ Mg ha}^{-1}$ ), cow manure compost ( $145 \text{ Mg ha}^{-1}$ ) and hay ( $5 \text{ Mg ha}^{-1}$ ), and sewage sludge ( $145 \text{ Mg ha}^{-1}$ ).

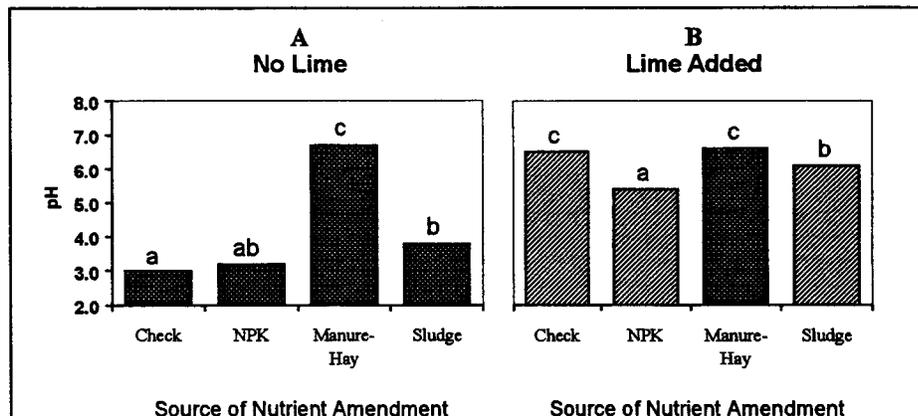


Figure 2. pH in molybdenum tailing with no added lime (A) or with the addition of lime (B) as influenced by nutrient amendment\*. Similar letters above bars indicate no significant differences ( $P>0.05$ ) among those nutrient treatments. If the bar for a single nutrient treatment is black in Fig. A and gray in Fig. B, then those two means are significantly different ( $P<0.05$ ). \*Application rates: Agricultural lime ( $145 \text{ Mg ha}^{-1}$ ), check (no nutrient amendment), 11-15-11 NPK fertilizer ( $1 \text{ Mg ha}^{-1}$ ), cow manure compost ( $145 \text{ Mg ha}^{-1}$ ) and hay ( $5 \text{ Mg ha}^{-1}$ ), and sewage sludge ( $145 \text{ Mg ha}^{-1}$ ).

associated with increased shoot biomass; therefore, plant survival in the NPK fertilizer treatment may be related to the slight increase in pH observed in these pots (Fig. 2) or to the plant's increased ability to withstand acidic conditions when nutrient deficiencies were resolved. Shoot biomass was significantly ( $p < 0.05$ ) increased by sludge and manure-hay amendments. Elevated shoot biomass may be associated with relatively high organic C (Figs. 3 and 4) and total N (Table 3) values in organically amended treatments or with the near-neutral pH found in manure-hay amended tailing regardless of lime treatment (Fig. 2). The addition of lime significantly increased shoot biomass for all nutrient treatments except manure-hay amended tailing (Fig. 1B). Plants survived in tailing that was limed but received no nutrient amendment, but plants grown in tailing amended with lime and NPK fertilizer or manure-hay produced more shoot biomass (Fig. 1A, B). The largest values for shoot biomass production occurred in tailing amended with sewage sludge and lime. The high shoot biomass values observed in sludge amended tailing may reflect hotspots of nutrient availability within the tailing (Robinson 1994).

Table 3. Main effects of nutrient amendment of molybdenum tailing. Similar letters in rows indicate no significant differences ( $P > 0.05$ ) among those nutrient treatments. Amendment application rates: Check (no amendment); 11-15-11 NPK fertilizer (1 Mg ha<sup>-1</sup>), cow manure compost (145 Mg ha<sup>-1</sup>) and hay (5 Mg ha<sup>-1</sup>), and sewage sludge (145 Mg ha<sup>-1</sup>).

	<i>Nutrient Amendment</i>			
	Check	NPK	Manure-Hay	Sludge
<b>EXPERIMENT 1: Units (variable)</b>				
Total N (%)	0.00 a	0.00 a	0.10 c	0.04 b
FDA-active bacteria (No. g <sup>-1</sup> )	4.9E+06 a	3.3E+06 a	2.3E+07 b	1.5E+07 b
FDA-active hyphal length (cm g <sup>-1</sup> )	10 a	<0 a	120 b	30 a
Total hyphal length (cm g <sup>-1</sup> )	870 a	270 b	830 a	850 a
Nematodes (No. g <sup>-1</sup> )	<0 a	2 a	31 b	40 b
<b>EXPERIMENT 2: Units (variable)</b>				
Shoot biomass (g pot <sup>-1</sup> )			10.0 a	12.0 b

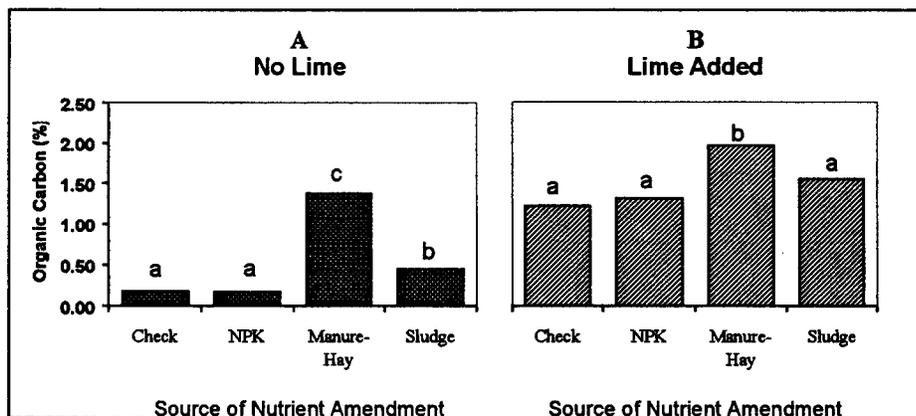


Figure 3. Total organic carbon in molybdenum tailing with no added lime (A) or with the addition of lime (B) as influenced by nutrient amendment\*. Similar letters above bars indicate no significant differences ( $P>0.05$ ) among those nutrient treatments. If the bar for a single nutrient treatment is black in Fig. A and gray in Fig. B, then those two means are significantly different ( $P<0.05$ ).

\*Application rates: Agricultural lime ( $145 \text{ Mg ha}^{-1}$ ), check (no nutrient amendment), 11-15-11 NPK fertilizer ( $1 \text{ Mg ha}^{-1}$ ), cow manure compost ( $145 \text{ Mg ha}^{-1}$ ) and hay ( $5 \text{ Mg ha}^{-1}$ ), and sewage sludge ( $145 \text{ Mg ha}^{-1}$ ).

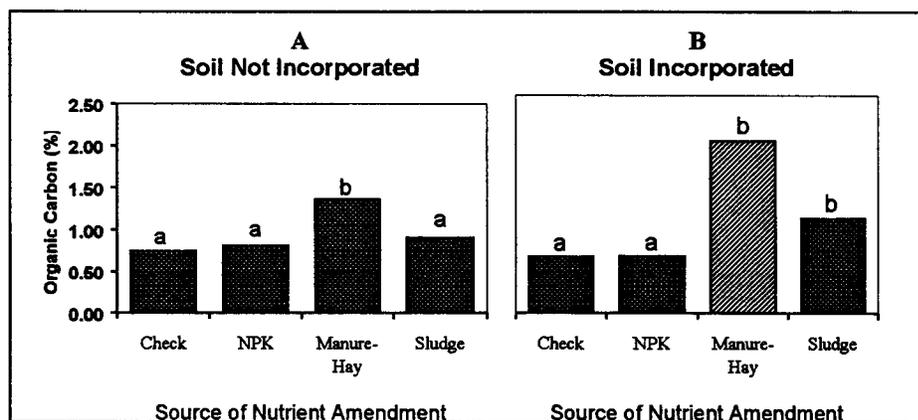


Figure 4. Total organic carbon in molybdenum tailing with no incorporated soil (A) or with the addition of soil (B) as influenced by nutrient amendment\*. Similar letters above bars indicate no significant differences ( $P>0.05$ ) among those nutrient treatments. If the bar for a single nutrient treatment is black in Fig. A and gray in Fig. B, then those two means are significantly different ( $P<0.05$ ). \*Application rates: Soil ( $8 \text{ Mg ha}^{-1}$ ), check (no nutrient amendment), 11-15-11 NPK fertilizer ( $1 \text{ Mg ha}^{-1}$ ), cow manure compost ( $145 \text{ Mg ha}^{-1}$ ) and hay ( $5 \text{ Mg ha}^{-1}$ ), and sewage sludge ( $145 \text{ Mg ha}^{-1}$ ).

Among those plants grown in tailing that received no lime amendment, root biomass was greatest for plants grown in manure-hay amended tailing (Fig. 5A). This may be a response to nutrient availability and distribution (Robinson 1994) or increased pH and changes in soil structure (Stirzaker 1996). Relative to the check treatment, root biomass was increased by the addition of NPK fertilizer and sewage sludge. Lime increased root biomass among plants grown in tailing that received no nutrient amendment or NPK fertilizer but did not significantly increase root biomass in organically amended pots (Fig. 5B).

Several field studies have demonstrated that depth of topsoil and topsoil plus subsoil significantly increase aboveground plant production (Power *et al.* 1979; Pinchak *et al.* 1985; Cotts *et al.* 1991; Trlica *et al.* 1994) and root growth (McGinnies and Nicholas 1980), and it is well known that plants grown in nutrient rich environments allocate fewer resources to roots than to shoots (e.g. Robinson 1994). In Experiment 2, shoot biomass was greatest among plants grown with 0- or 15- cm soil caps (Table 4) and, relative to manure-hay amended tailing, was increased 22% by the use of sewage sludge. Root biomass was increased with each increase in soil cap depth (Table 4). When shoot biomass and root biomass were summed, there were no significant differences ( $p>0.05$ ) for total plant biomass related to depth or source of nutrient amendment.

#### Bacteria, Fungi, and Nematodes

Numbers of FDA-active bacteria were highest in organically amended tailing (Table 3). Averaged over all other treatments, the addition of lime increased FDA-active bacteria 58%. Although incorporated soil did not significantly influence FDA-active bacteria in Experiment 1 or 2, the presence of a soil cap increased FDA-active bacteria in the underlying amended tailing (Table 4). It is possible that when Experiment 2 pots were watered, soil was washed down from the soil cap into the underlying tailing and served as an additional source of microbial inoculum and organic matter. This wash-down effect may account for increased FDA-active bacteria in tailing underlying soil caps.

Table 4. Main effects of soil cap depth over amended molybdenum tailing. Similar letters in rows indicate no significant differences ( $P>0.05$ ) among those soil cap depths.

	<i>Soil Cap Depth</i>		
	0-cm cap	15-cm cap	30-cm cap
Shoot biomass (g pot <sup>-1</sup> )	11.9 ab	12.1 b	9.4 a
Root biomass (g pot <sup>-1</sup> )	4.9 a	8.3 b	11.5 c
FDA-active bacteria (No./g <sup>-1</sup> )	2.3E+07 a	3.5E+07 ab	3.8E+08 b

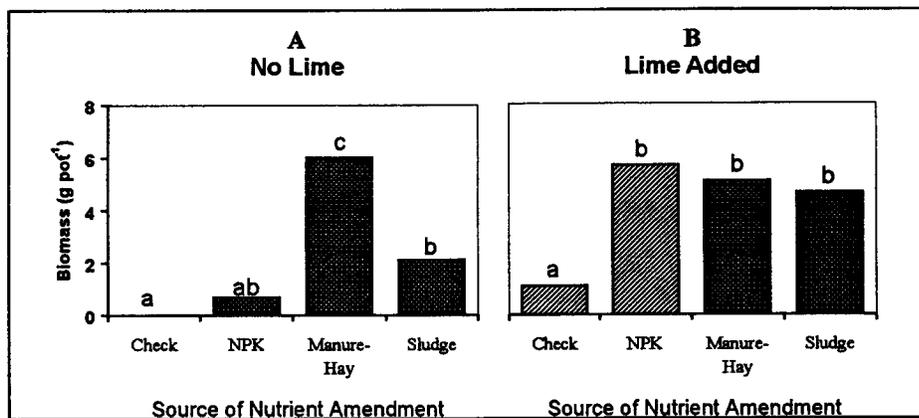


Figure 5. Root biomass in molybdenum tailing with no added lime (A) or with the addition of lime (B) as influenced by nutrient amendment\*. Similar letter above bars indicate no significant differences ( $P>0.05$ ) among those nutrient treatments. If the bar for a single nutrient treatment is black in Fig. A and gray in Fig. B, then those two means are significantly different ( $P<0.05$ ). \*Application rates: Agricultural lime ( $145 \text{ Mg ha}^{-1}$ ), check (no nutrient amendment), 11-15-11 NPK fertilizer ( $1 \text{ Mg ha}^{-1}$ ), cow manure compost ( $145 \text{ Mg ha}^{-1}$ ) and hay ( $5 \text{ Mg ha}^{-1}$ ), and sewage sludge ( $145 \text{ Mg ha}^{-1}$ ).

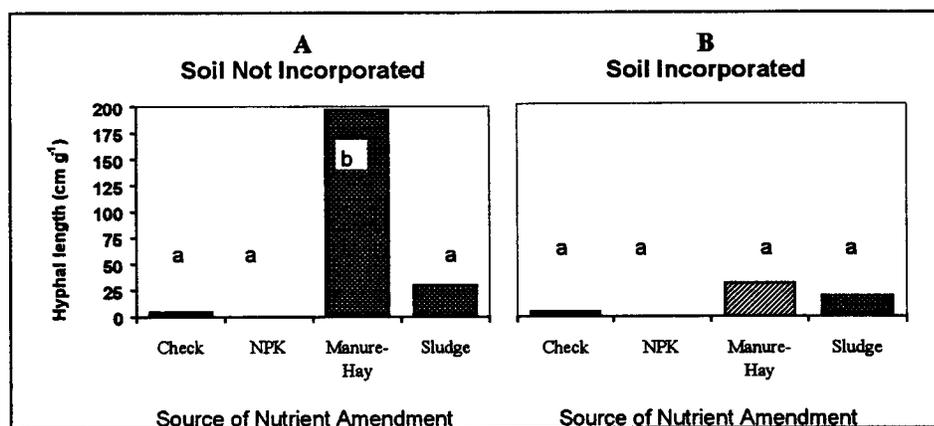


Figure 6. FDA-active fungi in molybdenum tailing with no incorporated soil (A) or with the incorporation of soil (B) as influenced by nutrient amendment\*. Similar letters above bars indicate no significant differences ( $P>0.05$ ) among those nutrient treatments. If the bar for a single nutrient treatment is black in Fig. A and gray in Fig. B, then those two means are significantly different ( $P<0.05$ ). \*Application rates: Soil ( $8 \text{ Mg ha}^{-1}$ ), check (no nutrient amendment), 11-15-11 NPK fertilizer ( $1 \text{ Mg ha}^{-1}$ ), cow manure compost ( $145 \text{ Mg ha}^{-1}$ ) and hay ( $5 \text{ Mg ha}^{-1}$ ), and sewage sludge ( $145 \text{ Mg ha}^{-1}$ ).

Relative to pots with no nutrient amendment or with either organic treatment, total fungi were decreased in the presence of NPK fertilizer (Table 3). Because fungal hyphae facilitate N translocation within heterogeneous soil environments, previous researchers have attributed decreased hyphal length in the presence of mineral fertilization to the loss of the functional advantage of N translocation in the relatively homogeneous environment created by fertilization (Turner and Newman 1984; Klein *et al.* 1989). The interaction between source of nutrient amendment and presence or absence of incorporated soil was significant for FDA-active fungi (Fig. 6A, B). Among pots that received no incorporated soil (Fig. 6A), no FDA-active fungi were recorded in the NPK treatment. This response is similar to the decrease in total fungi observed in the NPK amended tailing, but the value was not significantly different ( $p>0.05$ ) than FDA-active fungi values for the check treatment and sludge amended tailing. The highest values for FDA-active fungi occurred in manure-hay amended tailing. These values were significantly diminished by the incorporated soil amendment (Fig. 6B). FDA-active fungi also were decreased in sludge amended tailing that received the soil amendment, but this decrease was not significant ( $p>0.05$ ). It is speculated that decreased FDA-active fungi in pots that received incorporated soil as an amendment may be related to a change in competitive relationships among microbial and mesofaunal communities within the pots, but this speculation is not substantiated. In Experiment 2, tailing in sludge amended pots had an average of 20 cm of FDA-active hyphae  $g^{-1}$  and tailing in manure-hay amended pots had an average of 100 cm FDA-active hyphae  $g^{-1}$ . There were no significant effects for total fungal hyphae in Experiment 2.

Nematodes were increased by the addition of organic amendments (Table 3). With few exceptions, identified nematodes were bacterial-feeders; the presence of bacterial-feeding nematodes can beneficially affect nutrient cycling and plant growth (Ingham *et al.* 1985). Incorporated soil amendment increased nematode frequency from a mean of 13 to 23 nematodes  $g^{-1}$ . Nematode frequency is likely related both to the introduction of nematodes into the pots and to their survival. Steinberger *et al.* (1984) demonstrated that adequate organic matter is of more importance to nematodes in dry soil than supplemental water. Mitchell *et al.* (1978) has shown that sludge that was aerobically digested and dewatered in drying beds was a significantly better source of nematodes than sludge that was anaerobically digested and dewatered by centrifuge. Plots, which were amended with sludges originally deficient in nematodes, showed a rapid increase when exposed to other sources of nematodes, i.e. soil. Additionally, Mitchell *et al.* (1978) reported that the density of nematodes in sewage sludge amended systems was directly related to the densities of the bacterial populations upon which they feed.

Mycorrhizal infection enhances the host plant's drought and nutrient stress tolerance (Paul and Clark 1996) and is generally seen as a desirable outcome of reclamation techniques (e.g. Allen and Friese 1992). Infected roots and soil that contain fungal spores are important sources of inocula. Although roots that grew directly in soil caps (Experiment 2) were infected by mycorrhizal fungi (not shown), no roots that grew

directly in amended tailing became infected. This lack of infection may be related to the short duration of this study. Previous researchers have found that it may take two to four years for soils to regain infectivity (Jasper *et al.* 1987; Noyd *et al.* 1996).

## CONCLUSIONS

Nutrient amendments (NPK fertilizer, cow manure compost and hay, and sewage sludge) and agricultural lime resulted in increased plant biomass in the molybdenum tailing. NPK fertilizer increased nematode frequency; but, relative to increases noted in organically amended tailing, this effect was minor. Additionally, the use of NPK fertilizer decreased lengths of fungal hyphae. Root biomass and lengths of fungal hyphae were greater in the manure-hay amended tailing than in all other treatments. Amended tailing that underlaid soil caps was utilized as a plant rooting zone.

Results of this short-term greenhouse study suggest that amendments can be used to overcome growth limitations in molybdenum tailing, that tailing can be amended to serve as an adequate plant growth medium, and that amended tailing can be used to increase rooting depth beyond the depth of applied soil caps. This project was of short duration and removed water, wind, and weather related extremes as limiting conditions; therefore, results should be interpreted cautiously. Additional research that relates short-term greenhouse studies to field studies where application rates and combinations of amendments are evaluated should provide useful information.

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# NITROGEN AMENDMENT FOR REVEGETATION OF DRASTICALLY DISTURBED SITES

Vic Claassen and Michael Hogan

Soils and Biogeochemistry Section  
Department of Land, Air and Water Resources  
One Shields Avenue  
University of California, Davis  
Davis, CA 95616

## ABSTRACT

Low plant available nitrogen has been shown to be a major factor in revegetation of drastically disturbed soils. In order to eliminate this soil characteristic from the list of potential plant growth limiting conditions, we propose to amend disturbed sites so that the N release from amendments is approximately similar to that of vegetated soils, both in short term N availability and also in reserve pools of N. Delivery of a relatively low but constant supply of plant available N is expected to favor steady growth of native species as opposed to the promotion of rapid weedy growth from the use of highly soluble N fertilizers. To guide the selection of N levels appropriate for revegetation on degraded soils, sites in the Lake Tahoe basin were selected that had been previously disturbed and have now recovered to a range of vegetative cover. Several forms of soil N were measured on both granitic and volcanic parent materials. Indicators that correlate well with vegetative cover are used to develop target levels for N amendment.

## INTRODUCTION

Sustained revegetation of a variety of "problem soils" on drastically disturbed sites in California has been difficult to achieve. Such soils include low pH sands, and serpentine, volcanic and granitic parent materials in high mountainous or arid regions (Clary, 1983; Parks and Nguyen, 1984). The term "drastically disturbed" (Box, 1978, p. 2) is used to mean that the topsoil and biological components have been stripped or eroded away during disturbance, and that revegetation must be accomplished on biologically inactive geological substrates. Normal processes of secondary succession will not naturally revegetate these sites within a human lifetime.

On such altered materials, nitrogen is commonly a plant limiting nutrient (Bradshaw, 1987). Standard revegetation procedures on such sites often include application of 500 lb/ac of 16-20-0 fertilizer. While these amendments promote plant growth initially, empirical observations indicate that plant cover thins out within 5 to 10 years and soil erosion resumes. The high percentage of soluble, plant available nitrogen (N) in these fertilizers promotes rapid weedy growth and allows leaching of mobile forms of N out of the soil profile.

Recent work in the granitic parent materials in northern California indicates that the two primary differences between adjacent vegetated and unvegetated plots on similar parent materials, aspects and slope angles, are soil physical characteristics (mainly water holding capacity), and soil N pool sizes and distribution (Claassen and Zasoski, 1996) (Figure 1). Because of the ability of adequate soil N to improve plant growth and therefore increase rooting volume and improve

Soil Characteristic	Percent decrease on DG cut slopes compared to adjacent vegetated soil
- clay content	50 %
- soil organic matter	21 %
- water holding capacity	25-50%
- pH	same, non-limiting
- cation exchange capacity	same, moderately low
- exchangeable Ca, Mg	higher in cut slope
- exchangeable K	reduced, not deficient
- total nitrogen	29 %
- available nitrogen	33 %
- total phosphorus	same or higher
- available phosphorus	low to high availability
- sulfur	same, potentially limiting

Figure 1. Summary of the decrease in each soil parameter in DG cut slope samples compared to levels measured on native vegetated soil samples (averaged from topsoil and subsoil values).

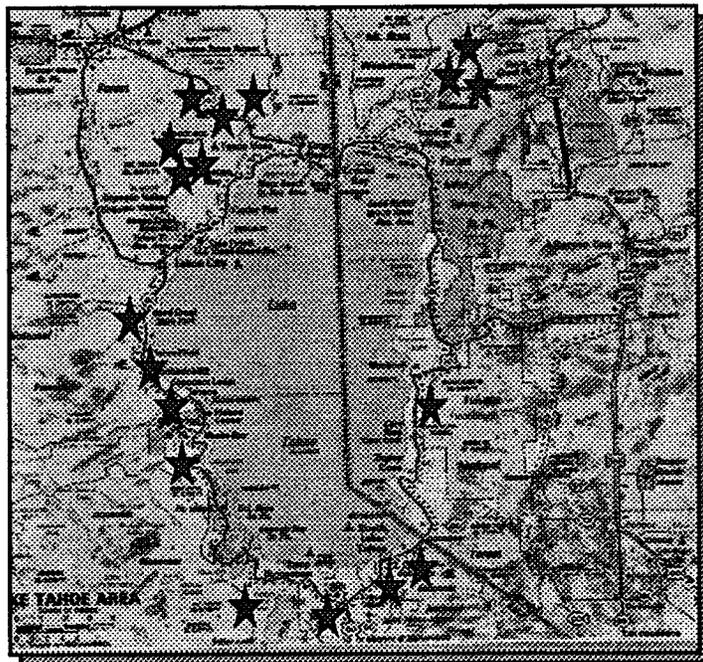


Figure 2. Map of Lake Tahoe Basin and 1995 survey sites (stars).

water uptake, we decided to focus initially on N amendments as a keystone to other improved soil processes.

The study described here addresses the role of low soil N in limiting plant growth on disturbed sites in the Lake Tahoe basin. It asks 1) whether vegetative cover is correlated to patterns of soil N pools, 2) whether soil N evaluation procedures differ in their correlation to vegetative cover, and 3) to what levels should the soil be amended to promote sustained growth of desirable plant species.

Because N pools in the soil differ in their mobility and plant availability, we selected several different operational measures of soil N for evaluation. These included 1) KCl extractable N, a measure of short term N fertility (days to weeks), 2) mineralizable N, a measure of N available over approximately a growing season (several months), and 3) total N, the sum of all N in the soil profile. Vegetative cover was measured and correlated with each estimate of soil N.

## MATERIALS AND METHODS

Thirty-one sites in the Lake Tahoe Basin were selected that had been previously disturbed but that currently support a stable vegetative cover (Figure 2). We selected sites that had equilibrated at least 5 years since disturbance so that transient effects of fertilizer N or plant establishment have declined. We concentrated on grass covered plots since we did not want to include residual effects from preexisting plant canopies (such as with large trees) or plant derived effects (such as N fixation). While ultimate revegetation objectives certainly include a range of these plant forms, grasses were used in this study as an on-site bioassay of soil fertility. Plant cover was measured within each selected site by line intercept on a randomly placed 20 m transect.

Soils were collected from four uniformly spaced locations along the transect and were sampled from 0-10 cm and 20-30 cm depth. Soils were air dried and sieved to < 2 mm. While air drying is known to have effects on soil N pools, this method was used as a standard sampling procedure because these soils commonly dry through the profile during the summer. Extractable ammonium and nitrate were measured by displacement with 2 M KCl and mineralizable N was measured by anaerobic incubation (Keeney, 1982). Inorganic solution N was measured by constant flow conductimetric analysis (Carlson, 1978, 1986). Total N was measured by dry combustion (Dumas, 1831)/gas chromatography/ TCD detection (Carlo-Erba NA 1500).

## RESULTS AND DISCUSSION

### Correlation of Vegetation and Soil N Pools.

The correlation of KCl extractable ammonium or nitrate and vegetative cover is poor (Figure 3, top two graphs). Extractable ammonium is relatively insensitive to changes in vegetative cover level and extractable nitrate concentrations are actually lower in the well vegetated sites than in the poorly vegetated sites.

These KCl extractable N indicators are commonly used in agricultural systems where N cycling is rapid (days to weeks) and where repeated N amendments are common. Agricultural systems commonly maintain high soluble N levels for maximum plant growth. In wildlands soils, however, high soluble N levels are expected to promote weedy plant growth and/or allow leaching losses of these mobile forms of N. The incorporation of N into above and below ground plant tissue, into accumulated litter and into microbial biomass is thought to reduce extractable N concentrations to low soil solution levels and increase N retention within the nutrient cycles. Our experience with analyses of many other disturbed wildlands soils is that inorganic ammonium

and nitrate concentrations are typically only a few  $\mu\text{g N/g}$  soil. The poor correlation between extractable N and vegetative cover indicates that these are not good indicators of soil N fertility resources for predicting potential vegetative cover.

In contrast, total N and mineralizable N are positively and relatively strongly correlated with vegetative cover (Figure 3, bottom left and right graphs). This suggests that N available for plant growth is related in some way to the soil N pool measured by anaerobic mineralization.

A west coast forest soil study (Myrold, 1986) indicates that the anaerobic N mineralization assay measures N released primarily from the microbial biomass. As substrates are consumed within the soil, the microbial populations decline, releasing their incorporated N. In addition to improving N retention within the system, maintenance of a constant, but low level of plant available N is influential in regulating vegetative succession on a site from early seral stages to later successional species (McLendon and Redente, 1991, 1992, Wedin and Tilman, 1996). In the present study, the mineralizable N pool is a relatively small proportion of the total soil N, amounting to about 2 % of total N in the well vegetated plots (> 40 % vegetative cover) and about 1.5 % in the poorly vegetated plots (< 15 % vegetation cover). Because the proportion is relatively constant, total N also is relatively well correlated with vegetative cover.

The amount of soil N that is correlated with a given level of vegetative cover can be estimated from the lower two graphs in Figure 3. If an acceptable vegetative level is set at 50 % (95 % reduction in soil loss compared to bare soil; Elwell, 1980), the total N associated with this vegetative level is estimated to be around 900 mg N / kg soil. Note that this calculation is for a 0-30 cm depth with 100 % fine soil fraction (< 2 mm). If coarse fragments are more realistically assumed to be 50 % of the total soil volume, and bulk density is assumed to be 1.3 g/cm this gives a calculated estimate of about 1800 kg total N/ha. By way of contrast, drastically disturbed soils in the area often have only a few hundred kg total N/ha, suggesting a chronic limitation of N for reestablishment of vegetation on these sites.

The amount of mineralizable N that correlates to 50 % vegetative cover is harder to estimate. The period over which this becomes available for plant growth is not known for these soils, but could be one to several times per season. The proportion of total N that is mineralized (about 2 % in this study) is roughly similar to native soils (3-5 %) Stevenson, 1994). The function of a nutrient cycling system involving a large reserve with a relatively low release rate is that the soil system can reestablish its vegetative cover several times over following disturbance as long as the nutrient rich topsoil resource is not removed.

## CONCLUSIONS

Soil N pool analyses on drastically disturbed sites such as these should include procedures that evaluate plant available N reserves as opposed to measuring only N in immediately available forms. Although commonly reported, extractable N measurements are insensitive to plant cover on these soils. Because of the tendency of soluble, highly available N fertilizers to favor weedy growth or to leach from the profile, the use of slow release forms is recommended. Amendments that contain organic materials can provide the slower release patterns that provide for years of plant N uptake, as well as provide alternative benefits to soil function, including improved water relations, and increased microbial activity.

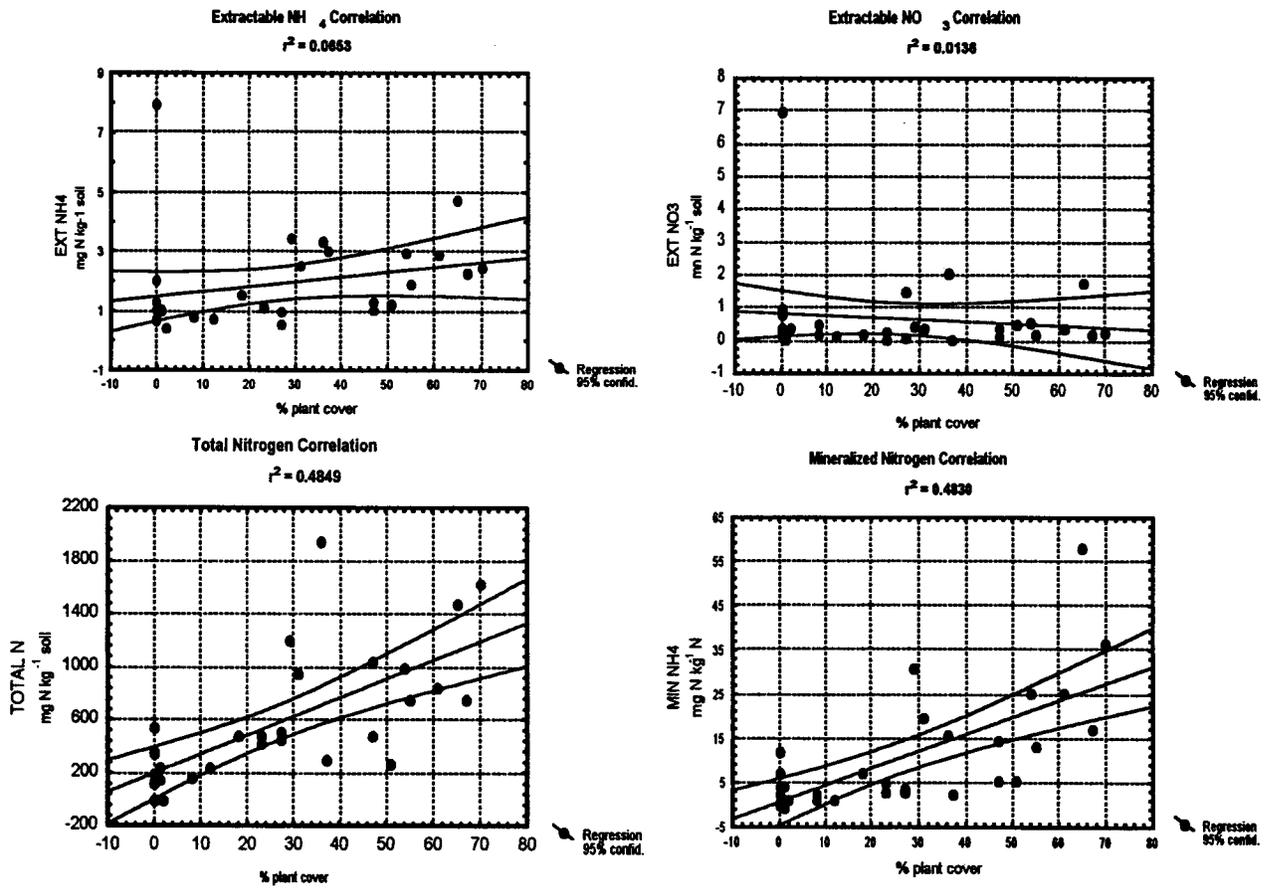


Figure 3. Correlation of vegetative cover in the Lake Tahoe basin with soil N pools: extractable ammonium (upper left), extractable nitrate (upper right), total nitrogen (lower left), and anaerobic mineralizable N (lower right).

The total N levels that are associated with adequate plant growth in this study are estimated to be in the low thousands of kg N/ha, with the mineralizable fraction accounting for about 2 % of this figure. Minimum levels for revegetation with sustainable plant communities may be less, but should be viewed in the context of capitalizing a plant/soil nutrient cycling system rather than as an agronomic fertilizer application to a short term "crop" of vegetative cover. Because we work with drastically disturbed soils, the same generalizations may not apply to old field succession, in which soil nutrient reserves are still largely intact, or to arid areas that do not leach N out of the profile and may have overriding water or P deficiencies.

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# REVEGETATION SUCCESS AT A TAILINGS REMEDIATION SITE ALONG SILVER BOW CREEK NEAR BUTTE, MONTANA

Warren R. Keammerer

Keammerer Ecological Consultants, Inc.  
5858 Woodbourne Hollow Road  
Boulder, Colorado 80301

## ABSTRACT

In the early 1900's flood events resulting from combinations of rainfall and accelerated snow melt in Butte resulted in massive amounts of sulfide mill tailings and waste rock being swept into Silver Bow Creek. These materials were deposited in the channel and on the terraces of the creek in varying patterns depending on the width of the floodplain, the creek velocity and degree of restriction at the time of the flood events. Even after 90 years, substantial areas of these tailings remain either non-vegetated or sparsely vegetated. The intent of the Rocker Demonstration Project was to evaluate possible reclamation techniques that could be used to create stable stands of vegetation on the Silver Bow Creek floodplain areas.

The Rocker Demonstration Project initiated in 1993 consisted of implementing three different treatments on the floodplain areas along Silver Bow Creek near Rocker, Montana. In all, 15.6 acres were treated as part of the project. The treatments consisted of removing tailings from the topographically lowest part of the floodplain (excavated areas) and relocating these tailings at the edge of the floodplain on the topographically highest part of the floodplain (relocation areas). In the moist areas on the floodplain between these two areas, the tailings were treated in place (*in situ*) treatment.

After four growing seasons, all of the treatments have been successful relative to establishing vegetation. Vegetation cover results show yearly differences as well inequalities among the three treatments. Excavated areas have the highest amount of cover and production. The relocated tailings have lower cover and production values.

## INTRODUCTION

The purpose of this project was to evaluate the success of revegetation associated with three remediation treatments and to evaluate whether differences among the treatments were statistically significant.

## SYNOPSIS OF THE PROJECT

In the early 1900's flood events resulting from combinations of rainfall and accelerated snow melt in Butte, resulted in massive amounts of sulfide mill tailings and waste rock being swept into Silver Bow Creek. These materials were deposited in the channel and on the terraces (even the highest terraces) of the creek in varying patterns depending on the width of the flood plain, the creek velocity and the degree of restriction at the time of the flood events. Even after 90 years, substantial areas of these tailings remain either non-vegetated or sparsely vegetated. The intent of the Rocker Demonstration Project was to evaluate possible techniques that could be used to create stable stands of vegetation on these flood plain areas.

The Rocker Demonstration Project consisted of implementing three different treatments on the flood plain areas along Silver Bow Creek in the vicinity of Rocker, Montana. In all, 15.6

acres were treated as part of the project (Map 1). The treatments consisted of removing the tailings from the topographically lowest part of the flood plain (excavated areas) and relocating these tailings to the edge of the flood plain on the topographically highest part of the flood plain (relocation areas). In the moist areas on the flood plain between these two areas, the tailings were treated in place (*in situ* treatment).

The activities associated with each of these treatments area summarized in the following sections:

#### Excavation – Removal Treatment

Lowest Point of Excavation. Sediments/tailings from the streamside area to the depth of the existing water table (identified as the Silver Bow Creek low flow elevation as of February, 1993) were excavated and removed.

Highest Level of Excavation. The highest level of excavation was defined by the iso-line that represented surfaces that were 30 inches above the water table.

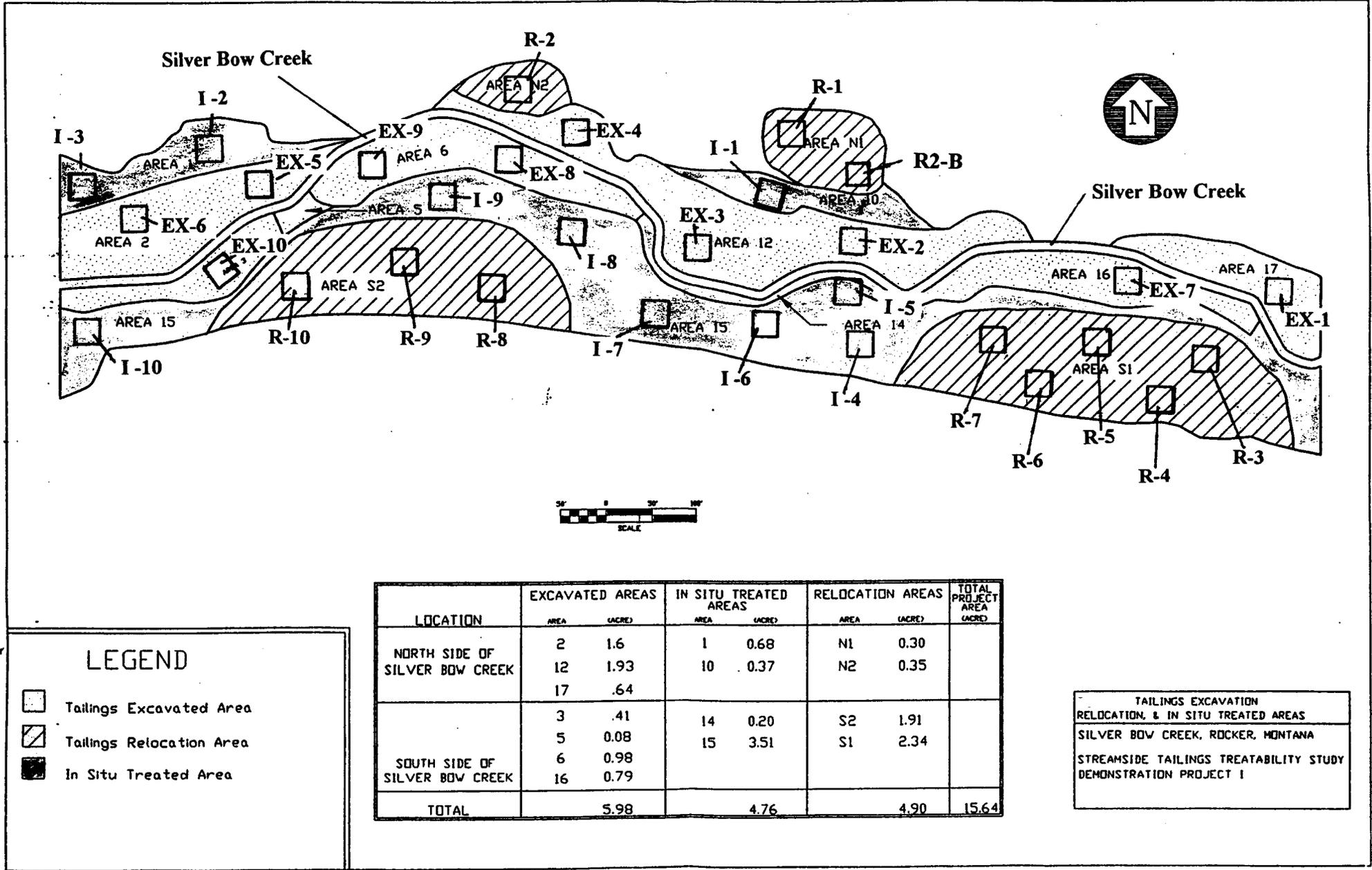
#### Excavation techniques:

- Conducted between 10 February 1993 and 3 April 1993
- Frozen surfaces ripped with a dozer; tailings excavated and loaded using a trackhoe. Approximately 25,075 lcy (loose cubic yards) were removed.
- After removal of tailings, the site was backfilled with clean material. Approximately 25,629 lcy of clean fill material were placed on the excavated area.
- Comment: It is important to note that the excavated and backfilled areas represent limited revegetation challenges related to low pH values or elevated metals concentrations because these problems were eliminated when the tailings were removed from the site. Any tailings that were left were located below the existing water table in a chemically reducing environment.

#### Relocation Sites

Tailings from the excavated sites were relocated to positions at the edge of the 100-year flood plain of Silver Bow Creek. The tailings were all treated with lime kiln dust to neutralize acid-producing potential of the material. Tailings were moved to four sites prepared in the following manner:

- Option 1: Existing surface treated with lime kiln dust to a depth of 48”  
Tailings placed in 1-foot lifts,  
Lime incorporated with agricultural tiller in each lift
- Option 2: No treatment of existing surface  
Tailings placed in 1-foot lifts  
Lime incorporated with agricultural tiller in each lift.
- Option 3: No treatment of existing surface  
Relocate tailings without lime treatment (except for surface lifts)  
Cap relocated tailings with two 1-foot lifts of limed tailings.



**LEGEND**

-  Tailings Excavated Area
-  Tailings Relocation Area
-  In Situ Treated Area

LOCATION	EXCAVATED AREAS		IN SITU TREATED AREAS		RELOCATION AREAS		TOTAL PROJECT AREA (ACRE)
	AREA	(ACRE)	AREA	(ACRE)	AREA	(ACRE)	
NORTH SIDE OF SILVER BOW CREEK	2	1.6	1	0.68	N1	0.30	
	12	1.93	10	0.37	N2	0.35	
	17	.64					
SOUTH SIDE OF SILVER BOW CREEK	3	.41	14	0.20	S2	1.91	
	5	0.08	15	3.51	S1	2.34	
	6	0.98					
16	0.79						
<b>TOTAL</b>		<b>5.98</b>		<b>4.76</b>		<b>4.90</b>	<b>15.64</b>

TAILINGS EXCAVATION  
 RELOCATION, & IN SITU TREATED AREAS  
 SILVER BOW CREEK, ROCKER, MONTANA  
 STREAMSIDE TAILINGS TREATABILITY STUDY  
 DEMONSTRATION PROJECT I

Map 1. Sampling site locations for the Rocker Demonstration Site.

The four relocation areas (Map 1) were treated in the following manner:

Relocation Area S1

Treated using Option 1.	Lime incorporated using a Jordan Deep Plow
Area:	2.34 Acres
Lime Added to Subgrade:	147 tons
Tailing volume:	Lower lift of 6760 lcy of tailings (Treated with 216 tons of lime) Upper lift of 4879 lcy of tailings (Treated with 178 tons of lime).

Relocation Area S2

Treated using Option 2.	
Area:	1.92 acres
Tailing volume:	Lower lift of 2070 lcy of tailings (Treated with 284 tons of lime) Upper lift of 7595 lcy of tailings (Treated with 234 tons of lime)

Tailings in each lift were track compacted and treated with lime kiln dust.

Relocation Area N1

Treated using Option 3.	
Area:	0.35 acres
Tailing volume:	1560 lcy of tailings (no lime in 36 inch lift) 1290 lcy of tailings in two lifts 395 lcy in lower lift (19.5 tons of lime) 895 lcy in upper lift (25 tons of lime)

Tailings in each lift were track compacted and treated with lime kiln dust.

Relocation Area N2

Treated using Option 2.	
Area:	0.30 acres
Tailing volume:	Lower lift of 600 lcy of tailings (Treated with 12.3 tons of lime) Upper lift of 330 lcy of tailings (Treated with 10.8 tons of lime)

Tailings in each lift were track compacted and treated with lime kiln dust.

(After the 1995 growing season, Relocation Area N2 was treated with additional lime and was re-seeded).

*In Situ* Treatments

All *in situ* treatments were deep plowed using a Jordan Deep Plow. The differences in the separate areas relate to the amount of lime that was added and the actual depth of plowing. Plowing depth ranged between 36 and 48 inches.

Surface preparation and seeding techniques were the same as those used in other areas.

Area Number	Acres	Amount of Lime (tons)	Tilling Depth (inches)
1	0.68	135	36
10	0.37	54	36
14	0.20	21	48
15	3.51	735	48

#### Activities Common to All Treatments at the Rocker Demonstration Site

Site Preparation: Fertilizer was added to the site at the following rates:

Nitrogen (elemental)	30 ± 2 lbs/acre
Phosphorus (P <sub>2</sub> O <sub>5</sub> )	60 ± 2 lbs/acre
Potassium (K <sub>2</sub> O)	75 ± 2 lbs/acre
Boron (elemental)	1.5 ± 0.5 lbs/acre

Wheat Straw Mulch was added in order to improve organic matter concentrations in the soil. Mulch was added at a rate of 2 tons/acre. Mulch was anchored using a crimper which forced the mulch approximately 3 inches into the soil.

Seeding: Sites were seeded in April and May of 1993. Flat areas were seeded with a drill pulled by a standard farm tractor. Streambank areas were broadcast seeded over the top of erosion control fabric.

The following seed mix was used on all treatments:

Species	Common Name	Pounds of Pure Live Seed/Acre
<i>Agropyron smithii</i>	Western Wheatgrass	7.0
<i>Agropyron trachycaulum</i>	Slender Wheatgrass	8.0
<i>Deschampsia caespitosa</i>	Tufted Hairgrass	0.5
<i>Elymus cinereus</i>	Great Basin Wildrye	3.0
<i>Puccinellia distans</i>	Alkali Grass	2.0
Total		20.5

On the basis of pounds of seed, the seed mix was dominated by slender wheatgrass and western wheatgrass (Figure 1), but was dominated by alkali grass on the basis of the number of seeds (Figure 2).

Source of Lime: Continental Limestone, Townsend, Montana.

Table 1. Comparison of cover, production and species diversity values for the three treatment areas at the Rocker Demonstration Site. Based on data collected in August of 1994, 1995, 1996 and 1997.

SUMMARY TABLE - ROCKER TEST SITES

**Cover Summary:**

	EXCAVATED SITE				IN-SITU SITE				RELOCATED SITE			
	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>
TOTAL VEGETATION COVER	36.00	58.30	45.70	44.90	25.70	62.80	52.10	54.10	32.40	62.10	31.90	35.80
LITTER AND ROCK COMBINED	39.20	34.40	47.10	51.00	36.90	21.60	36.90	37.70	39.10	26.60	60.70	58.40
BARE SOIL	24.80	9.30	7.20	4.10	37.40	15.60	11.00	8.20	28.50	11.30	7.40	5.80
TOTAL GROUND COVER	75.20	90.70	92.80	95.90	62.60	84.40	89.00	91.80	71.50	88.70	92.60	94.20

**Species Diversity:**

	EXCAVATED SITE				IN-SITU SITE				RELOCATED SITE			
	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1994</u>	<u>1995</u>	<u>1996</u>	<u>1997</u>
Number of species/sample	21.10	21.50	21.10	20.40	17.70	16.90	17.30	17.10	23.10	24.60	19.00	25.10

**Major Species: (By Importance Value)**

	1	2	3	4
<b>EXCAVATED SITE</b>				
<u>1994</u>	<i>Agropyron trachycaulum</i>	<i>Agrostis alba</i>	<i>Deschampsia caespitosa</i>	<i>Agropyron smithii</i>
<u>1995</u>	<i>Agropyron trachycaulum</i>	<i>Agrostis alba</i>	<i>Deschampsia caespitosa</i>	<i>Agropyron smithii</i>
<u>1996</u>	<i>Agropyron trachycaulum</i>	<i>Agrostis alba</i>	<i>Deschampsia caespitosa</i>	<i>Elymus cinereus</i>
<u>1997</u>	<i>Agrostis alba</i>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>	<i>Elymus cinereus</i>
<b>IN-SITU SITE</b>				
<u>1994</u>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>	<i>Agrostis alba</i>	<i>Agropyron smithii</i>
<u>1995</u>	<i>Agrostis alba</i>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>	<i>Elymus cinereus</i>
<u>1996</u>	<i>Agrostis alba</i>	<i>Elymus cinereus</i>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>
<u>1997</u>	<i>Agrostis alba</i>	<i>Elymus cinereus</i>	<i>Deschampsia caespitosa</i>	<i>Agropyron trachycaulum</i>
<b>RELOCATED SITE</b>				
<u>1994</u>	<i>Agrostis alba</i>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>	<i>Triticum aestivum</i>
<u>1995</u>	<i>Agrostis alba</i>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>	<i>Agropyron smithii</i>
<u>1996</u>	<i>Agrostis alba</i>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>	<i>Artemisia biennis</i>
<u>1997</u>	<i>Agrostis alba</i>	<i>Elymus cinereus</i> and <i>Sisymbrium loeselii</i>	<i>Agropyron trachycaulum</i>	<i>Deschampsia caespitosa</i>

Table 1. Comparison of cover, production and species diversity values for the three treatment areas at the Rocker Demonstration Site. Based on data collected in August of 1994, 1995, 1996 and 1997.

<b>Mean Production: (g/sq.m.)</b>					
	<b>Perennial Grasses</b>	<b>Annual Grasses</b>	<b>Perennial Forbs</b>	<b>Annual Forbs</b>	<b>Total</b>
<b>EXCAVATED SITE</b>					
<u>1994</u>	137.78	23.71	0.20	8.06	169.75
<u>1995</u>	284.30	0.01	4.27	0.54	289.05
<u>1996</u>	196.20	0.00	6.88	0.28	203.36
<u>1997</u>	156.92	0.00	9.93	2.66	169.51
<b>IN-SITU SITE</b>					
<u>1994</u>	142.92	16.67	0.60	2.91	162.87
<u>1995</u>	347.29	0.01	5.84	15.67	368.77
<u>1996</u>	193.38	0.00	9.46	2.29	205.13
<u>1997</u>	260.26	0.00	0.81	12.14	273.22
<b>RELOCATED SITE</b>					
<u>1994</u>	93.32	30.56	<0.01	1.97	125.85
<u>1995</u>	258.13	1.08	0.06	22.15	281.43
<u>1996</u>	98.08	1.00	7.55	5.38	112.02
<u>1997</u>	196.83	0.70	5.52	4.86	207.92

Table 2. Mean Cover Values for the Rocker Demonstration Site. Based on Data Collected from 1994 to 1997. Values in Percent.

Species	Excavated Sites				<i>In Situ</i> Sites				Relocated Sites			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
<b>INTRODUCED PERENNIAL GRASSES</b>												
<i>Agropyron cristatum</i>	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.10	0.00	0.10	0.01	0.20
<i>Agropyron elongatum</i>	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
<i>Agropyron intermedium</i>	0.01	0.01	0.01	0.01	0.20	0.10	0.01	0.01	0.01	0.01	0.00	0.01
<i>Agrostis alba</i>	4.70	16.50	15.90	24.40	13.70	19.70	20.10	22.50	18.70	40.60	10.70	17.30
<i>Agrostis tenuis</i>	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.01	0.01
<i>Alopecurus pratensis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
<i>Bromus inermis</i>	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.10	0.01	0.10
<i>Festuca ovina</i>	0.80	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.10	0.00	0.01	0.10
<i>Festuca pratensis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
<i>Phleum pratense</i>	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
<i>Poa pratensis</i>	0.01	0.10	0.01	0.10	0.10	0.10	0.40	0.10	0.01	0.10	0.01	0.10
Subtotal	5.53	16.64	15.95	24.53	14.02	19.94	20.53	22.72	18.84	41.15	10.75	17.83
<b>ANNUAL GRASSES</b>												
<i>Avena sativa</i>	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.00
<i>Bromus japonicus</i>	0.20	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.10	0.01	0.01
<i>Bromus tectorum</i>	0.10	0.01	0.01	0.00	0.10	0.01	0.00	0.00	0.10	0.01	0.01	0.10
<i>Triticum aestivum</i>	0.70	0.01	0.01	0.00	1.50	0.01	0.00	0.00	2.80	0.01	0.01	0.00
Subtotal	1.01	0.02	0.02	0.00	1.62	0.04	0.00	0.01	2.92	0.20	0.03	0.11
<b>PERENNIAL FORBS</b>												
<i>Achillea lanulosa</i>	0.00	0.00	0.01	0.10	0.00	0.01	0.01	0.01	0.10	0.01	0.01	0.01
<i>Antennaria rosea</i>	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Artemisia ludoviciana</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
<i>Aster adscendens</i>	0.01	0.01	0.01	0.20	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00
<i>Aster falcatus</i>	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
<i>Aster sp.</i>	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Astragalus agrestis</i>	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Astragalus cicer</i>	0.01	0.01	0.10	1.50	0.01	0.01	0.01	0.20	0.00	0.01	0.00	0.01
<i>Astragalus sp.</i>	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
<i>Barbarea orthoceras</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.90	0.00
<i>Cardaria draba</i>	0.01	0.01	0.01	0.01	0.30	0.20	0.01	0.01	0.00	0.01	0.00	0.01
<i>Cirsium arvense</i>	0.10	0.40	0.30	0.50	0.20	1.30	1.00	1.30	0.30	0.30	0.40	0.10
<i>Epilobium ciliatum</i>	0.01	0.10	0.30	0.10	0.01	0.60	0.10	0.10	0.01	0.01	0.00	0.01

Table 2. Mean Cover Values for the Rocker Demonstration Site. Based on Data Collected from 1994 to 1997. Values in Percent.

Species	Excavated Sites				<i>In Situ</i> Sites				Relocated Sites			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
<i>Equisetum arvense</i>	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Equisetum laevigatum</i>	0.01	0.01	0.01	0.01	0.01	0.10	0.10	0.01	0.00	0.00	0.01	0.00
<i>Erigeron lonchophyllus</i>	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
<i>Glycyrrhiza lepidota</i>	0.01	0.10	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Iva axillaris</i>	0.00	0.00	0.00	0.00	0.01	0.10	0.01	0.10	0.00	0.00	0.00	0.00
<i>Kochia americana</i>	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Linaria vulgaris</i>	0.01	0.01	0.10	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.30
<i>Medicago sativa</i>	0.01	0.01	0.01	0.10	0.00	0.00	0.01	0.10	0.01	0.00	0.01	0.10
<i>Mentha arvensis</i>	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
<i>Phacelia hastata</i>	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.10	0.01	0.00	0.01
<i>Plantago major</i>	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
<i>Plantago tweedyi</i>	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Potentilla anserina</i>	0.10	0.10	0.10	0.30	0.01	0.01	0.20	0.01	0.01	0.01	0.00	0.01
<i>Potentilla diversifolia</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
<i>Potentilla norvegica</i>	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
<i>Ranunculus cymbalaria</i>	0.01	0.10	0.01	0.01	0.10	0.00	0.00	0.00	0.01	0.01	0.01	0.01
<i>Rorippa sinuata</i>	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00
<i>Rumex crispus</i>	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.01
<i>Rumex salicifolius</i>	0.01	0.01	0.01	0.01	0.01	0.20	0.10	0.20	0.20	0.01	0.10	0.10
<i>Silene vulgaris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01
<i>Sonchus arvensis</i>	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Taraxacum officinale</i>	0.40	0.50	0.40	0.30	0.10	0.00	0.01	0.01	0.01	0.10	0.01	0.50
<i>Tragopogon dubius</i>	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01
<i>Trifolium repens</i>	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
<i>Trifolium sp.</i>	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
<i>Urtica dioica ssp. gracilis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.10
<i>Verbascum thapsus</i>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Subtotal	0.79	1.46	1.78	3.27	0.80	2.62	1.63	0.80	0.84	1.25	2.52	1.33
<b>ANNUAL AND BIENNIAL FORBS</b>												
<i>Alyssum alyssoides</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Amaranthus retroflexus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Artemisia absinthium</i>	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.10	0.10	0.20	0.30
<i>Artemisia biennis</i>	0.10	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.30	0.10	1.20	0.00
<i>Atriplex hastata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00

Table 2. Mean Cover Values for the Rocker Demonstration Site. Based on Data Collected from 1994 to 1997. Values in Percent.

Species	Excavated Sites				<i>In Situ</i> Sites				Relocated Sites			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
<i>Atriplex rosea</i>	0.00	0.01	0.01	0.01	0.01	2.60	0.90	0.20	0.00	0.00	0.00	0.00
<i>Camelina microcarpa</i>	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
<i>Capsella bursa-pastoris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
<i>Centaurea maculosa</i>	0.60	0.40	0.30	0.50	1.10	2.00	1.70	3.50	0.10	0.20	0.20	0.30
<i>Chenopodium album</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
<i>Chenopodium capitatum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Chenopodium sp.</i>	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.10	0.01	0.00	0.00
<i>Cleome serrulata</i>	0.01	0.01	0.01	0.01	0.20	0.20	0.10	0.01	0.01	0.01	0.00	0.01
<i>Descurainia pinnata</i>	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00
<i>Descurainia richardsonii</i>	0.01	0.01	0.01	0.00	0.01	0.10	0.10	0.00	0.01	1.00	0.00	0.00
<i>Epilobium paniculatum</i>	0.01	0.20	0.01	0.10	0.01	0.10	0.10	0.01	0.01	0.01	0.01	0.01
<i>Galium aparine</i>	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
<i>Hyoscyamus niger</i>	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Kochia scoparia</i>	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.20	1.30	0.10	0.10
<i>Lactuca serriola</i>	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.10	0.01	0.00	0.01
<i>Lepidium latifolium</i>	0.01	0.20	0.10	0.40	0.01	0.10	0.00	0.70	0.10	0.20	0.40	0.30
<i>Lepidium perfoliatum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.40	0.20	0.01
<i>Machaeranthera canescens</i>	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Matricaria inodorata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10
<i>Melilotus officinalis</i>	0.50	1.30	0.00	0.20	0.10	0.01	0.00	0.10	0.01	0.40	0.00	0.01
<i>Mentzelia laevicaulis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00
<i>Polygonum aviculare</i>	0.30	0.30	0.01	0.01	0.01	0.40	0.01	0.01	0.40	0.50	0.01	0.30
<i>Polygonum convolvulus</i>	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00
<i>Salsola iberica</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Silene noctiflora</i>	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00
<i>Sisymbrium altissimum</i>	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.40	0.00	0.01
<i>Sisymbrium loeselii</i>	0.00	0.00	0.01	0.01	0.00	0.00	0.11	0.01	0.00	0.01	0.40	4.30
<i>Spergularia marina</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Thlaspi arvense</i>	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.00	0.00
Unknown forb	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Subtotal	1.60	2.50	0.51	1.25	1.52	5.56	3.07	4.57	1.69	5.31	2.76	5.79
<b>SEMI-SHRUBS OR HALF-SHRUBS</b>												
<i>Artemisia frigida</i>	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01
Subtotal	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01

Table 2. Mean Cover Values for the Rocker Demonstration Site. Based on Data Collected from 1994 to 1997. Values in Percent.

Species	Excavated Sites				<i>In Situ</i> Sites				Relocated Sites			
	1994	1995	1996	1997	1994	1995	1996	1997	1994	1995	1996	1997
<b>SHRUBS</b>												
<i>Artemisia tridentata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00
<i>Chrysothamnus nauseosus</i>	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00
<i>Salix exigua</i>	0.00	0.00	0.00	0.00	0.10	0.10	0.20	0.10	0.00	0.00	0.00	0.00
Subtotal	0.01	0.00	0.01	0.01	0.10	0.10	0.21	0.10	0.00	0.00	0.01	0.00
<b>TREE SPECIES</b>												
<i>Populus balsamifera</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Populus tremuloides</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
Subtotal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01
<b>MOSSES</b>	0.00	0.01	0.01	0.30	0.00	0.00	0.01	0.10	0.00	0.00	0.01	0.10
<b>LITTER</b>	38.20	32.20	46.70	50.50	36.60	21.50	36.90	37.60	37.20	26.00	59.80	57.40
<b>ROCK</b>	1.00	0.20	0.40	0.50	0.30	0.10	0.00	0.10	1.90	0.60	0.90	1.00
<b>TOTAL VEGETATION</b>	36.00	58.30	45.70	44.90	25.70	62.80	52.10	54.10	32.40	62.10	31.90	35.80
<b>LITTER/ROCK</b>	39.20	32.40	47.10	51.00	36.90	21.60	36.90	37.70	39.10	26.60	60.70	58.40
<b>BARE SOIL</b>	24.80	9.30	7.20	4.10	37.40	15.60	11.00	8.20	28.50	11.30	7.40	5.80
<b>TOTAL COVER</b>	75.20	90.70	92.80	95.90	62.60	84.40	89.00	91.80	71.50	88.70	92.60	94.20
<b>No. Species/Sample</b>	21.10	21.50	21.10	20.40	17.70	16.90	17.30	17.10	23.10	24.60	19.00	25.10

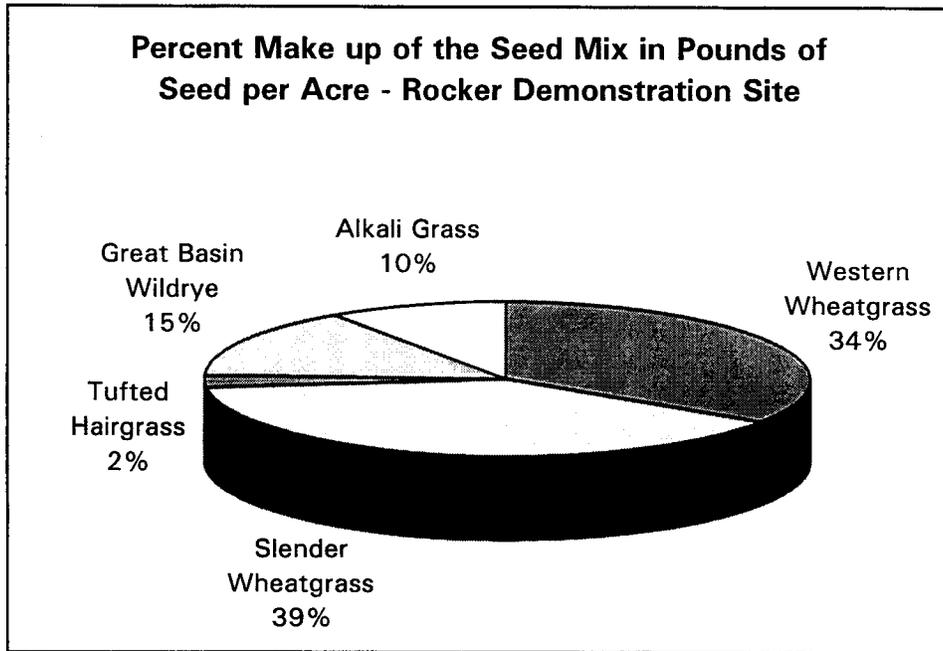


Figure 1. Percent make up of the Seed Mix used at the Rocker Demonstration Site based on Pounds of Pure Live Seed. per Acre.

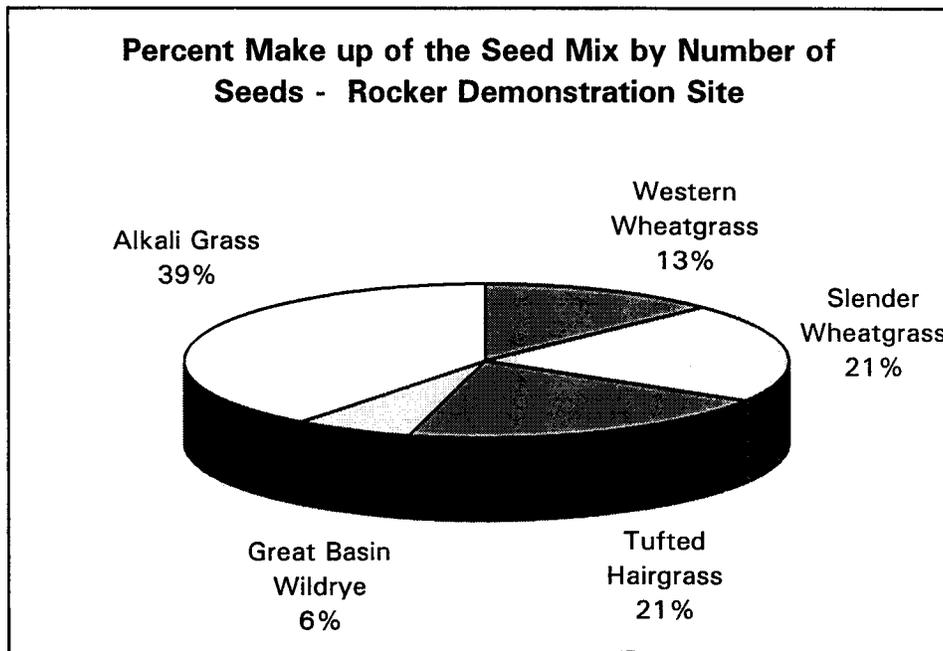


Figure 2. Percent make up of the Seed Mix used at the Rocker Demonstration Site based on Number of Seeds.

## SAMPLING METHODS

**Sampling Design.** The design consisted of sampling ten plots in each of three different treatment areas: 1) Tailings removal areas, 2) *In situ* treatment sites, and 3) Tailing relocation sites. The ten sampling locations in each of the areas were allocated on the basis of the areal extent of the separate parcels within each treatment. Each sampling site consisted of a square quadrat 10 meters on a side. Plots were located such that, to the extent possible, all sub-areas within each of the treatment areas were included in the sample. Since the "N2" relocation area was reseeded in 1995, no sample plots were placed in the area in 1996 or 1997. An additional plot was located in the "N1" area.

**Sampling Methods.** The treatment areas were sampled in August 1994, 1995, 1996 and 1997 at the end of the second, third, fourth and fifth growing seasons. Cover data were collected using a point transect sampling approach using an optical sighting device. The sighting device consists of an objective lens equipped with a set of crosshairs and a mirror. The mirror reflects an image of the vegetation into the eyepiece. Observations are then made on what is intercepted by the crosshairs. "Hits" on vegetation are recorded by species. Other observations are categorized on the basis of plant litter, mosses, bare soil or rocks. Each of the 100 square meter sampling locations was sampled with ten 10-meter transects. Observations were made with the sighting device at one meter intervals along each transect for a total of 100 observations for each plot. Data from each sampling location were summarized to obtain mean cover values for each species and each measured parameter. Species that were present within the 100 square meter sampling area, but were not encountered on any of the transects were recorded as being present at less than one percent cover.

Production data were obtained using a harvest method. A single 0.5 square meter plot was clipped at each of the sampling locations. All of the clipped biomass from each plot was sorted on the basis of species. Clipped samples were placed in paper bags and were then oven dried and weighed.

## RESULTS AND DISCUSSION

### Excavated Areas

The excavated areas are located where groundwater is within two to three feet of the surface and are generally adjacent to the channel of Silver Bow Creek. Due to their proximity to the channel and the groundwater table, many of these sites are sub-irrigated. The major species in these areas (Table 1) include slender wheatgrass (*Agropyron trachycaulum*), red top (*Agrostis alba*), tufted hairgrass (*Deschampsia caespitosa*), and western wheatgrass (*Agropyron smithii*). In 1994 these four species accounted for 83.8 percent of the cover by all species; in 1995 they accounted for 89.2 percent of the cover by all species; in 1996 they accounted for 82.5 percent and in 1997 they accounted for 78 percent. In 1997, red top (which was not included in the seed mix) accounted for 55 percent of the cover and 47 percent of the production by all species (Figures 3 and 4). Alkali grass, which dominated the seed mix on the basis of the number of seeds, was not encountered in the 1997 samples.

In 1994 the remaining 16 percent of the cover was distributed among 61 other species; in 1995 the remaining 11 percent of the cover was distributed among 61 species; in 1996 the remaining 17.5 percent was distributed among 59 other species and in 1997 the remaining 22 percent was distributed among 48 other species. While the overall species diversity has remained much the same during the four years of sampling (20-21 species per 100 square meters) the overall species composition among the four years has been somewhat different (Table 2).

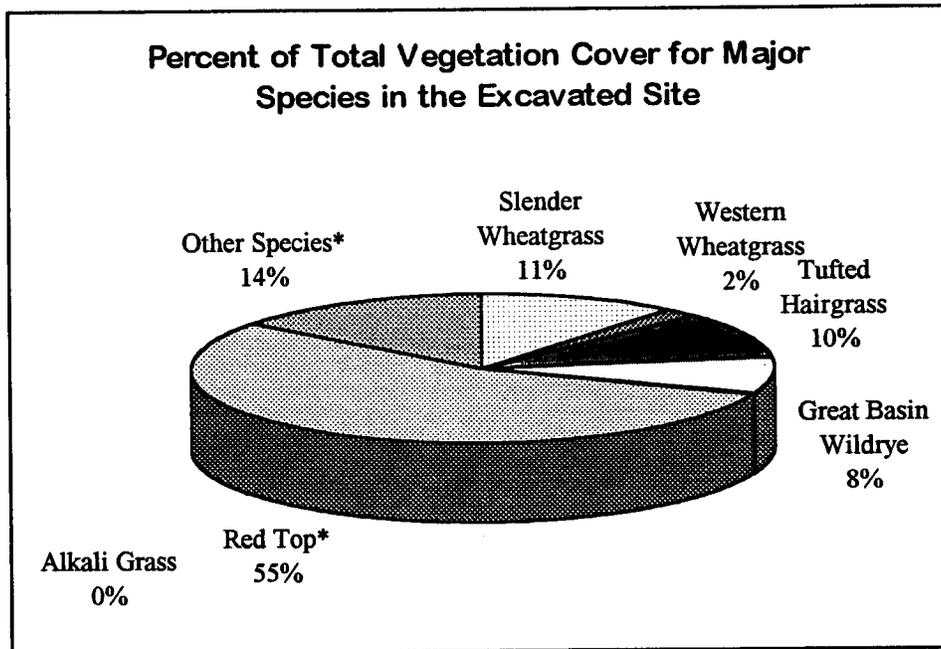


Figure 3. Percent of total cover for species included in the seed mix, and other major species. 1997 data from the Excavated Tailings Site.

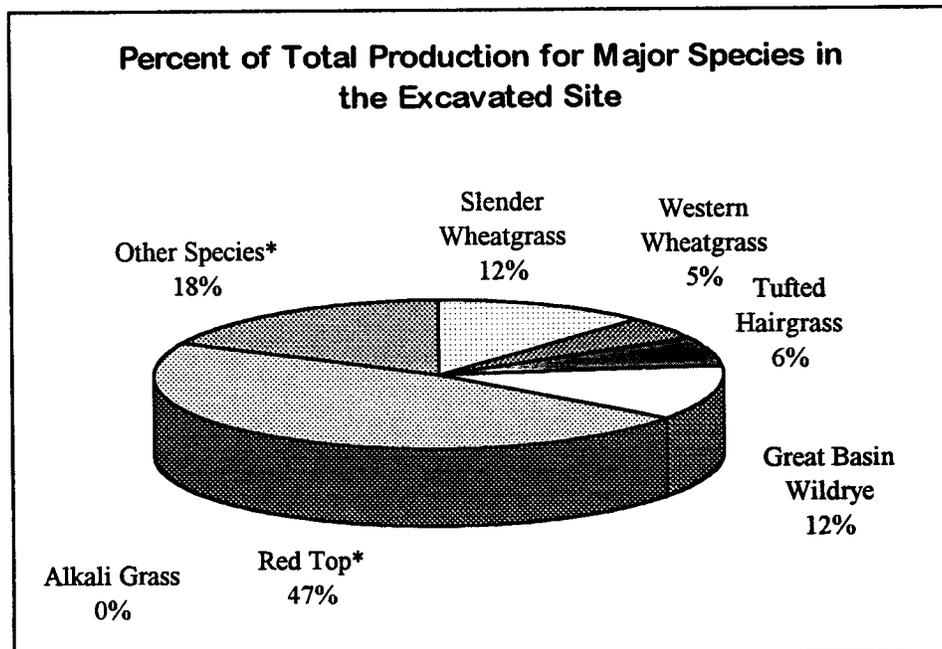


Figure 4. Percent of biomass production for species included in the seed mix, and other major species. 1997 data from the Excavated Tailings Site.

\* Indicates species not included in original seed mix.

During the four years of sampling, mean total vegetation cover was 36 percent in 1994, 58.3 percent in 1995, 45.7 percent in 1996 and 44.9 percent in 1997. Cover by litter and rock combined ranged from a low of 34.4 percent in 1995 to a high of 51 percent in 1997. Bare soil has decreased from 25 percent in 1994 to 4.1 percent in 1997.

In all four years, perennial grasses occurred as the dominant life form and accounted for 76 percent of the cover by all species in 1994; 94 percent in 1995; 96 percent in 1996 and 90.3 percent in 1997. Annual grasses decreased in percent of total cover from 2.8 percent in 1994 to less than one percent in the other sampling years. Percent of total cover by perennial forbs has increased from a low of 1.5 percent in 1995 to 7 percent in 1997, percent of total cover by annual and biennial forbs has decreased from 4.2 percent in 1994 to 2.7 percent in 1997.

Mean total production in 1994 was 169.8 g/m<sup>2</sup>, 289.1 g/m<sup>2</sup> in 1995, 196.2 g/m<sup>2</sup> in 1996 and 169.5g/m<sup>2</sup> in 1997. In all years, most of the production was attributable to perennial grasses.

Changes Over Time. The Rocker Demonstration Site was seeded in April and May of 1993. The vegetation monitoring program was initiated in 1994 and has spanned the years 1994-1997 which represent the second through the fifth growing seasons. During this time the overall vegetation structure and species composition has remained quite consistent, however some changes in the dominant species can be seen. Slender wheatgrass which occurred as the dominant species (on the basis of cover) between 1994 and 1996, decreased in cover in 1997, and red top which had occurred as the second major species between 1994 and 1996 became the leading dominant species in 1997 (Figure 5). A similar pattern was seen in the production data (Figure 6).

#### *In situ* Treatment Areas

The *in situ* treatment areas are topographically higher than the excavated areas, but still occur on the flood plain of Silver Bow Creek. The major species in these areas (Table 1) included red top, slender wheatgrass, Great Basin wildrye (*Elymus cinereus*), tufted hairgrass and western wheatgrass. In 1994 these five species accounted for 79.7 percent of the cover by all species; in 1995 they accounted for 83.4 percent; in 1996 they accounted for 84.4 and in 1997 they accounted for 80 percent of the total. Western wheatgrass, which ranked fourth in dominance in 1994 and 1995, dropped to a rank of six in 1997. Great Basin wildrye occurred as the fourth ranked species in 1995 and was the second ranked species behind red top in 1996 and 1997. All of the dominant species, except for red top, were included in seed mix. In 1997, red top (which was not included in the seed mix) accounted for 41 percent of the cover and 34 percent of the production by all species (Figures 7 and 8). Great Basin wildrye accounted for 21 percent of the cover and 38 percent of the biomass. Other than red top, most other species that were not included in the seed mix occur only as minor species.

In 1995, the remaining 16.6 percent of the cover was distributed among 52 other species; in 1996 the remaining 15.6 percent of the cover was distributed among 46 other species and in 1997 the remaining 16.6 percent of the cover was distributed among 44 other species (Table 2). Species diversity as measured by the mean number of species per 100 square meters has been consistent throughout the four years of sampling ranging between 16.9 and 17.7 species per 100 square meters.

Total vegetation cover was 25.7 percent in 1994; 62.8 percent in 1995; 52.1 percent in 1996 and 54.1 percent in 1997. Cover by litter and bare rock combined was 36.9 percent in 1994; 21.6 percent in 1995; 36.9 percent in 1996 and 37.7 percent in 1997. The amount of bare soil decreased from 37.4 percent in 1994 to 15.6 percent in 1995; 11 percent in 1996 and 8.2 percent in 1997. In all four sampling years, most of the total vegetation cover was provided by perennial grasses.

### TRENDS IN COVER FOR MAJOR SPECIES IN THE EXCAVATED AREA · ROCKER DEMONSTRATION SITE

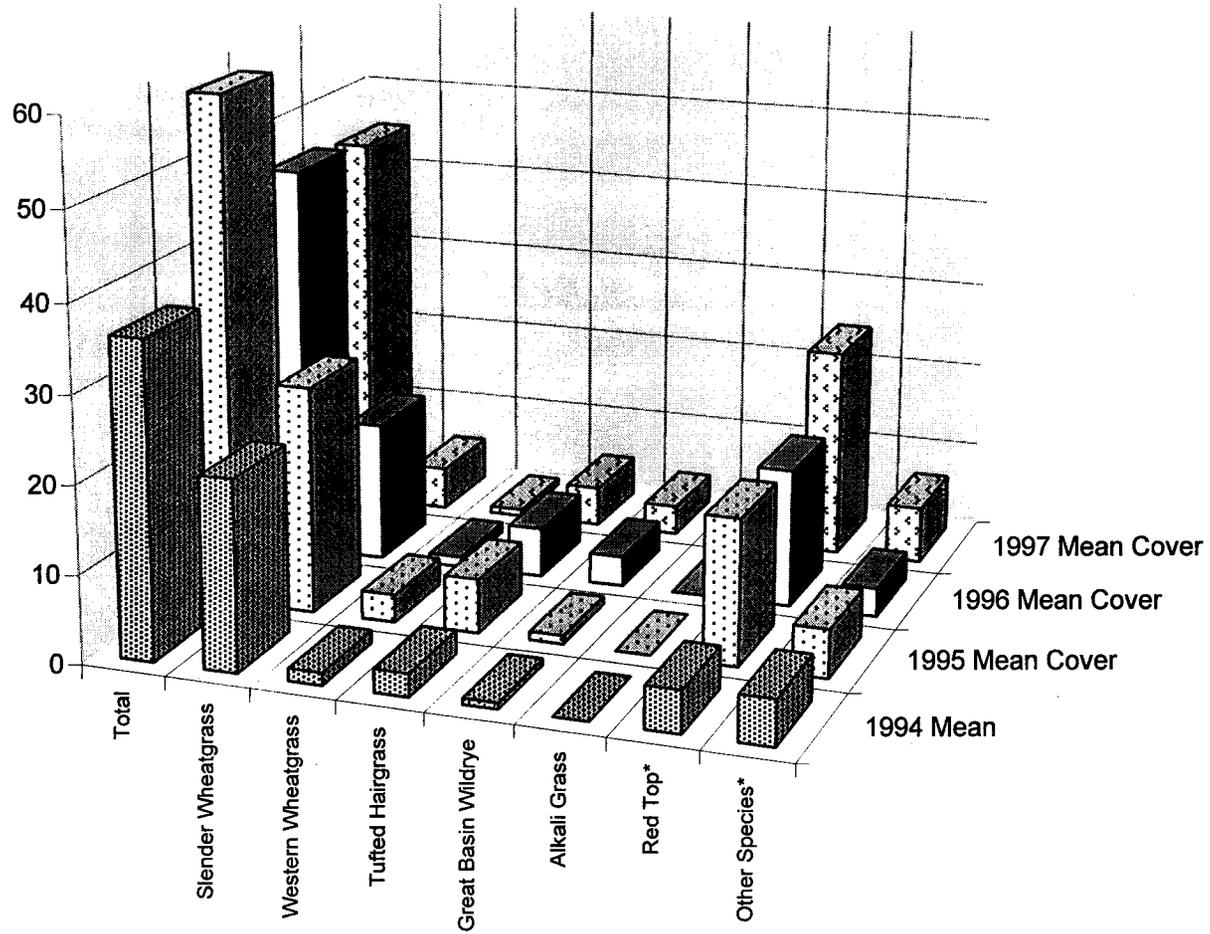


Figure 5. Trends in mean cover (percent) for major species in the Excavated Area (1994-1997). Rocker Demonstration Site.

### TRENDS IN PRODUCTION FOR MAJOR SPECIES IN THE EXCAVATED AREA - ROCKER DEMONSTRATION SITE

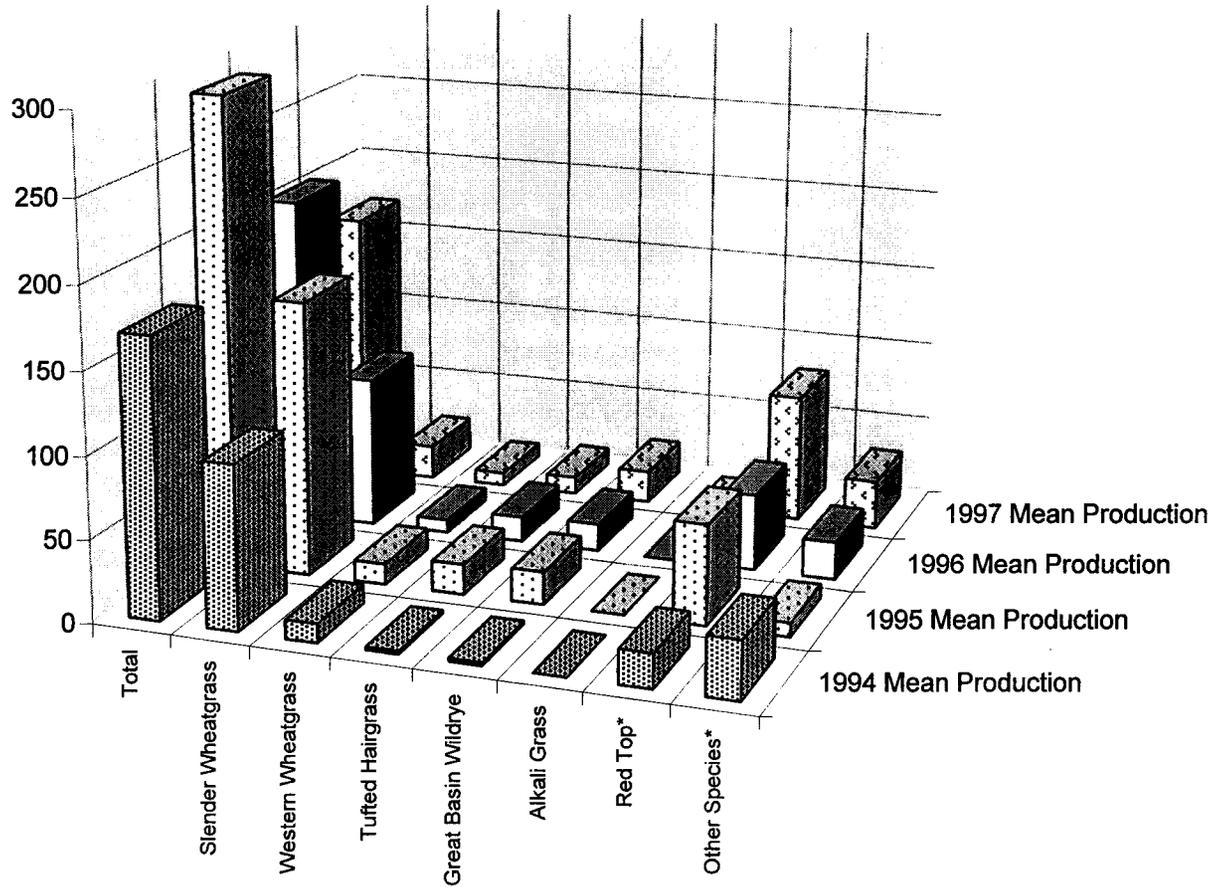


Figure 6. Trends in mean production (g/m<sup>2</sup>) for major species in the Excavated Area (1994-1997). Rocker Demonstration Site.

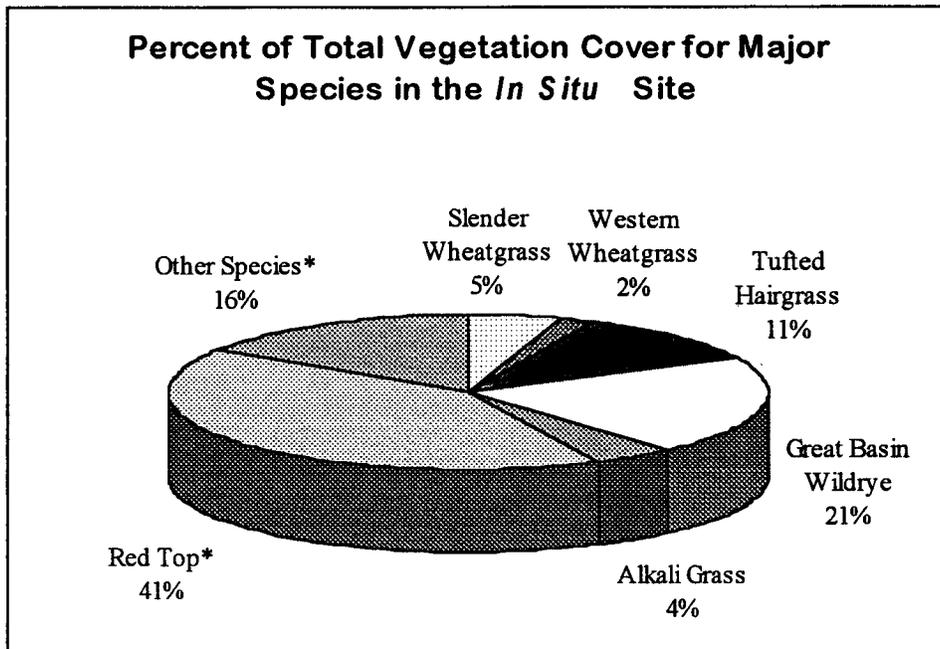


Figure 7. Percent of total cover for species included in the seed mix, and other major species. 1997 data from the *In Situ* Site.

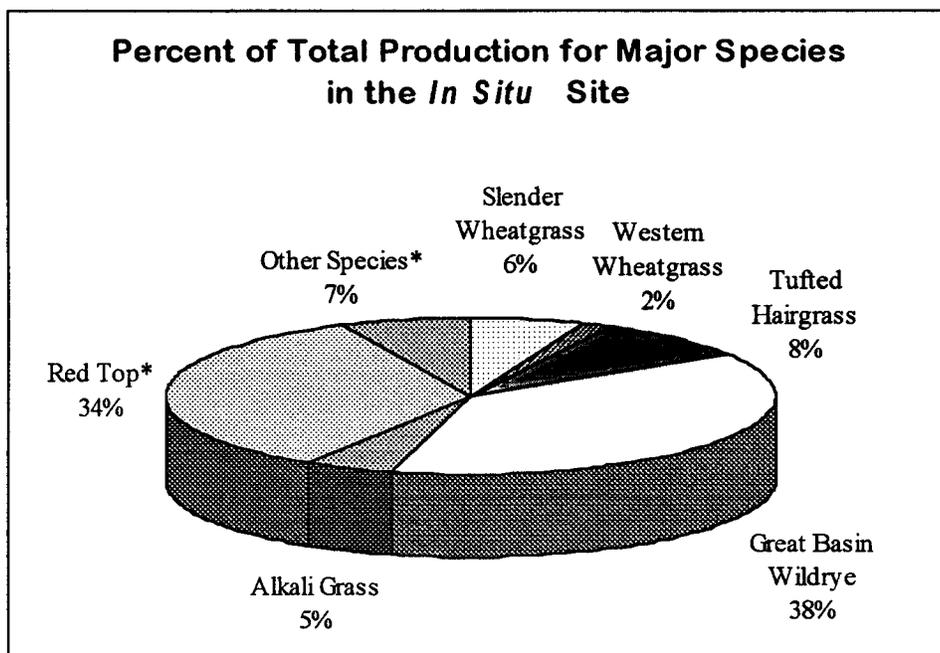


Figure 8. Percent of biomass production for species included in the seed mix, and other major species. 1997 data from the *In Situ* Site.

\* Indicates species not included in original seed mix.

Mean total production in 1994 was 162.9 g/m<sup>2</sup>; 368.8 g/m<sup>2</sup> in 1995, 193.4 g/m<sup>2</sup> in 1996 and 273.2 g/m<sup>2</sup> in 1997. In all years, most of the production was attributable to perennial grasses.

Changes Over Time. The highest levels of cover and production were recorded in 1995 and the lowest values were recorded in 1994 (Figures 9 and 10). This is the same pattern as noted in the excavated areas. Cover and production by slender wheatgrass have decreased between 1995 and 1997. Increases in cover and production were recorded for both red top and Great Basin wildrye.

Differences Between the Two Tilling Depths. The primary interest in this study was to evaluate differences among the three different tilling treatment areas. The initial design of the study called for ten samples to be located in each of these different areas. Once the sampling program was underway, a second level of evaluation was examined that entailed looking at whether any differences in vegetation success could be noted relative to two different plowing depths in the *in situ* areas. Examination of the sample plot locations showed that seven of the ten samples had been placed in areas plowed to a depth of 48 inches and three of the samples had been placed in areas plowed to a depth of 36 inches. These sample sizes were too small to evaluate statistical differences, however it was possible to portray the 1997 cover and production results graphically (Figures 11 and 12). The 1997 results suggested that the 48-inch tilling treatment resulted in somewhat higher cover and production values (primarily related to differences in the amount of red top). Results from earlier years suggested that the 36-inch tilling produced better results, or that the two approaches were essentially comparable. While differences do occur in the two different tillage techniques, the results have not been consistent from year to year.

#### Relocation Areas

The tailings relocation areas are located in protected sites just within the boundary of the 100-year flood plain of Silver Bow Creek. The tailings that were excavated from the removal areas along the creek were placed in these relocation areas. The major species in the relocation areas (Table 1 and 2) include red top, slender wheatgrass and tufted hairgrass. In 1994 these three species accounted for 81 percent of the cover by all species; in 1995 they accounted for 86.8 percent; in 1996 they accounted for 79 percent and in 1997 they accounted for 63 percent. Great Basin wildrye, which was not a major species until 1997, accounted for 12 percent of the cover measured in 1997. Perennial grass species as a group accounted for 84.1 percent of the cover in 1994; 91.6 percent in 1995; 84.4 percent in 1996 and 80.3 percent in 1997. After five growing seasons, species that were included in the seed mix accounted for 27 percent of the cover by all species (Figure 13), and 68 percent of the total production (Figure 14). Total vegetation cover was 32.4 percent in 1994; 62.1 percent in 1995, 31.9 percent in 1996 and 35.8 percent in 1997. Cover by litter and rock combined was 39.1 percent in 1994; 26.6 percent in 1995; 60.7 percent in 1996 and 58.4 percent in 1997. Bare soil cover has decreased from 28.5 percent in 1994 to 5.8 percent in 1997 (Table 1).

Species diversity has been consistent within the relocation areas. The mean number of species per 100 square meters has ranged between 19 and 25.1 species. The total number of observed species has ranged between 52 and 71 species.

Mean total production in the relocation areas was 162.9 g/m<sup>2</sup> in 1994; 281.4 g/m<sup>2</sup> in 1995; 98.1 g/m<sup>2</sup> in 1996 and 207.9 g/m<sup>2</sup> in 1997. In all sampling years, most of the production was attributable to perennial grasses.

Changes Over Time. Other than yearly differences in total vegetation cover and production (Figures 15 and 16), the most notable differences among the four years of sampling

### TRENDS IN COVER FOR MAJOR SPECIES IN THE *IN SITU* AREA - ROCKER DEMONSTRATION SITE

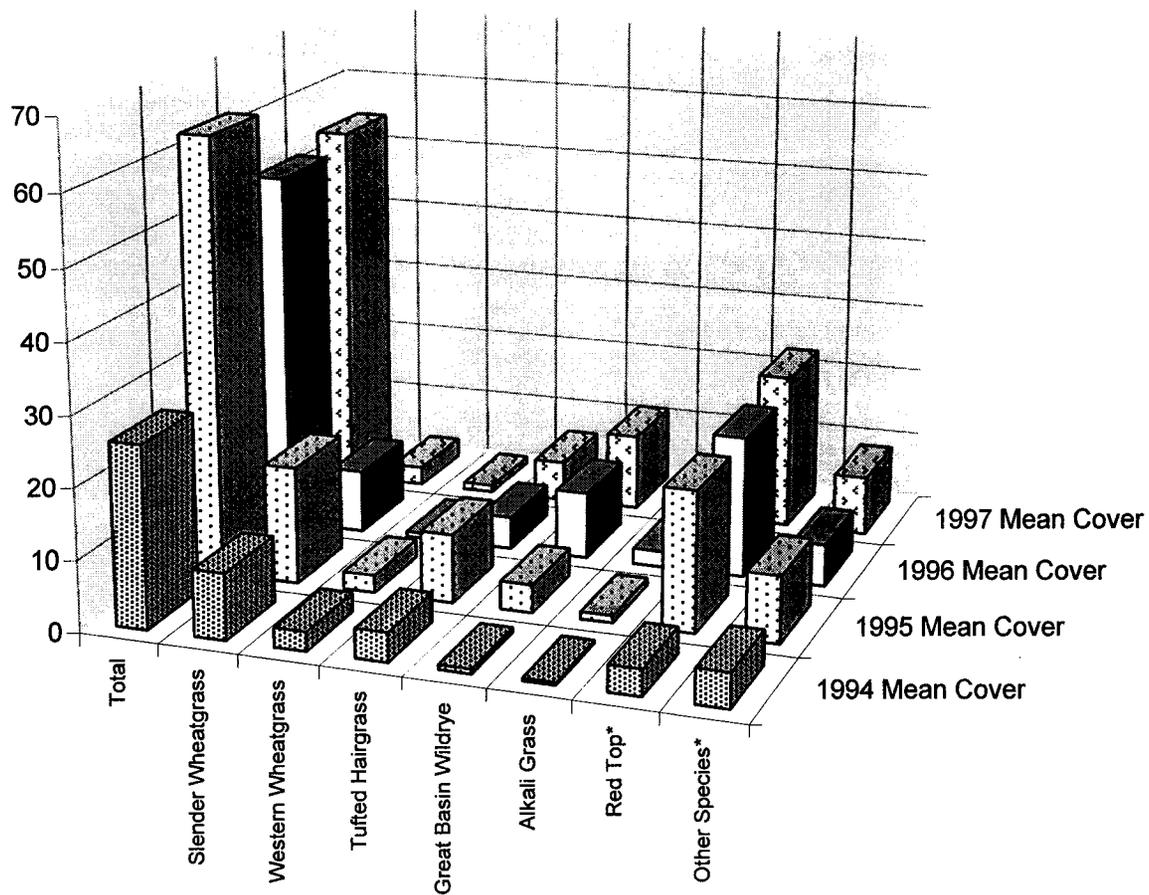


Figure 9. Trends in mean cover (percent) for major species in the *In situ* Area (1994-1997). Rocker Demonstration Site.

### TRENDS IN PRODUCTION FOR MAJOR SPECIES IN THE *IN SITU* AREA - ROCKER DEMONSTRATION SITE

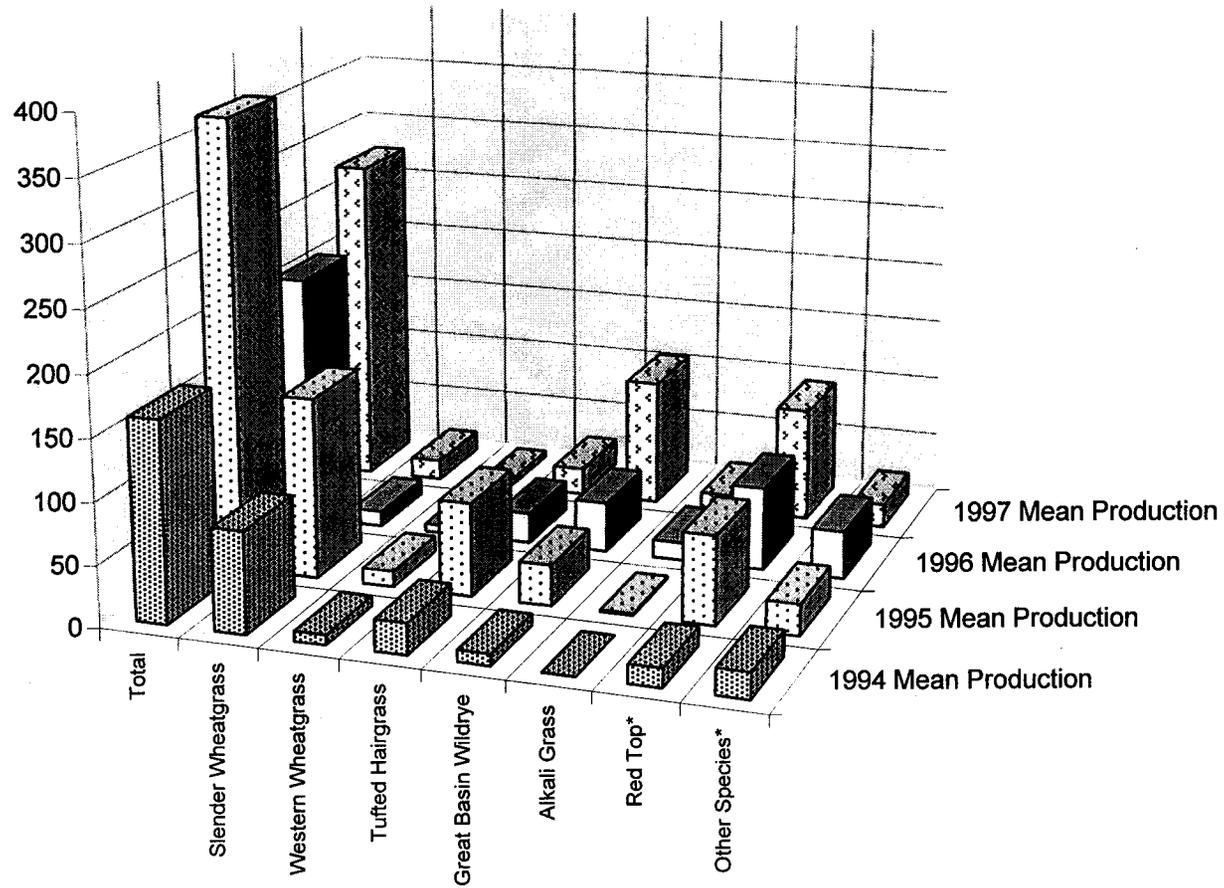


Figure 10. Trends in mean production (g/m<sup>2</sup>) for major species in the *In Situ* Area (1994-1997). Rocker Demonstration Site.

MEAN COVER VALUES (%) FOR THE TWO PLOWING DEPTH OPTIONS IN THE *IN SITU* AREA  
ROCKER DEMONSTRATION SITE

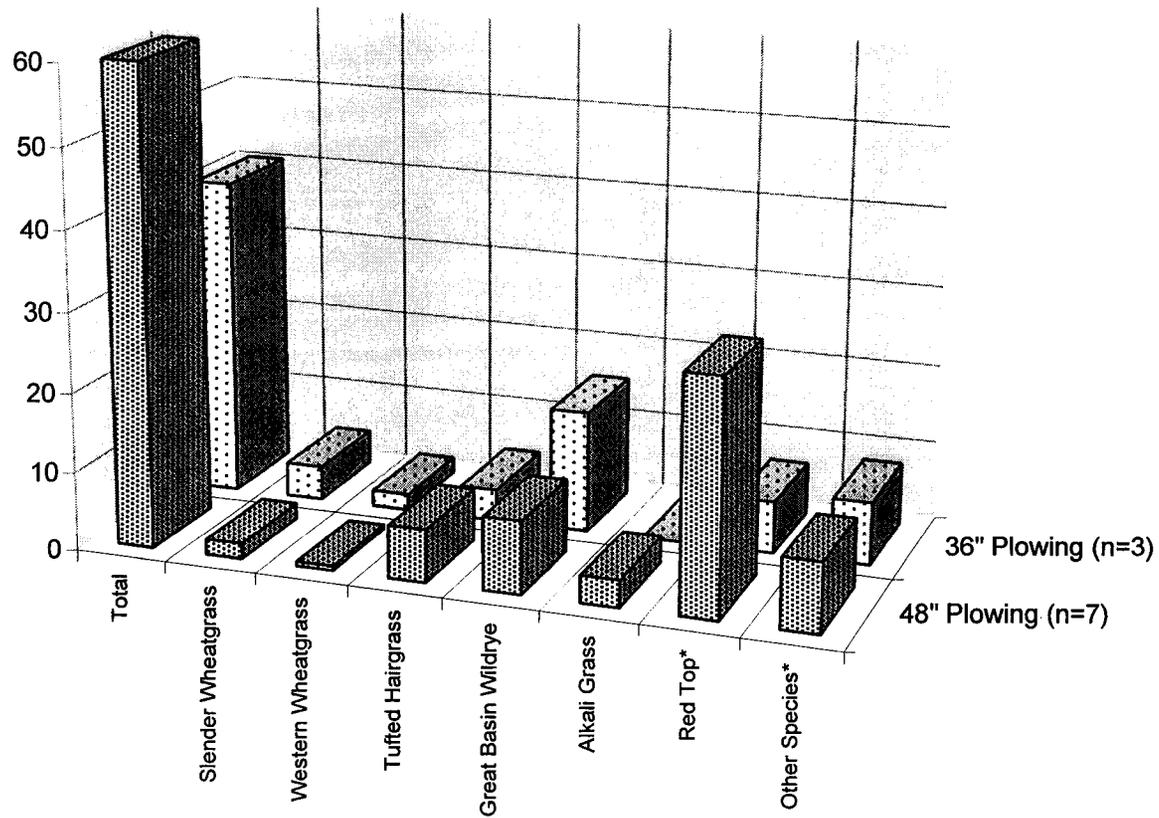


Figure 11. Mean cover (percent) for the two plowing depth options in the *In Situ* Area. 1997 data. Rocker Demonstration Site.

### MEAN PRODUCTION (G/M<sup>2</sup>) FOR THE TWO PLOWING DEPTH OPTIONS IN THE *IN SITU* AREA ROCKER DEMONSTRATION SITE

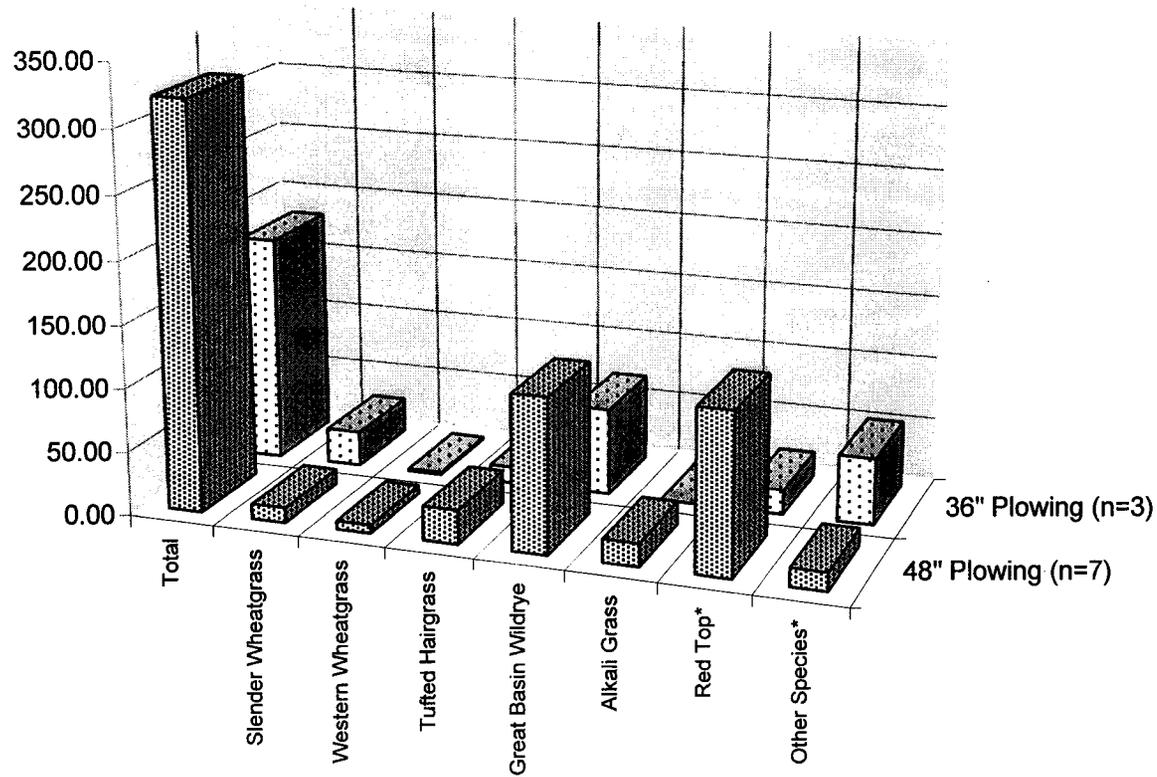


Figure 12. Mean biomass production (g/m<sup>2</sup>) for the two plowing depth options in the *In Situ* Area. 1997 data. Rocker Demonstration Site.

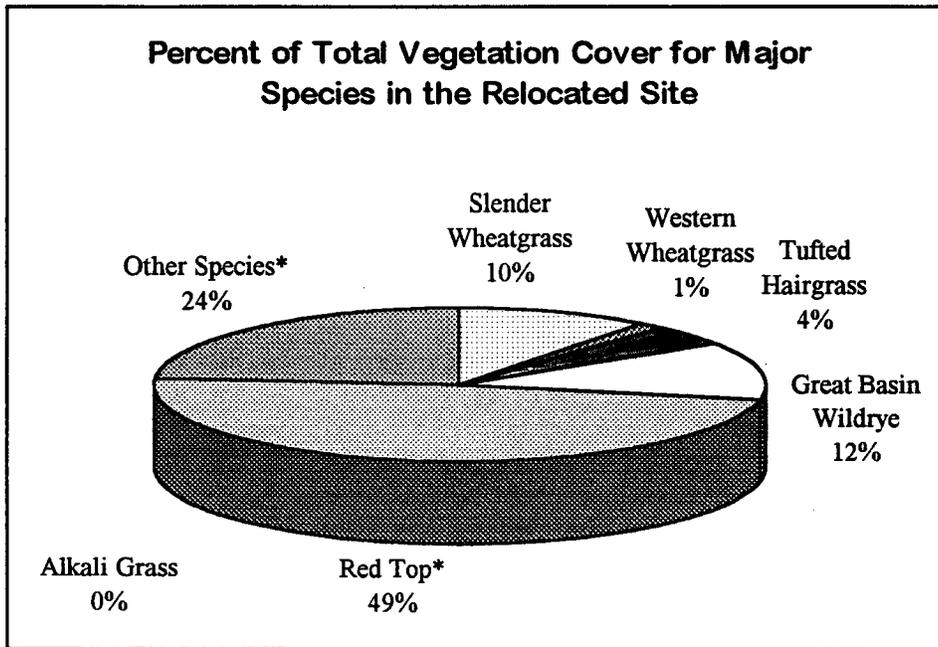


Figure 13. Percent of total cover for species included in the seed mix, and other major species. 1997 data from the Relocated Site.

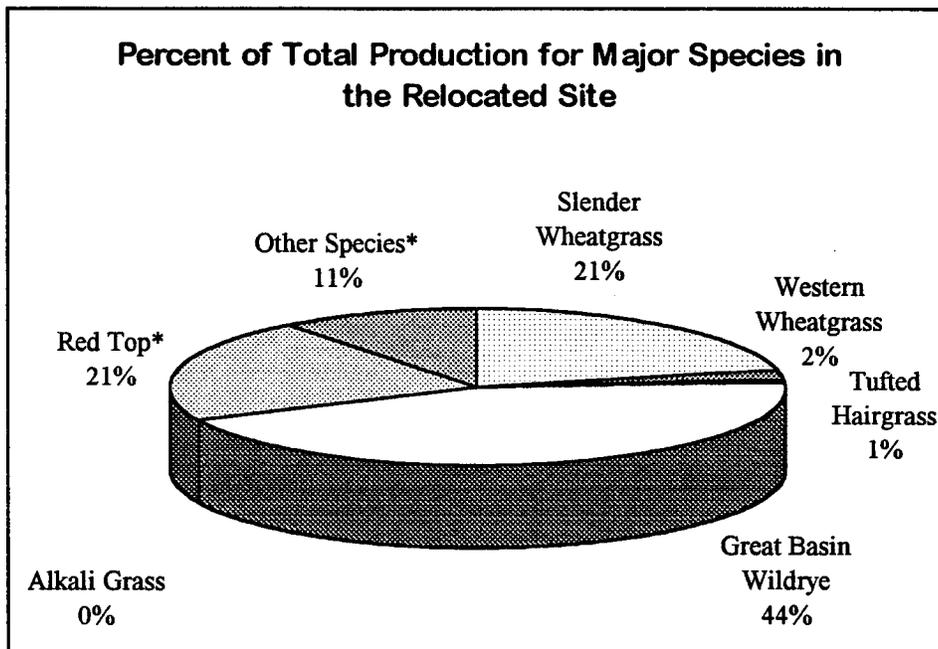


Figure 14. Percent of biomass production for species included in the seed mix, and other major species. 1997 data from the Relocated Site.

\* Indicates species not included in original seed mix.

### TRENDS IN COVER FOR MAJOR SPECIES IN THE RELOCATED AREA - ROCKER DEMONSTRATION SITE

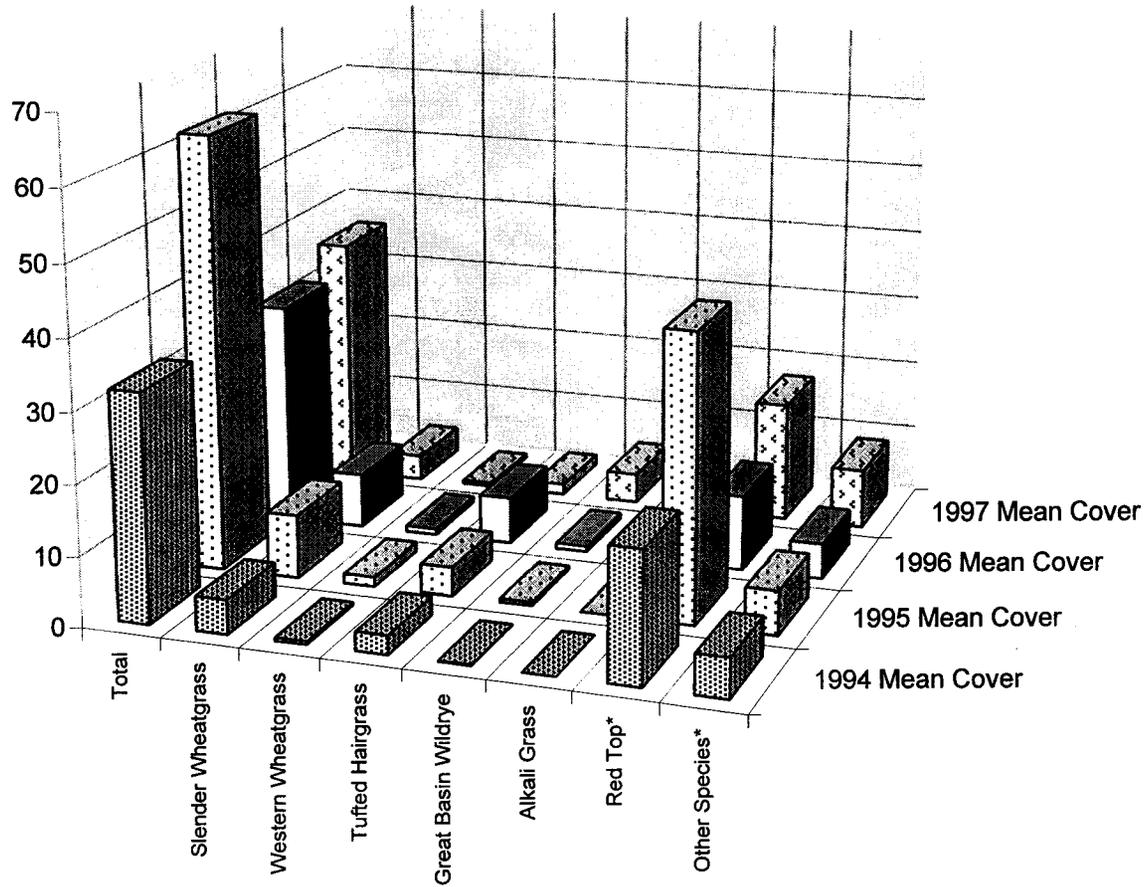


Figure 15. Trends in mean cover (percent) for major species in the Relocated Area (1994-1997). Rocker Demonstration Site.

### TRENDS IN PRODUCTION FOR MAJOR SPECIES IN THE RELOCATED AREA - ROCKER DEMONSTRATION SITE

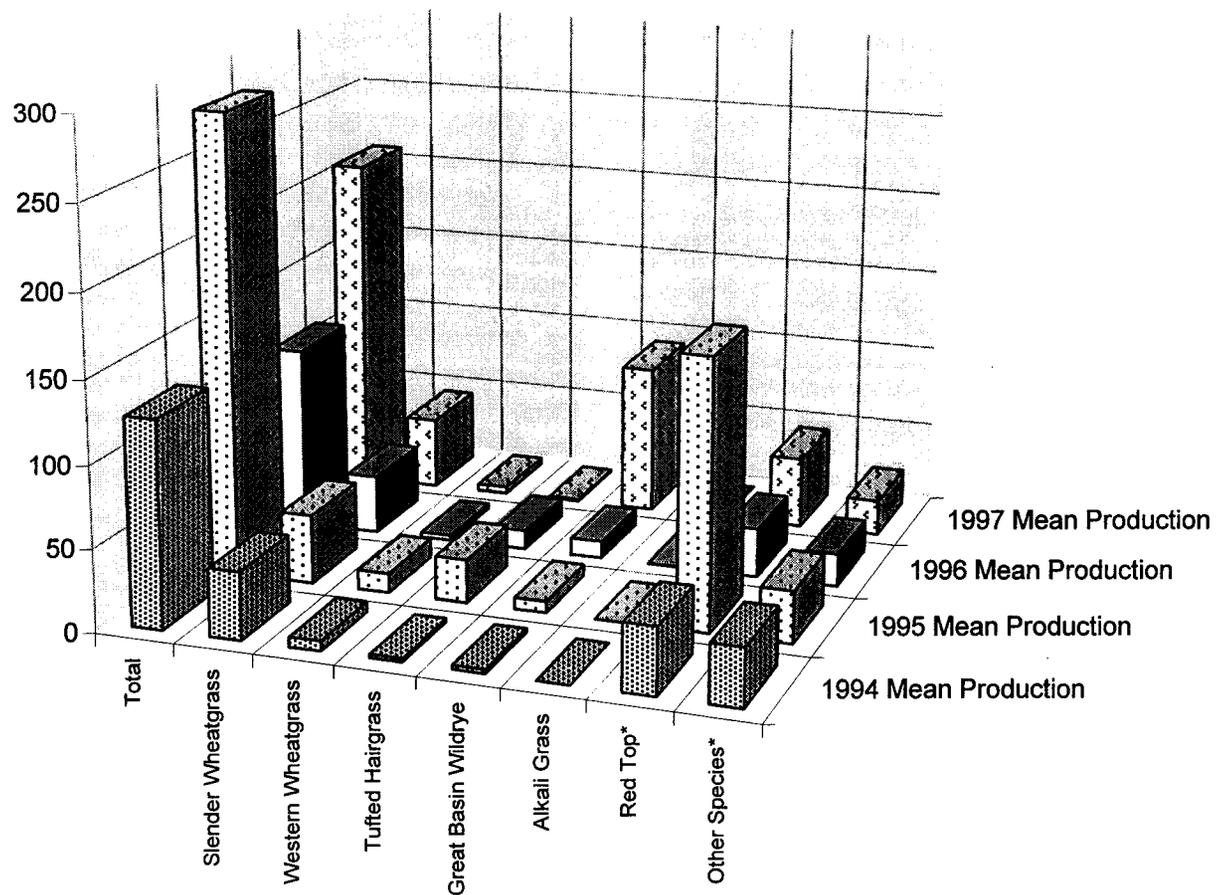


Figure 16. Trends in mean production ( $\text{g/m}^2$ ) for major species in the Relocated Area (1994-1997). Rocker Demonstration Site.

are the changes in the amount of red top and Great Basin wildrye. Red top reached a peak in 1995, showed a reduction in 1996 and a subsequent increase in 1997. Great Basin wildrye has shown a pattern of consistently increasing cover and production values. It is important to remember that the relocated sites are essentially upland areas compared with the excavated and *in situ* areas which are bottomland, partially sub-irrigated sites. As such, the relocated sites are more likely to respond to annual precipitation changes.

Differences Among the Three Liming Options. As mentioned in the description of the project, three different liming options were used in the tailings relocation areas. Mean cover and production results for 1997 for the three different options were not evaluated statistically, but were portrayed graphically (Figures 17 and 18). The data suggest that the three different options produce comparable results, however it is important to recognize that this analysis was based on limited sample sizes. The 1997 results were comparable to those obtained between 1994 and 1996. Each of the liming approaches was adequate to neutralize the acidic tailings, and produce a growth medium capable of sustaining plant growth.

#### Evaluation of the Seed Mix Used in the Demonstration Study

Of the species included in the seed mix, slender wheatgrass, tufted wheatgrass and Great Basin wildrye were the most successful species on all the treatments. In the excavated areas after four years, slender wheatgrass and tufted hairgrass continue to occur as major species on the basis of cover and production, and Great Basin wildrye is showing increasing amounts of cover and production. Red top, the other major species in this area was not included in the seed mix. Red top is a common species along Silver Bow Creek, especially in areas immediately adjacent to the stream channel. Seed for this species occurs throughout the flood plain and unless specific control measures are taken, it tends to become a major species even though it was not included in the seed.

In the *in situ* treatment areas a similar pattern has occurred, except that red top has occurred as the dominant species since 1995. Red top and Great Basin wildrye have increased in cover and production, while slender wheatgrass has declined.

In the areas with relocated tailings, red top has been the dominant species in all four sampling years. Slender wheatgrass and Great Basin wildrye have been the most consistent of the seeded species.

Other than red top, most other species that were not included in the seed mix occur only as minor species. As was noted earlier, many species occur in the demonstration area (Table 2), but most of them occur only sporadically and most have mean cover values that are well below one percent.

#### Evaluation of Treatments and Techniques

Comparisons of cover, production and species diversity values for the three treatment areas for 1994-1997 are presented in Table 1. When compared statistically (one-way analysis of variance) there were no significant differences in cover and production among the three treatment areas in 1994 and 1995. In 1996, cover and production in the relocation areas were significantly lower than the other two treatments, but there were no statistically significant differences between the excavated and *in situ* areas. In 1997, there were no significant differences in production, but cover in the relocated areas was significantly less than the other two treatments.

Comparisons of 1997 mean total vegetation cover and mean cover values for major species in each of the treatment areas are shown in Figure 19, and comparisons of mean total production and mean production for major species are shown in Figure 20. After five growing seasons, differences among the three treatment areas are beginning to appear. In general, cover

### MEAN COVER VALUES (%) FOR THE THREE TREATMENT OPTIONS IN THE RELOCATED TAILINGS AREA - ROCKER DEMONSTRATION SITE

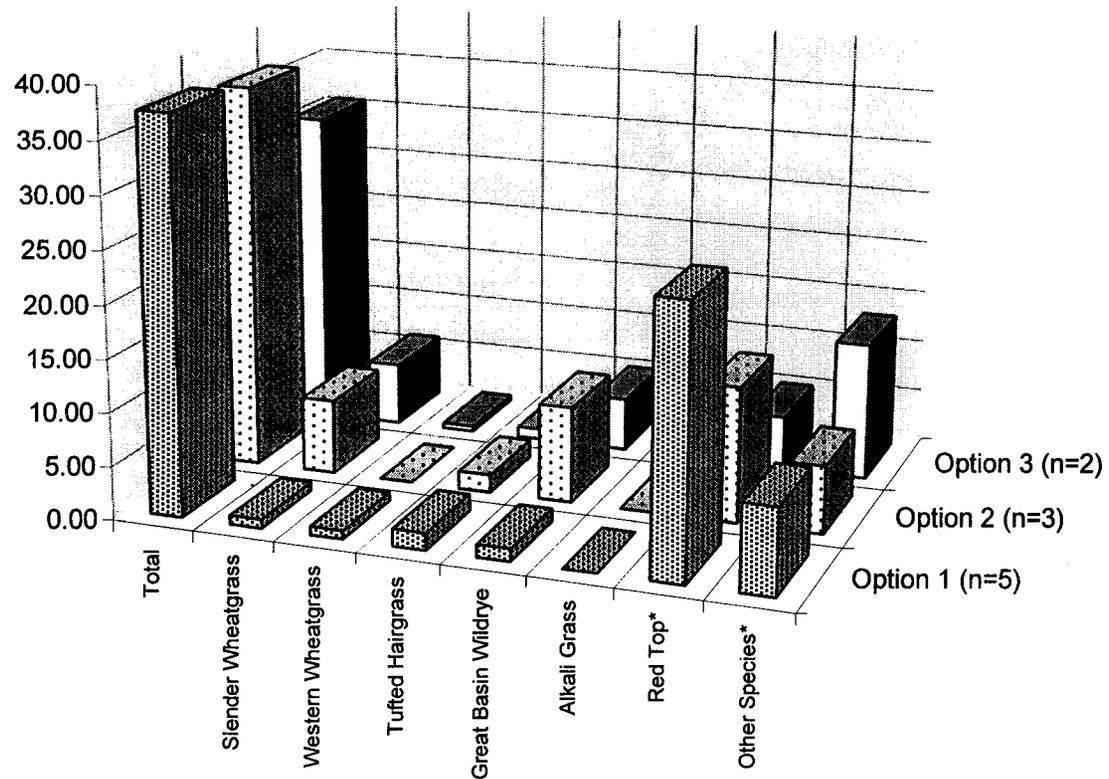


Figure 17. Mean cover (percent) for the three treatment options in the Relocated Tailings Area. 1997 data. Rocker Demonstration Site.

### MEAN PRODUCTION (G/M<sup>2</sup>) FOR THE THREE TREATMENT OPTIONS IN THE RELOCATED TAILINGS AREA - ROCKER DEMONSTRATION SITE

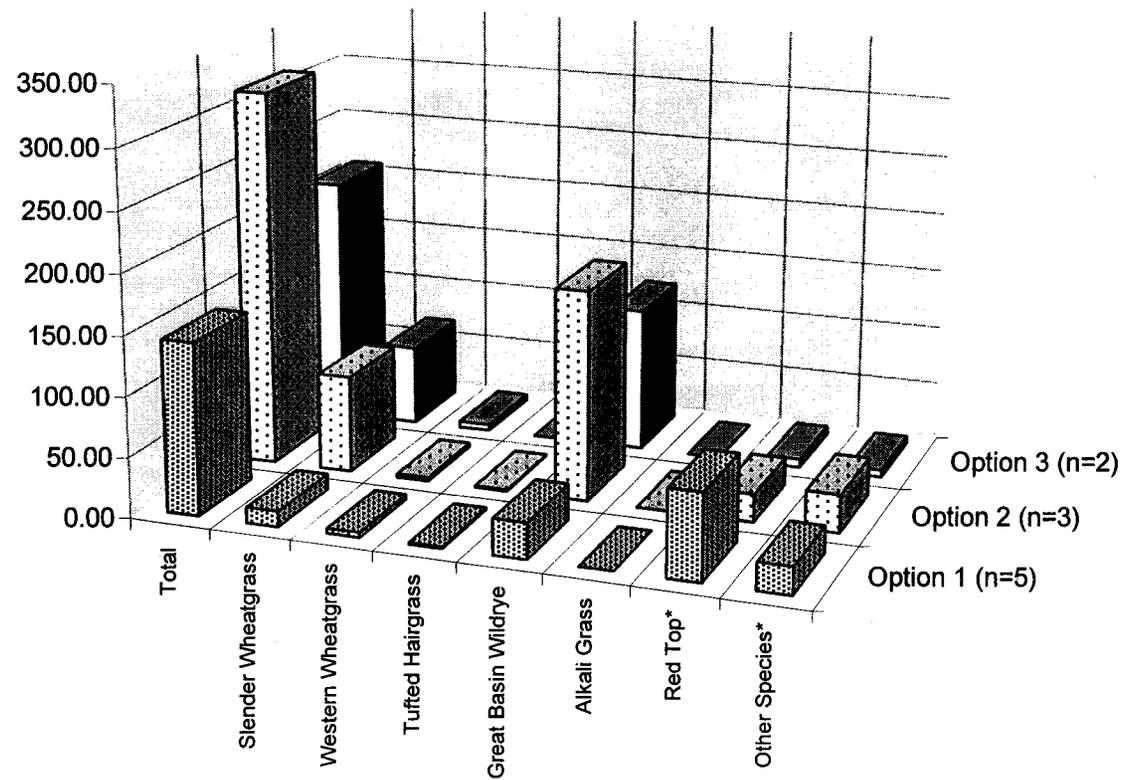


Figure 18. Mean biomass production (g/m<sup>2</sup>) for the three treatment options in the Relocated Tailings Area. 1997 data. Rocker Demonstration Site.

### 1997 MEAN COVER (%) FOR MAJOR SPECIES IN THE THREE TREATMENT AREAS AT THE ROCKER DEMONSTRATION SITE

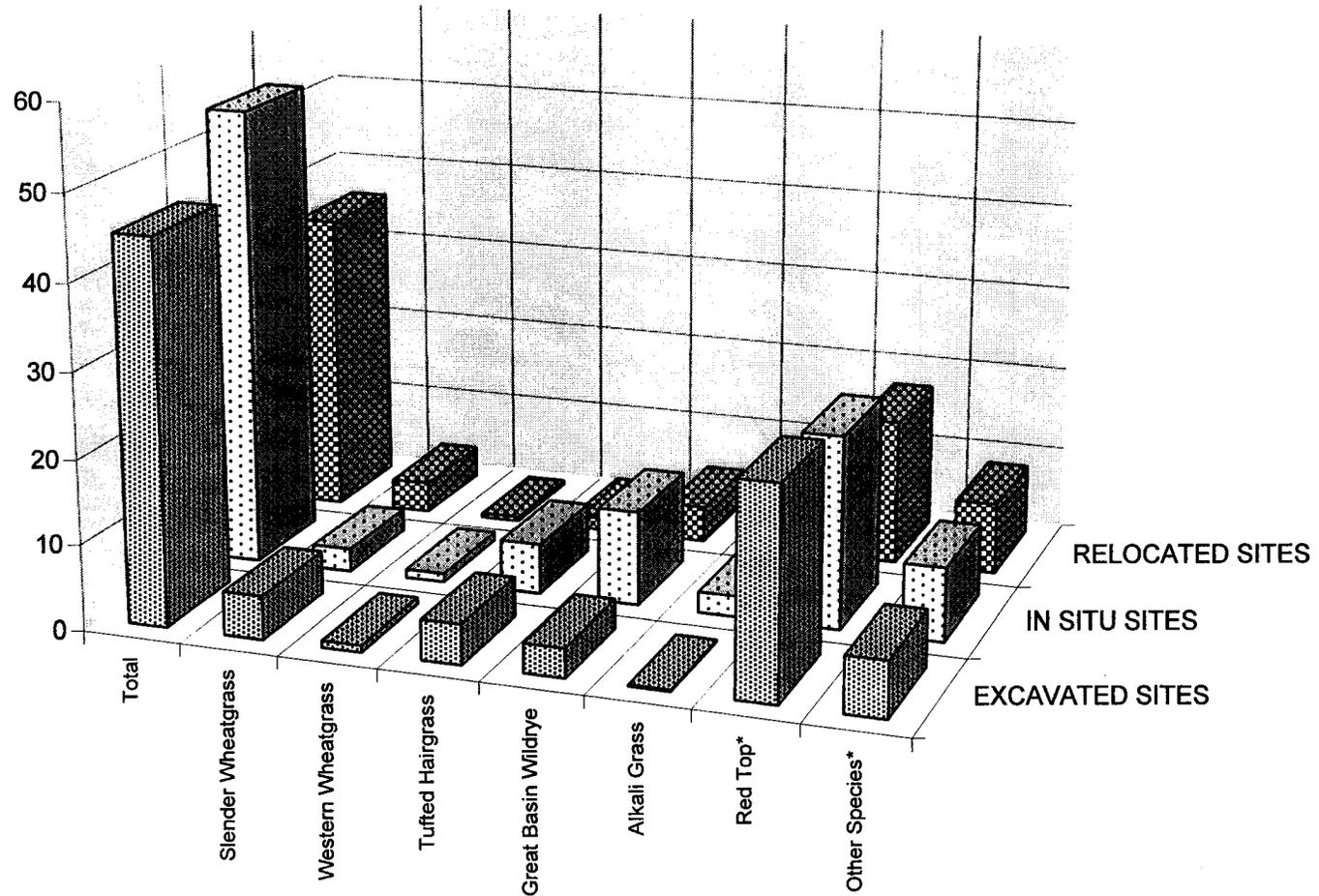


Figure 19. Mean cover values (percent) for major species in each of the three treatment areas. 1997 data. Rocker Demonstration Site.

### 1997 MEAN PRODUCTION (G/SQ.M.) FOR MAJOR SPECIES IN THE THREE TREATMENT AREAS AT THE ROCKER DEMONSTRATION SITE

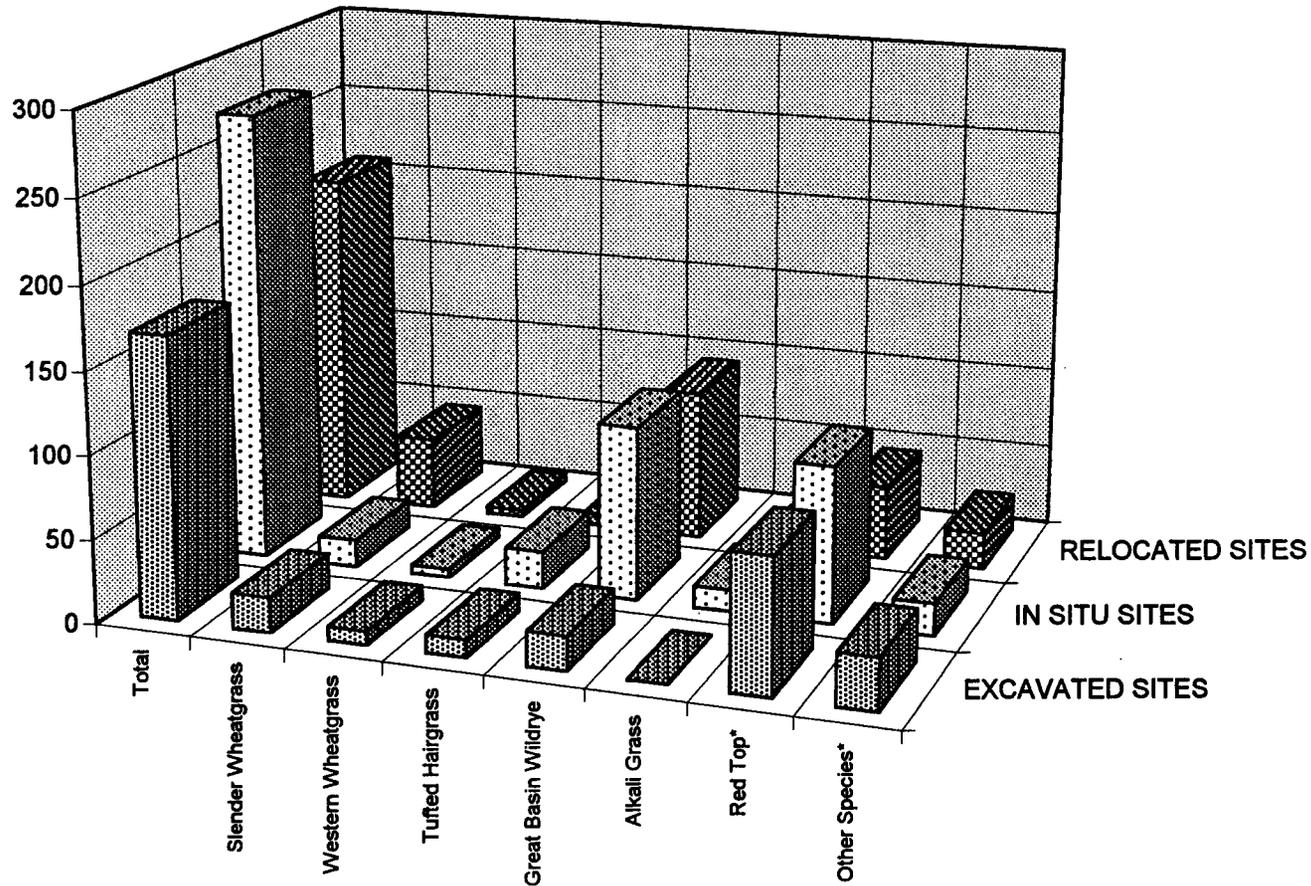


Figure 20. Mean production (g/m<sup>2</sup>) for major species in each of the three treatment areas. 1997 data. Rocker Demonstration Site.

and production on the drier relocation sites tend to be lower than on the other two treatments. Slender wheatgrass tends to be more prevalent in the excavated areas. Red top, tufted hairgrass and Great Basin wildrye tend to be more prevalent in the *in situ* areas. Great Basin wildrye tends to be increasing in all treatment areas.

The abundance of cover and production by perennial grass species indicates the initial success of all three treatments. It is expected that the abundance of slender wheatgrass will decrease over time, and that red top, Great Basin wildrye, tufted hairgrass and western wheatgrass are likely to continue to increase in abundance.

## CONCLUSIONS

- The species included in the seed mix have been very successful and occur as dominant species on the different treatment areas. In addition to the species included in the seed mix, many other species occur on the sites.
- Each of the three treatment areas supports substantial amounts of vegetation after five growing seasons. There were no statistically significant differences in cover among the treatment areas in 1994 and 1995 and no significant differences in production in 1994, 1995 and 1997. In 1996, cover and production values were significantly lower in the relocated areas, and in 1997 cover values were significantly lower in the relocated areas.
- While differences exist among the three different treatment areas, it is likely that the observed differences are related to a moisture gradient rather than to the treatments used in the demonstration project. All of the treatments were shown to be successful approaches to establish vegetation.
- The dominant species in the demonstration project area include slender wheatgrass, tufted hairgrass and Great Basin wildrye, all of which were included in the seed mix; and red top, which was not included in the seed mix but is a major species in non-remediated portions of the silver Bow Creek flood plain.

## **NATIVE PLANT RESTORATION ON THE GOING-TO-THE-SUN ROAD, GLACIER NATIONAL PARK**

David E. Lange and Joyce Lapp  
Glacier National Park  
West Glacier, MT. 59936

Since 1991, 53 acres of roadside vegetation and soil have been removed along sections of the historic Going-to-the-Sun Road (GTSR) during road rehabilitation activities. Restoration strategies use indigenous plant material to re-establish plant cover, prevent erosion, compete with exotics and improve aesthetics. From several hundred collections, seed mixes are created that include early colonizers and mid and late seral species. Native forbs, shrubs and trees are propagated as bare-root and containerized material. Grass is field grown to increase quantities with off-site seed production plantings. Revegetation incorporates a combination of plant and soil salvage, seeding, inplanting, and natural regeneration. Our monitoring program helps us to assess results and make decisions with species selection, seeding rates, successional strategies and realistic objectives for restoration.

### **INTRODUCTION**

Glacier National Park is one of the world's most significant natural areas containing spectacular topography, active glaciers, and unique biotic diversity. It is located in the northern Rocky Mountains of Montana at the center of an extensive ecosystem stretching from Banff and Jasper National Parks in Canada south to Yellowstone and Grand Tetons National Parks in Wyoming. This is an internationally significant location from the standpoint of scientific, aesthetic and conservation values.

The GTSR is renowned for its scenic beauty, historic value, and unparalleled driving experience. Nearly two million visitors travel the road annually. The historic qualities of the road combined with the vegetation, rock and scenery surrounding the road are key parts of the experience for visitors to Glacier National Park. The National Park Service (NPS) manages the GTSR to preserve its cultural and natural values as well as to maintain this unique visitor experience.

The GTSR was constructed in 1932 as the only road linking the Park's east and west sides across the continental divide. Construction was truly an engineering feat, that literally carved a road out of the mountainside. This unique road was designated a National Historical Landmark because of its design significance in 1997. It was the action with the Federal Highway Administration (FHWA). With passage of the National first park road built in this country in cooper Surface Transportation Assistance Act of 1982, Congress recognized a nationwide need for rehabilitating and upgrading roads in the national parks. In partnership with the FHWA, the NPS established a road improvement program. Glacier National Park became a participant in 1984. Since then, there have been seven road projects funded at Glacier, at a total cost of \$25 million.

### **RESTORATION PROGRAM**

When native vegetation is removed as part of the construction process, the consequences include erosion, invasion by exotic plants, displacement of animals, loss of screening or buffers,

and reduced aesthetic value. Our restoration strategies seek to emulate structure, function, diversity and dynamics of the adjacent plant community. Indigenous plant material is used in order to maintain genetic integrity and diversity. Soil and plants are salvaged and stored for replanting after construction. Native seed and cuttings are collected annually and propagated in the Park's native plant nursery and greenhouse. Seed is sent to the Natural Resources Conservation Service (NRCS) Plant Materials Center in Bridger, Mt. for storage or increased production, or sent to private contractors for propagation. A resource crew implements revegetation plans and monitors results.

### Restoration Goal

The goal for restoration is that within 5 years following construction, a vegetation cover of native plants is established that blends with the adjacent plant communities, is ecologically compatible with those communities, and is consistent with functional maintenance and safety requirements.

### Restoration Objectives

Objectives are project specific, measurable and follow from the goal. They are to:

- \*Preserve genetic integrity of native floral populations.
- \*Provide for optimum survival and vigor of plant material by using species collected at or near the disturbed site.
- \*Quickly provide plant cover to stabilize soil and prevent erosion.
- \*Keep coverage of exotic plants low in cut and fill slopes, and prevent invasion into undisturbed sites.
- \*Restore species composition and structure of disturbed site with plantings that are compatible with adjacent undisturbed plant communities.
- \*Use roadside vegetation that will not be a long-term food attraction to wildlife.
- \*Select vegetation that is low maintenance, durable, safe, and able to stand up under heavy foot and automobile traffic.
- \*Provide opportunity for research and technology transfer.

### Partnerships in Restoration

Since 1986 Glacier National Park has utilized partnerships in the planning, design and construction components on seven road projects within GNP. To date we have revegetated nearly 53 acres of roadside disturbance through varied habitats along the GTSR. Revegetation costs have ranged from 4 - 8% of construction project costs. Budgets have included 3% Administration, 40% plant production, 32% revegetation, 14% monitoring, and 11% planning and design. Engineering and construction specifications have been modified to reflect a high degree of consideration for the existing flora and fauna.

Planning efforts began with an interagency core team to define long term goals and measurable objectives for revegetation. Strategies were tested on the local Coram Experimental Forest and Biosphere Reserve on road cuts similar to those on the GTSR. Interagency Agreements

were completed with the US Forest Service and the Natural Resource Conservation Service for technical assistance. Revegetation strategies were evaluated through a peer review process with the NPS Denver Service Center. Implementation of revegetation was accomplished through partnering strategies with the Federal Highway Administration and the National Park Service. A cooperative greenhouse at the local high school was constructed to grow additional plant materials while involving students and their parents in the Park revegetation program.

#### Lake McDonald Section, 1991

This was the first Federal Lands Highway Program (FLHP) in GNP. The project involved 10 miles of roadside along Lake McDonald within a cedar-hemlock forest. Through partnering and teamwork we formulated strategies that were tested at the Coram Experimental Forest. During the revegetation of 12 acres of roadside we learned to integrate restoration activities with the planning, design and construction activities of a road project. We refined our methods to collect, propagate, plant, and protect indigenous species.

#### St. Mary to Rising Sun, 1993

This project was located within aspen forests and fescue grasslands for 9 miles along St. Mary Lake. The Park and contractor staff learned to work with large machinery on steep slopes to salvage and replace topsoil, and saw the advantage of taking steep slopes down to 2:1 slope if possible for long term retention of plant material. Clearing limits were designed to avoid straight lines. The combination of salvage, natural regeneration, seeding and inplanting worked together for best results. Within grassland communities we met the challenge of integrating noxious weed control and the use of herbicides with reseeding strategies. We saw advantages to enlarging cut slopes to smooth out the transition of berms in old backslopes. Although labor intensive, we saw very positive results with hand seeding and hydromulching. Slopes were left in a roughened condition with an uneven transition to the undisturbed area.

#### Logan Pass, 1995

Logan Pass is located on the crest of the continental divide at an elevation of 6600 ft. The area is snow covered, frigid and wind blasted for up to nine months of the year, with an extremely limited growing season. By 1997 visitation to this fragile subalpine environment had reached an estimated 1.6 million visitors each season. The Logan Pass revegetation project utilized all the experience, partnerships and teamwork accumulated from past projects. Three acres of disturbance were treated to re-establish soil and vegetation to roadside subalpine areas. Comprehensive site analysis, planning, seed collection, and plant production were needed, and over 55,000 containerized plants were prescribed. Restoration strategies included soil and plant salvage, imported soil pasteurization, mycorrhizal production and plant inoculation, planting, seeding, fertilizing, mulching, irrigation, monitoring and site protection.

### SITE CONDITIONS

Site analysis were completed to collect information on revegetation sites prior to construction disturbance. From this information, strategies were developed in the revegetation plan

that were designed to overcome factors of difficult site conditions in order to achieve our restoration goal and objectives.

### Topography

The GTSR was built through rugged mountainous terrain with elevations that range from 3100 ft at Lake McDonald to 6600 ft at Logan Pass and down to 4500 ft at St. Mary. The road travels through the forested Lake McDonald valley for twenty miles to the base of the upper mountains. At this point the road traverses steep cliffs for ten miles up to the continental divide at Logan Pass. From here the road travels down the eastside into the St. Mary valley, along St. Mary Lake to prairie grasslands at the base of the eastern Rocky Mountain front.

### Soils

Soils are typically gravelly fine sands and silts from sedimentary bedrocks of argillites and limestones. Volcanic ash and loess deposits had a major influence on surface soil development with resultant fertility and moisture holding characteristics. The degree of weathering influenced the amount of clay in the soil profile, the thickness of the soil profile, and the amount of organic matter and water holding capacity. For example, the soils at Logan Pass are very shallow, but in the fescue grasslands they are fairly deep and well developed. Soils were classified along the GTSR based on a field inventory of land forms. Land forms are structural configurations of the topography that resulted from past and present geological activity. The soil component is interrelated with vegetation, drainage, and climate to determine the landtype designation.

### Weather and Climate

The mountainous character of the area has marked effects on its climate, which varies widely within short distances. Average annual precipitation ranges from 28 inches at the lower elevations to 100 inches on the continental divide. At the lower elevations snow is on the ground typically until May, with an average 90 day growing season. At Logan Pass there is an average of 60 snow-free days within which planting can occur. Harsh weather and persistent snow do not allow access to this project site until late June or July. Even then, stormy weather alters work schedules.

### Diverse Plant Communities

The GTSR passes through four distinct eco-regions: montane forest, sub-alpine meadow and forest, aspen parkland and fescue grassland. Plant materials lists and seed mixes need to not only provide revegetation species for the eco-regions, but provide for site variability within each project area. For example, the sub-alpine plant community has very shallow soil with varying ranges of texture, pH and moisture regimes. Within the three acre Logan Pass project area several microsites or distinct plant communities have been defined. This complex arrangement of plants with variable growing requirements created challenges for the nursery and greenhouse operations.

The plant communities along the GTSR include exotic plants and five noxious weed species. In 1991 an Exotic Vegetation Management Plan was implemented which used Integrated Pest Management to devise strategies to control exotic plants. These strategies include inventory,

monitoring, education, prevention, research and control. Herbicides are used along the GTSR to contain and reduce populations of noxious weeds. Monitoring results indicate optimism in reducing these exotics while still retaining native species richness and diversity

### Wildlife

The wide diversity of habitat types is reflected in a similar diversity of fauna including several endangered or threatened birds and mammals and many rare species. People stop along roadsides to watch and follow wildlife, which results in trampling of natural vegetation and loss of soil. Work schedules were modified when grizzly bears passed through construction projects to prevent undesired encounters. Some project areas were closed for periods during the season to protect wildlife, such as nesting bald eagles.

### Visitor Use

The GTSR is the primary route of travel for two million people visiting Glacier National Park, and this is concentrated during a three month period in the summer. The road was maintained open during construction, with flag persons directing traffic. Overflow roadside parking, congestion, and social trails were evidence of visitor use that was greater than the developed areas could handle. The challenge is not only to restore vegetation to the areas disturbed by construction, but protect it from the impacts of very high levels of visitor use.

### Past Construction

Unresolved problems of past construction continued to worsen each year, such as erosion and slumping soil on over-steepened slopes. Some of these ills were corrected during the new road work, if they were within the project area. Examples included taking steep slopes down to a gentler grade to retain vegetation, smoothing out lips of cuts and weaving clearing lines to blend in with natural openings.

### Construction Specifications

The construction zone had very tight limits for work in order to confine impacts to within the project area. Often construction limits were immediately adjacent to pristine meadows and water courses. Since the road was open during construction there was congestion with visitor traffic and construction equipment. Access to the project areas was very difficult for revegetation crews. Coordination between the contractor and restoration staff was critical in site preparation and planting.

## SEED COLLECTION

Large quantities of native seeds and plants were required for the revegetation of each segment of disturbance on the GTSR. Collection and propagation of this material required several years of advance planning prior to construction. In 1992 Glacier National Park established genetic guidelines for restoration projects that were developed to minimize the possibility of genetic contamination to the existing native vegetation adjacent to a disturbed site. Our genetic guidelines

required collections be within the same habitat type, elevation, aspect, and drainage as the species removed during construction. Large numbers of seeds were collected among separate populations within similar community types. Over the last twelve years the staff of Glacier has made several hundred collections of over one hundred different native plant species for restoration work.

Species selection was based upon the predisturbance site analysis and projections of what site conditions would be like after construction. Species lists and planting palettes emphasized colonizer species but also included mid and late seral species to provide a better blending of the disturbance with the adjacent undisturbed vegetation. The Logan Pass project required a mix of 10 grass/carex species, 26 forb species and five shrub and tree species. Seven distinct planting prescriptions were developed to address the extreme variables in soils, moisture, topography and plant communities throughout the three acre project.

Seed collection was extremely time consuming and expensive as conditions were so varied from project to project and from year to year. Collection sites were located, maturity of seed monitored and all seed collected by hand. The taller grasses and forbs were harvested with a small sickle while the lower growing species were harvested with scissors. Yearly fluctuations in weather affected seed ripeness, and some years there were complete crop failures when seeds did not mature.

An interagency agreement with the Natural Resources Conservation Service was initiated in 1987 to assist us with seed management. After our seed was collected in the Park, it was accessioned, dried and sent to the Plant Materials Center in Bridger, Mt. The Bridger staff provided seed cleaning, testing and storage as well as technical expertise in regards to species selection and collection. Some seed was returned to the Park for direct seeding or propagation into containerized plant material. The remaining seed was stored or sent to private contractors for propagation or planted for seed production.

We estimated that collection costs ranged from \$25.00 a pound to \$500.00 a pound for Glacier's native seed depending upon the species. The Logan Pass project required a total of 18 pounds of grass, carex and forb seed for seeding and another 16 pounds of seed for plant production. Our seeding rates for grasses were generally 70 seeds/ft.<sup>2</sup> which translates to an average of 20 to 25 pounds of seed per acre. Seeding rates for Logan Pass were considerably higher at 120 seeds/ft.<sup>2</sup>

## SALVAGE OF PLANTS AND SOIL

On each project we salvaged as much plant material and soil as possible prior to disturbance. Plants were salvaged in clumps, as whole shrubs and small trees and as sod mats in prairie or subalpine meadow situations. This plant material was either heeled-in on site in a protected environment or held in our native plant nursery until construction was completed. We stored several thousand ft.<sup>2</sup> of salvaged subalpine sod in planter boxes on site for periods of one to three years with no measurable mortality.

We salvaged topsoil prior to construction in order to capture the native seed and propagule bank present in the soil. In some instances this topsoil was moved to the top of the cut and pulled back down after construction was completed. If this was not possible, soil was stored in windrows of no more than four feet in depth, and replaced the same season to insure the viability of the soil and seed once it was replaced.

Where there was not sufficient quantities of salvaged topsoil available, we considered soil importation. Inspections were made to determine seed bank species, and prevent occurrence of

invasive weed seeds. Laboratory analysis were made to determine texture and chemical compatibility with native soils. In the pristine subalpine environment at Logan Pass the soil was very shallow, and we had a deficit of soil available for revegetation following construction. In this case, imported soil was pasteurized to prevent the introduction of any exotic plant material. It was necessary to import 450 cubic yards of pasteurized soil media for the Logan Pass project. This material consisted of 25% well-rotted sawdust, 25% sphagnum peat moss, 10% sand and 40% loam soil. This media was heated to 180 degrees for 30 minutes to insure pasteurization.

## PRODUCTION OF PLANT MATERIAL

### Plant Material Center

Some of the seed that was sent to the Bridger Plant Materials Center was planted for seed production and harvested to provide increased quantities of viable seeds for each construction project. Shrubs were grown in production beds as bare-root planting stock. Propagation methods were tested on difficult species to improve production.

### Native Plant Nursery

A small native plant nursery was constructed at the Park Headquarters area in 1987 to develop propagation procedures for native plant species which were not commercially available at that time. Currently the purpose of this facility is to develop propagation techniques, produce plant material from seed and cuttings, serve as a staging area for revegetation efforts, and provide educational opportunities for the staff, public and cooperators. With a new road project scheduled every two years, we manage a number of projects simultaneously, in various stages of planning, design and construction. We utilize the nursery for coordination of plant material demands for these multiple projects. This need is projected to continue over the next 20 years. We are able to improve efficiency with shared resources, respond quickly to changing revegetation needs, and produce small quantities of species that meet our strict genetic guidelines for outplanting.

By the end of the 1997 season we provided a wide variety of plant species and size classes for individual road projects. The transplants had exceptionally high survival, with an average of 80% survivorship in our monitoring plots. In 1996 we were holding over 50,000 plants in our nursery facility in preparation for the Logan Pass restoration project. We produce an average of 25,000 plants per year for revegetation needs on the GTSR. Additionally, our facility provides resource education to many visitors and students that tour and volunteer to work in the nursery.

The planting plan prescribed approximately 55,000 plants for the Logan Pass project. These plants were propagated by the Bridger Plant Materials Center, the Park's native plant nursery and private growers. In addition, the private grower was contracted to propagate plant-specific mycorrhizal fungi and inoculate 30,000 containerized plants prior to delivery to Glacier. Bridger Plant Materials Center supplied an average of 2000 bareroot shrubs annually and also grew some of the more difficult species in their greenhouse.

### Greenhouses

In 1993 we received a grant that served as seed money for the construction of a small greenhouse at a local high school, and development of an educational outreach program for 5th

through 12th grade biology students. The facility was completed with additional moneys and supplies donated by community members and local businesses. Each year approximately 6000 plants are produced in the greenhouse. Students collect seed in the fall at the Park, propagate containerized plants throughout the winter, and plant the material in the spring. Over 60 classes and nearly 1000 students have participated in this innovative program..

Construction operations were initiated for two other greenhouse facilities in 1997. A hoophouse was located at the native plant nursery specifically designed as a weed-free, enclosed growing environment for production of sub-alpine and alpine species as individual plants or in sod flats. Also, funding was secured for a cooperative greenhouse at the Blackfeet Community College as a joint venture to produce plant material for revegetation projects on Blackfeet Tribal Lands and Glacier National Park.

### PLANTING STRATEGIES

The revegetation crew consisted of four crew members and a crew supervisor. They worked ten hour days, four days a week from early May through October. During the Logan Pass project, this crew was assisted in their work by a six person crew from AmeriCorps Montana Conservation Corp. The short planting window at Logan Pass of mid-July to early September, and the large number of plants to be installed, necessitated a larger planting crew. Although they often faced difficult work conditions, these people were extremely motivated, hard working and believed in the importance of their work. Leadership provided by the crew supervisor was critical to achieving the restoration objectives.

Successful implementation of restoration work required careful coordination between planning, design, construction, and supervisory personnel. Comprehensive revegetation plans and planting designs were developed based upon years of extensive site analysis and evaluation. These revegetation plans laid out the needed plant materials by planting unit, supplies and equipment, soil strategies, personnel requirements and sequencing of work activities. Considerations of the visitor use, natural and cultural resource values, and historical record of construction along the road corridor had significance to revegetation planning as well.

One of the biggest coordination challenges was the tracking and moving of the large quantities of plant materials to the project sites. Plants were trucked daily from the nursery to the project sites to avoid mortality from desiccation, and unpredictable weather conditions. Since the GTSR was kept open to visitor traffic during construction, the highly congested nature of the work site made access very difficult. Many thousands of plants had to be moved about by hand or in wheelbarrows along busy roadways to reach individual planting units. Crew safety was always of greatest concern because of the need to work in proximity to large construction equipment and because of the heavy visitor traffic on this extremely narrow road.

Revegetation efforts began immediately after the contractor finished final grading. Salvaged topsoil was pulled down over the new grade at an average depth of two inches. In cases where imported soil was needed, the salvaged native soil was spread thinly over this imported material and mixed to make a more homogenous planting media and inoculate the pasteurized material with indigenous soil microbes. At Logan Pass a low analysis (6:1:3) slow-release organic fertilizer was applied at a rate of 500 lb/acre over the site. We used a fertilizer in this instance because it was believed this product would facilitate the recolonization of soil biota and enhance seedling establishment.

Seed was sown by hand prior to the installation of a biodegradable agronomy blanket composed of straw and coconut fiber woven with cotton string. Because of the high winds and extreme run-off from snow-melt this agronomy cloth was used to hold the seed and soil in place and retain moisture. An overseeding of forb and carex species requiring light for germination was completed prior to the installation of containerized plant materials.

Landscape design was incorporated into the revegetation plan with written descriptions and drawings. Planted species needed to be durable to vehicle and foot traffic, compatible with adjacent plants, and diverse in terms of texture of close-up and distant views. Plant material placement followed general design guidelines and wire flags were used to define locations of clumps of five to seven individual species.

Since we were dealing with cold climate species, most revegetation was scheduled in the early fall or spring, and discontinued between June 15 and September 1. Seeded areas were usually not irrigated. However, at Logan Pass, irrigation was used the first two years to enhance establishment, vigor and survivorship of planted materials. A low-tech, passive irrigation system was developed in order to plant in July and August during the heat of the summer. An intake valve and over 1000 feet of two inch plastic pipe were used to draw water out of two perennial streams with steep waterfalls. Simple valves and lengths of sprinkler hose delivered up to eight gallons per minute of water to all planting units.

With completion of the planting, a significant challenge was to protect the newly established vegetation from being trampled by the nearly two million visitors traveling on the GTSR. Signs were placed at the sites to inform visitors of the restoration efforts. Within the concentrated Logan Pass Area we installed an unobtrusive and easily maintained chain fence around all planted areas. Uniformed staff monitored and enforced the posted areas.

## MONITORING STRATEGIES

### Assessment of Results

The Revegetation Monitoring Program was established in 1991 to provide baseline data for revegetation planning and assessment of results. The program helped evaluate completed revegetation work and determine whether objectives for restoration were met. Monitoring has been applied to seven road projects at Glacier National Park. This data is used to determine future strategies, to project trends over time and to improve our revegetation methodologies. Monitoring results to date lead us to conclude that our revegetation methods have been appropriate to achieve most of our goals and objectives. Results of monitoring data are documented in annual reports.

Monitoring strategies include establishing permanent transects on each plot that are used for line-intercept cover measurements of shrubs and trees. Canopy cover of all native and exotic plants and ground cover are measured in microplots along each transect (Asebrook et al, 1996). Lifeform canopy cover estimates for each microplot are recorded as well. Ocular estimates are done in conjunction with microplot monitoring. Nested frequency monitoring is done where appropriate. The objective of each monitoring technique is to obtain sufficient data to provide for robust statistical comparisons.

### Lake McDonald Section

The trend on these plots has shown that seeding native grasses and forbs resulted in higher native cover and lower exotic cover. Seeded plots had significantly higher native grass cover and significantly lower exotic forb cover than unseeded plots since monitoring began in 1992. Shrub survival remains high at 85 per cent. This data suggests that revegetation should continue on these roadside areas, instead of relying on natural regeneration, for restoration of native communities (Asebrook et al, 1996).

### St. Mary to Rising Sun Section

To date all seeded species have been noted along the roadcut resulting in a significant native cover in these revegetated areas. On steep slopes native grasses dominate the sites, and there is little erosion evident. Planted material had better survival and vigor when planted in spring rather than in the fall. Overall plant mortality increased on the revegetation plots over time but there is still 60 - 70% survival of planted shrub species. Native grasses and shrubs showed the most success at controlling the dominance of exotic plants, but exotic species continue to be long-term components of the roadside communities (Asebrook et al, 1997). Although exotic forb cover has decreased, exotic grass cover dominates some roadcuts. It appears that seeding is necessary to introduce a native grass component to roadsides with salvaged soil in order to compete with exotic grass and forbs.

### Logan Pass Section

Data collected the first year suggests that the survival of grasses is greater than 90% and survival of forbs and shrubs is greater than 80%. Of the live plants evaluated, greater than 90% had a vigor rating of good/fair (Asebrook et al, 1997). Initial data supports the use of fertilizer treatments as the treated areas showed greater cover of seeded material, particularly grass germinants. Additional evaluations will help us determine if our seeding rates were appropriate, and if only seeding would have been as effective at reestablishing vegetation over time as the more costly and time consuming planting and seeding.

## CONCLUSION

The restoration of native plant communities removed during new construction is part of the Federal Lands Highway Program to rehabilitate the Going-to-the-Sun Road. The methods that are used include pre-construction inventories, extensive planning, collection of seed and cuttings, propagation of containerized and bare root material, increase of seed, and planting of grass, forb, shrub and tree species. The success of these strategies depends on people with diverse disciplines working together and learning from experience. Although costly, results have shown we can achieve quality park roads, quality park experiences for visitors, and preservation of cultural and natural resources. Over the years we have developed a working relationship through partnerships and teamwork to assure the Going-to-the-Sun Road will continue to provide access to the Park consistent with sustaining the world class quality of the natural and cultural resources of Glacier National Park.

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**ASEXUAL PLANT PROPAGATION: SPECIAL TECHNIQUES AND  
CONSIDERATIONS FOR SUCCESSFUL HIGH ALTITUDE REVEGETATION.**

Joseph D. Scianna, Susan R. Winslow, Mark E. Majerus,  
Lori M. Gruber\* and Sam A. Reid\*

United States Department of Agriculture  
Natural Resources Conservation Service  
Bridger Plant Materials Center  
Route 1, Box 1189  
Bridger, MT 59014

\*United States Department of Interior  
National Park Service  
Yellowstone National Park  
P.O. Box 168  
Wyoming 82190

**ABSTRACT**

High altitude restoration with woody plants poses unique propagation challenges for natural resource managers including unpredictable wildland seed crops, short growing seasons, limited access to wildland plants, genetic considerations, seasonal staffing, uncertain and changing construction schedules, and short revegetation intervals. Although sexual propagation (seed) is generally less labor and equipment intensive, limited seed and long or unknown dormancy requirements can result in lengthy production schedules. Asexual propagation (cuttings) of woody trees and shrubs provides a viable alternative for high altitude settings. Dormant hardwood cuttings provide ease of handling and storage, however, access to donor plants, winter browsing, seasonal staffing, and reduced winter greenhouse operations often limit their use. Summer cuttings facilitate access to donor plants, reduced browse competition, improved percentage rooting, shorter production intervals, adequate labor, and efficient greenhouse operation. The selection of a propagation technique depends on genetic considerations, the propagation characteristics of the species, site and environmental factors, economic and procurement considerations, and construction schedules and goals. Favorable propagation conditions include proper and limited storage, fungicide dip, wounding, recut base, treatment with growth regulators, intermittent mist, sterile well drained media, bottom heat, shade, and strict environmental control.

## INTRODUCTION

Natural resource managers responsible for the revegetation of high altitude disturbances are faced with numerous and complex biological, environmental, and economic challenges as a result of the severe climate and limited growing season characteristic of these environs. The revegetation of high altitude disturbances requires land managers to make decisions based on site- and project-specific considerations. The method of plant propagation employed depends on many interrelated variables including genetic considerations, the propagation characteristics of a given species, site and environmental factors, economic and procurement considerations, and construction schedules and goals. The asexual propagation of woody plants from stem cuttings taken during the growing season is an often overlooked approach that may lend itself well to certain high altitude situations.

## PROPAGATION DEFINITIONS

Plant propagation is defined as the science and art of multiplication of plants by either sexual or asexual means. *Sexual* reproduction involves meiotic cell division that ultimately produce progeny (seedlings) with new or differing genotypes relative to their male and female parents. Most woody plants are highly *heterozygous*, that is, a relatively high number of genes on one chromosome of a Mendelian pair differ from those on the other chromosome. As a result, the progeny of woody plants grown from seed tend to exhibit a relatively high amount of genetic variation (Hartmann and Kester 1983). For the purposes of this discussion, sexual reproduction is synonymous with propagation by seed, although not all embryos develop from sexual processes.

*Asexual* propagation by cuttings involves removing sections of stem or root tissue from the parent or donor plant, treating this tissue with plant growth regulators, and then inducing adventitious root or shoot formation under controlled environmental conditions. Asexual propagation is reproduction from the vegetative parts of the donor plant and involves mitotic cell division in which the chromosomes duplicate and divide to produce two nuclei that are genetically identical to the original nucleus. This can occur through the formation of adventitious roots and shoots or through the combining of vegetative tissues, such as in grafting. This clonal process, in which the genotype of the parent plant is exactly duplicated, is made possible because of two unique plant characteristics. *Totipotency* is the property of vegetative plant cells to carry all of the genetic information necessary to regenerate the original plant. *Dedifferentiation* is the ability of mature (differentiated) cells to return to a meristematic condition and produce a new growing point (Hartmann and Kester 1983). In the context of this discussion, asexual reproduction refers to the induction of adventitious roots from stem cuttings and is synonymous with vegetative and clonal propagation.

Although there are numerous variations of the stem cutting, they can be broadly classified into two groups based on the time of year that they are taken. *Dormant hardwood* cuttings are taken in mid to late winter of mature tissue from fully dormant

plants, i.e., plants that have dehisced their leaves but have not yet initiated spring growth. Usually the previous season's growth is used, although two year and older wood can be used in some cases. Dormant hardwood cuttings are easy to take, handle, and store; which allows for flexibility in the preparation of the cutting and, in general, require less care than cuttings that include actively growing tissue. The cuttings are taken at a time of year when field responsibilities are limited and there is little need for special care, other than cold storage, prior to treatment in the greenhouse. More dormant deciduous cuttings can be stored per unit area than summer cuttings because of the absence of foliage. There is less chance of cutting desiccation or mechanical damage during all stages of handling, storage, preparation, and placement in the greenhouse.

The second type of stem cutting is the *summer cutting* and includes *softwood* and *semihardwood* (greenwood or ripe-wood) cuttings. These types consist, at least in part, of actively growing tissue, and are taken from early to late summer. Softwood cuttings consist of succulent, new growth only, although any cutting that includes actively growing tissue is sometimes erroneously referred to as 'softwood'. True softwood cuttings generally produce adventitious roots faster and have a higher percentage rooting than their hardwood counterparts. Semihardwood cuttings are also new growth but are partially-matured wood taken in mid to late summer. Softwood and semihardwood cuttings, because of their succulent nature, are more susceptible to mechanical injury and tissue desiccation than hardwood cuttings (Hartmann and Kester 1983; Macdonald 1986).

It is also possible to take summer cuttings that include stem tissue that is two or more years old. These are sometimes referred to as *summer hardwood* or *active hardwood* cuttings. Using summer hardwood tissue is practiced infrequently because mature tissue generally does not produce adventitious roots as readily as actively growing, current season's tissue. Also, there is less physiological stress on a dormant hardwood cutting than on a summer hardwood cutting because of the absence of foliage (with deciduous species). This method may prove useful, however, in high elevation situations when softwood and semihardwood tissue is too small or weak to produce roots or when access to dormant hardwood cuttings is limited by inclement weather.

## GENETIC CONSIDERATIONS

The degree to which genetic factors will influence plant propagation depends on the goal of the construction project. More latitude may be possible if the goal is simply to establish plant cover on the disturbance, i.e., 'revegetation'. If the goal is to recreate the genetic variation of the site to some predisturbance level through 'restoration', fairly systematic and comprehensive measures will be needed (Majerus 1997). Research suggests that the long term success of high altitude revegetation and restoration efforts depend largely on the genetic makeup of the revegetation material as it reflects the plants ability to tolerate and adapt to a harsh and variable environment. Plant propagation techniques and the manner in which they are implemented can have a dramatic effect on the genetic composition of the target site. The preservation of genetic variation may be particularly important in high elevation settings where biological diversity is

characteristically low (Harris 1984). Poor planning and decision making during plant propagation could ultimately result in alterations in the genetic composition and structure of the revegetated ecosystem causing reduced genetic variation, inbreeding depression, and genetic drift. This in turn may lead to poor plant adaptability and decreased ecosystem stability over time.

Specific, practical methodologies for the preservation of genetic variation within and between woody plant populations during plant production are often lacking or are inappropriate for restoration purposes. Inadvertent selection may occur during propagule collection, processing, propagation, harvesting, and reintroduction (Meyer and Monsen 1992). The technology needed to identify the extent and distribution of genetic variability within or between populations exists, although little of this research has been applied to commercially unimportant woody species. Substantial research has been conducted on the genetics of native and cultivated grasses, agronomic crops, rangeland species, and the commercially important timber species (conifers). The applicability of this information to restoration is questionable, however, in that genetic variation was often evaluated in terms of some short term economic criteria and not long term ecological significance. In fact, natural adaptations that enhance long term survival often reduce the economic value of timber species (Smith 1962).

The development of guidelines for the collection and production of woody plant material for restoration also depends on an understanding of the manner in which they naturally reproduce. The genetic structure of plant populations is largely determined by their mating system, i.e., the degree to which they are self or cross pollinated (Brown 1990). Cross-pollinated species generally exhibit significant genetic variation both among individuals within a population as well as between populations (Millar and Libby 1989). Most trees and shrubs are cross-pollinated and highly heterozygous, having a high potentiality for genetic variability and subsequently, the opportunity for evolutionary change should environments change (Hartmann and Kester 1983). In conifer species, however, much of the genetic variation is distributed within instead of among populations (Loveless and Hamrick 1984). Conifers tend to have greater seed and pollen dispersal than herbaceous species (Levin 1981) as well as a relatively continuous spatial distribution. These traits increase the likelihood of uninterrupted gene flow and consequently decrease the likelihood for frequent genetic differentiation between populations, relative to a life form such as a grass or even a shrub (Knapp and Rice 1996). Tree seed zones have been established for several of the commercially important conifer species based on known patterns of genetic similarity or, on climatic contours when genetic information is lacking. Planting of seed outside the zone in which it was collected is avoided. In addition, within each seed zone, seed is not planted on sites differing more than 1,000 feet (305 meters) vertically or 100 miles (161 kilometers) horizontally from the collection site (Smith 1962; Buck 1970; Kitzmiller 1990).

There is substantial evidence and support for selecting populations native to or in close proximity to the revegetation site (Vallentine 1989; Meyer and Monsen 1992; Guinon 1993). For some species and habitats, however, this may not necessarily be true (McArthur and others 1983; Namkoong 1969). Recommendations for the systematic

sampling from both representative populations and from extreme or unusual populations represents one approach (Ledig 1988). For large scale revegetation, the sampling of all genotypes representative of all of the typical native environments of the species has been recommended. For cross-pollinated species, it may even be possible to produce new genotypes adapted to various intermediate environments (Munda and Smith 1995). Perhaps a cautious and reasonable approach to population selection is the recommendation to use collection sites as closely matched as possible to the restoration site in terms of geographic location, climate, soil, and matrix vegetation (Meyer and Monsen 1992). The issue is complicated by the fact that disturbed sites are environmentally changed, and the ecotypes that are best suited for long term survival may not necessarily be those found growing in close proximity on undisturbed sites.

The method of initial propagule collection and increase is thought to have a significant impact on the survival, establishment, and long term persistence of revegetated sites (Munda and Smith 1995). Adequate sampling of the genetic variation within a population is necessary to assure relatively predictable performance and the ability to adapt to changing environmental conditions over time. Most cross-pollinated species are sensitive to inbreeding depression, and care must be taken to secure an adequate sampling of genotypes, perhaps 100 or more, that are widely dispersed within the reference population. Research indicates that for cross-pollinated species, the loss of genetic variation over time correlates closely with the original number of plants sampled. (Frankel and Soule 1981). Improper sampling and the subsequent loss of genetic variation is especially serious when it occurs during initial propagule collection because little can be subsequently done to reverse this condition (Munda and Smith 1995).

It is possible for genetic change to occur when seed orchards or vegetative cutting blocks are established for the large scale increase of plant propagules. The risks are likely to be greater when these orchards are located at distant sites and/or in different environments relative to the collection site. It is unclear to what degree this may occur for any given species. The risk of change would seem great in seed orchards of open, cross pollinated trees when they are inadequately isolated from undesirable populations of the same species or a close relation. Loss of orchard trees, inbreeding depression, the unequal production of seed by the individual orchard trees, and other factors may be involved. In addition, some hybridization may occur between orchard plants leading to the creation of entirely new genotypes adapted to intermediate environments (Munda and Smith 1995).

In contrast to sexual reproduction, asexual propagation is clonal and assures preservation of the original genotype. Asexual propagation effectively eliminates the need to isolate cutting blocks, for future vegetative propagation, unless volunteer plants contaminate the orchard or random genetic mutations occur. On the other hand, the potential for restricting the genetic variation of a reference population is great with propagation by cutting if exceptional care is not taken during initial population sampling. It is also possible that some of the cutting block trees will die or that there will be differential rooting of the cuttings leading to a bias in the distribution of population genetics.

## PROPAGATION CHALLENGES

The selection of a propagation method often depends on the reproductive characteristics of the species involved. Some species propagate readily by seed, producing frequent, abundant, and viable seed crops. Most woody plants indigenous to northern temperate climates possess one or more dormancy mechanisms that prevent seed germination until environmental conditions are favorable for germination, survival, establishment, and ultimately, species perpetuation. Cold chilling, warm stratification, mechanical or chemical seed coat scarification, or some combination of these or other treatments are usually needed before germination will occur. These conditions are fulfilled naturally by sowing seeds outdoors and allowing seasonal climatic conditions and soil processes to break dormancy. The same dormancy breaking requirements can be met with artificial techniques such as acid scarification, warm stratification in a greenhouse, prechilling in a cooler, and others. These requirements vary by individual plant, seed lot, species, population, time of year, method of seed handling and storage, climatic conditions, and other factors. Lengthy dormancy requirements may result in a more costly product or a longer construction schedule. Unknown dormancy requirements may prevent propagation by seed entirely.

As with propagation by seed, some species are easily propagated by cuttings while others are not. In some cases, propagation by stem cuttings is not possible because the species is incapable of producing adventitious roots or there is a lack of technology to do so. Adventitious roots may be produced, but at a rate so low as to not be practical. Some species can be propagated by stem cuttings but only at certain times of the year, i.e., only from hardwood or softwood cuttings and this may conflict with site access, greenhouse operations, etc., as previously described.

## SITE AND ENVIRONMENTAL FACTORS

There are numerous site and environmental conditions that can influence the type of plant propagation system selected for producing plants. These conditions can directly impact propagation by effecting the production of wildland seed or by reducing plant and cutting vigor. Factors inhibiting the use of seed include poor weather as it impacts production and timely collection, consumption by animals, attack by insects and disease, and other factors.

Site conditions may also favor one type of asexual propagation technique over another. Despite the inherent ease of hardwood propagation, high altitude revegetation may impose limits on this type of reproduction. Dormant hardwood cuttings are usually taken from December through February when unpredictable weather conditions make travel difficult or impossible. Low stature trees and shrubs may be buried under snow and ice and not accessible. As forage decreases with the onset of winter, many herbivores turn to succulent woody stems and buds for sustenance. In most cases, severe and repeated browsing ultimately reduces the vigor of the plant and subsequently diminishes the ability of its cuttings to produce adventitious roots. Seasonal labor pools are usually low at this

time of year and greenhouse operations curtailed or suspended because of the high cost of heating. Certain combinations of these factors may favor the use of summer cuttings or propagation by seed over dormant cuttings.

## ECONOMIC AND PROCUREMENT CONSIDERATIONS

In most cases, propagation by seed is the most labor and cost effective method of reproducing plants, given that genetic variability, such as germination requirements, can be managed within acceptable limits (Hartmann and Kester 1983). Seed may be gathered by commercial collectors on a contractual basis or by the restoration staff directly. Raw fruit requires proper storage prior to cleaning, processing to some clean product level, inventorying, and proper storage prior to sowing. Large amounts of seed can be planted outdoors in woody production beds with relatively simple machinery. For a given species in which seed is readily available, viability high, dormancy requirements known and minimal, and cultural techniques established; sexual propagation represents a low cost, labor and facility efficient method of multiplying plants.

As the conditions for the collecting, sowing, and culturing of seed become less than ideal, asexual propagation by cutting becomes an increasingly viable production option. As noted earlier, seed availability may be low, available seed expensive, or a lengthy or difficult dormancy mechanism involved. Although seed may be in abundant supply, its viability may be low--a condition that may be a regular or periodic phenomena.

Once acceptable collection sites have been identified and the propagules collected, verification of origin and the maintenance of the sampled genetics is necessary throughout all stages of production. It may even be necessary to isolate seed or cuttings by individual parent plant, depending on the restoration strategy. For this reason, the purchase of bulked lots or propagules of questionable origin may not be an acceptable option for National Park and Forest projects. Managers need to recognize the additional expense associated with site specific propagule collection and the cost of verification and maintenance of these sources.

Other factors may increase the cost of production as well. A lack of commercial incentive has resulted in less propagation research being conducted on the native woody species in comparison to ornamental selections that have been through breeding or selection programs. Project-specific wildland collections are often small and irregular in amount and viability, preventing economies of scale from being reached. These factors in combination will increase the cost of production. Procurement specifications need to reflect these needs and resources allocated accordingly. One option may be to reimburse commercial growers in two stages, one for attempting to produce a difficult-to-grow species and the second on a "per plant" basis for the actual product grown. Given some level of success, the sum of the two contracts might approximately equal the per plant cost of producing some relatively easy-to-grow species.

## CONSTRUCTION SCHEDULES

Of the aforementioned limitations, seed dormancy often presents the greatest challenge because of its impact on construction schedules. Seed may not germinate until the second or third spring after field sowing and usually requires one to three additional growing seasons prior to lifting. Adequate planning should provide enough lead time in the construction process for propagation by seed. Propagation by cuttings becomes increasingly attractive as construction schedules advance and completion deadlines approach. Although there are wide differences among species, a summer cutting is normally rooted in 6 to 10 weeks, transplanted to a container in 3 to 4 months, and ready for planting sometime the following year.

### THE BASICS OF ASEXUAL PROPAGATION BY SUMMER CUTTINGS

#### Collecting Cuttings

As noted earlier, the pool of plants that can be used as cutting sources (stock plants) will depend largely on the genetic constraints imposed by management, as well as the physiological condition of the stock plant. Given the clonal nature of this technique, attempts should be made to secure cuttings from as many different populations and individual plants as is practical. The broadest range of phenotypes possible should be secured. Genetic concerns notwithstanding, variation in the ability of populations and individual plants to produce adventitious roots warrants the use of multiple sources of germplasm. All donor plants should be relatively vigorous and free of insects and disease. One year prior to taking cuttings, potential donors should be scouted during the growing season, their location marked and recorded, and the plants revisited just prior to taking cuttings to assure the availability of an adequate quantity and quality of tissue. Avoid plants showing signs of severe environmental stress or isolated groups of few individual plants.

#### Field Equipment and Supplies

The amount of equipment required depends on the number of cuttings needed, the amount of labor available, the mode of transportation, distance to the source of the cuttings, and how the cuttings will be handled and temporarily stored. In most situations, the following supplies will be needed: large zip-lock bags, spray bottles, clean water, permanent markers, plastic labels, metal tags (for labeling stock plants should future reference be required), large white trash bags and ties, high quality pruners, heavy gloves (if handling thorny species), day pack (if transporting the cuttings on foot any distance), large cooler(s), ice or snow, and a vehicle capable of storing the sacks of cuttings out of the sun and wind.

## Harvesting Techniques

Summer cuttings are best taken in the early morning hours when turgidity is high. Use only high quality hand pruners to minimize tissue damage to the stock plant and cutting. Cuttings from rank, leggy, or excessively soft growth should be avoided. Softwood cuttings will snap and break cleanly when bent at a sharp angle when they are adequately mature. Semihardwood cuttings, because they are partially matured, are more difficult to break. Thin, weak cuttings or abnormally thick, vigorous cuttings should be avoided. Material grown in partial sun, of an average rate of growth, taken from lateral (side) branches is generally best. Cuttings should be 3 to 6 inches (7.6 to 15.2 centimeters) in length with stems up to pencil diameter ( 0.25 inch; 6.4 millimeters) in thickness. One or two nodes per cutting is optimal.

## Handling and Storage

Immediately place cuttings in zip-lock bags and then moisten with water and place in a cooler or large sack with ice. Cuttings should not be allowed to dry out, sit in standing water, heat up, or freeze. Optimal storage includes a relative humidity near 100 percent and temperatures between 34° to 37°F (1.1° to 2.8°C). If refrigeration is impossible, the cuttings should be kept wrapped in moist cloth and stored in a cool place in unsealed plastic bags. Summer cuttings are extremely perishable and transportation and storage should be minimized. Placement in greenhouse propagation beds or containers should occur within 48 hours of the time of cutting for best results. Cuttings to be shipped any distance for propagation should be sent by overnight delivery. Avoid taking and sending cuttings late in the week when there is a chance that they may be held in a post office or that no one will be available on a weekend to receive and prepare them for the greenhouse.

## Cutting Preparation

Cuttings are prepared by removing the leaves from the basal end of each stem cutting. If the cutting has large or numerous leaves, prune 25 to 50 percent of each of the remaining leaves to reduce water loss. Carefully remove all flowers and fruit from the cuttings. Basal wounding of semihardwood and hardwood cuttings, i.e., the removal of a thin layer of tissue down to the cambium along the axis of the stem for approximately 1 to 2 inches (25 to 50 mm), often improves rooting. The base of each cutting should be recut at an angle with a sharp knife prior to treatment with a growth regulator.. This is done because pruners, especially the 'anvil' type, tend to crush stem cells during the cut thus restricting water uptake prior to adventitious root formation. In addition, some degradation of the base of the cutting stem occurs during transport and storage and requires removal. Cuttings should be kept cool and moist at all times. Keep cuttings wrapped in papers towels moistened regularly with clean water. Submerge cuttings in a broad spectrum fungicide solution (as per label) prior to treatment with growth regulators.

Evidence exists that a preplanting soak of the propagation media with fungicide provides additional benefits.

### Growth Regulators

In most cases, treatment with plant growth regulators is necessary to encourage adventitious rooting. There are numerous commercial products containing one or more plant growth regulators at various concentrations. Most formulations contain auxin-type compounds or hormones including indolebutyric acid (IBA) or naphthaleneacetic acid (NAA). Both liquid and powder formulations are available. Some products also contain a fungicide to prevent infection, particularly at the base of the cutting. There is wide variation among species in their response to the various types and concentrations of rooting substances. In general, softwood cuttings require the lowest concentration of growth regulator (1,000 to 3,000 parts per million), semihardwood an intermediate concentration (3,000 to 5,000 ppm), and hardwood the highest concentration (3,000 to 10,000 ppm or more). Easily rooted cuttings may not need treatment.

### Environmental Control

Environmental control is extremely important for successful asexual propagation, especially for summer cuttings. Air temperatures should be maintained between 65° to 75°F (18° to 27°C) during the day and 60° to 65°F (16° to 18°C) at night. The relative humidity of the greenhouse should be as high as possible, without promoting disease, during the early stages of root formation. Overhead, intermittent mist operated by automatic controls is necessary to minimize transpirational losses. Bottom heating of the propagation media may further assist the rooting process. Partial shade may also be helpful in preventing cutting desiccation, although actively growing tissue will require some light for normal growth and survival.

### Rooting Media

There are numerous types of rooting media that can be used propagation beds including soil, sand, peat, vermiculite, pumice, Styrofoam, and others. All media should be sterile, and the reuse of media is not recommended. The frequent application of moisture to the media surface from the mist system requires the use of a formulation that is well-drained in order to provide adequate aeration for tissue survival and growth. If multiple species are being propagated simultaneously in a single bench, it may be necessary to use a single, multi-purpose mix. Difficult-to-root species may require a very specific combination of aeration and water holding capacity to facilitate rooting.

## SUMMARY

In review, there are certain combinations of factors that will encourage or discourage the use of one propagation method over another. Conditions that favor the use of summer cuttings include poor seed production, a lack of seed availability, poor seed viability, long or unknown seed dormancy mechanisms, short revegetation intervals, high visibility sites, small or linear disturbances, lack of dormant cuttings, poor rooting of dormant cuttings, and site or plant access limitations. Favorable propagation techniques include proper and limited storage, fungicide dip, wounding, recut base, treatment with growth regulators, intermittent mist, sterile well-drained media, bottom heat, and strict environmental control.

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# **AN ASSESSMENT OF EXOTIC PLANT SPECIES OF ROCKY MOUNTAIN NATIONAL PARK**

## **An Evaluation of the Potential Impacts of Known Exotic Plants and Summary of Management Options for Species of Concern**

Presented by  
Jeff Connor  
Rocky Mountain National Park

Prepared by  
Chris R. Rutledge  
Dr. Terry McLendon  
Department of Rangeland Ecosystem Science  
Colorado State University  
Ft. Collins, Colorado

### **INTRODUCTION**

The invasion of exotic plants is becoming a problem in many ecosystems including some areas in Rocky Mountain National Park (RMNP) (Rocky Mountain National Park Resource Management Reports #1 and #13). Some exotic species, such as leafy spurge and spotted knapweed, are capable of rapidly colonizing areas, altering community composition, and even displacing native species (Belcher and Wilson 1989, Tyser and Key 1988). In many cases, the processes of invasion are poorly documented, and little information is available on an area's past history. However, there is a large amount of information available in the literature which relates to the life history traits of exotic species and the distribution of exotic species. This information can be used to help predict the potential distribution and threat of exotic species to ecosystems.

Exotic plants can be thought of as those plants which did not originally occur in the ecosystem, and have since been introduced to the area. The National Park Service (NPS) defines an exotic species as, "those that occur in a given place as a result of direct or indirect, deliberate, or accidental actions by humans." This somewhat conservative definition of exotic species is necessary to insure that natural resources in national parks are preserved.

NPS policy generally prohibits the introduction of exotic species into natural areas of national parks. Exotic species which threaten park resources or public health are to be managed or eliminated if possible. In addition, the NPS recently signed a memorandum of understanding with 10 other federal and state agencies in the state of Colorado. This agreement states that all paid management agencies will work with private and county entities to manage exotic plants and, in

particular, “noxious weeds.” RMNP is currently working with Estes Park in exotic plant control as part of this agreement.

The process of invasion by exotic species has been naturally occurring for thousands of years. However, modern landscapes present “...unparalleled opportunities for invasive weeds as a result of modern transportation systems and the intensity of modern land-use practices” (Forcella 1992). As a result, exotic species threaten to impact other plant species and communities as they expand their ranges and invade new areas. In western Montana, for example, invasive species such as spotted knapweed have reduced plant community diversity and forage quality Forcella (1992).

The invasion of exotic plants into ecosystems is detrimental on an ecological level because it can potentially alter the balance between the native species. The term “niche” is often used to describe the range of conditions and resource qualities within which the organism or species persists (Ricklefs 1990). Systems that have evolved under natural conditions have niche overlaps which allow different species to exist together. However, the introduction of exotic species can disrupt this balance. As Bedunah (1992) pointed out, “..since the exotic (plant) did not evolve in the community, it has not had time to move toward niche and habitat differentiation there, and it may be a more direct competitor with the dominant and co-dominant plants.” There are now many examples where exotic plants have indeed altered this balance, and made significant ecological changes to plant communities. A review of the invasion process can provide some understanding about how exotic species become problems in natural areas.

The process of invasion can be thought of as an initial colonization of a system, followed by the establishment of a viable population within the system. There are several important steps to a successful plant invasion, including: seed dispersal, initial seedling establishment, and the establishment and persistence of a viable population (Figure 1). The overall ability of a plant to successfully invade an area is related to its life history traits.

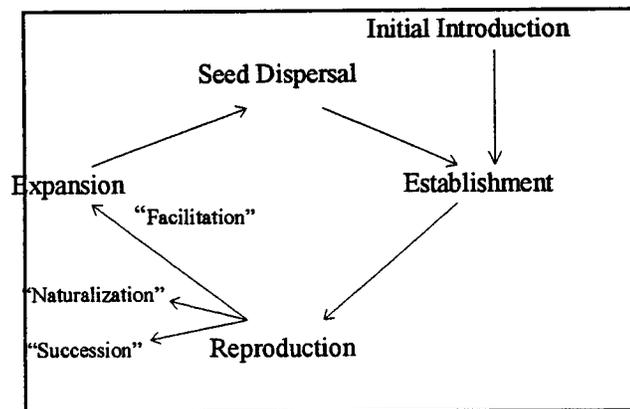


Figure 1. Diagram illustrating the key components of the “invasion cycle.” The ability of a species to invade an ecosystem is directly related to its life history traits.

Seed dispersal is one of the most important factors that influences the ability of a species to colonize new areas. For an invasion to occur, seeds must first be dispersed to a potential habitat. Seeds have an entire array of morphological and structural adaptations which allow them to be dispersed by natural processes and human activities.

Seeds may be naturally dispersed by wind, water, and animals. For example, Canada thistle and dandelion produce seeds that have a hairy structure called a pappus that allows them to

be easily dispersed by wind. Similarly, mature Russian thistle plants break off at the base, allowing the "tumbleweed" to disperse seeds. Many seeds are buoyant and can be dispersed by water. Seeds may also have specialized structures that allow them to cling to animals. Cheatgrass seeds, for example, possess barbs on the caryopses that attach to animal fur. Finally, seeds can remain viable after passing through the digestive tracts of animals. Once eaten, these seeds can be dispersed over potentially large areas by birds, cattle, horses, and other mammals. In RMNP, the use of horses has likely contributed to the spread of a number of exotics including Canada thistle (McLendon 1992).

Humans activities are another important vector for seed dispersal. For example, cultivation has promoted the spread of exotics. A number of exotic plants were intentionally introduced into RMNP area for use as cultivars or as ornamentals before the area became a National Park. More recently, exotic plants have been introduced as part of erosion control programs, or accidentally by park visitors. For example, spotted knapweed was found in one of the RMNP campgrounds and was likely brought in by park visitors. Exotic plants continue to be unintentionally introduced and dispersed in RMNP by clinging to clothing and mud on hiking boots, and by attaching to motor vehicles.

Once seeds reach a new potential habitat, climatic and abiotic factors may affect the establishment of seedlings. For seedlings to successfully become established, the temperature and precipitation regimes of the area must fall within the tolerance ranges of that species. However, many invasive species may be "pre-adapted" to the climatic and abiotic conditions of the new potential habitats (Newsome and Noble 1986). These species may have evolved under similar climatic conditions, or may have broad tolerance ranges that allow them to occupy a variety of habitat types.

The establishment of a single plant in an ecosystem generally does not constitute a successful invasion. Instead, an invasive species must establish a self-sustaining population. Bazaaz (1984) points out that colonizing species are more likely to become established with a large number of repeated introductions of a large number of seeds. The establishment of invasive species is rare with single introductions of a small number of seeds. Thus, species that are capable of producing and distributing a large number of seeds have a higher probability of a successful invasion. Species which have a high number of propagules in close proximity to natural areas such as RMNP also have a high invasion potential.

Species that are good competitors for soil moisture and nutrients have a higher chance of establishment and persistence in ecosystems. Characteristics of good competitors include plants that hold their leaves higher than other plants (in light limited environments), or push roots deeper into the soil (in water limited environments). Good competitors often possess rapid early growth, leading to a rapid development of the root system. The development of a root system early in the spring may allow the plant to access available resources that are unavailable to dormant species. Through the acquisition of these available resources, the exotic plant may then become established in the ecosystem.

Once an exotic plant population becomes established, there are three potential outcomes to a plant invasion: naturalization, facilitation, and species replacement through succession. Naturalization refers to a species that is more or less in equilibrium with the other plants in the community. If a species invades an ecosystem and does not expand its range within that ecosystem, it might be considered "naturalized." However, naturalization may only be a short term phenomenon.

Facilitation can occur when a disturbance alters the community. Following the disturbance, the exotic species may then begin to invade larger areas. In a sense, the subsequent invasions were "facilitated" by the disturbance. An exotic species can be facilitated to spread by the introduction of a suitable seed dispersal agent or pollinator, or the provision of disturbance

(Cronk and Fuller 1995). Facilitation helps to complete the invasion cycle by allowing the species to disperse seeds and establish plants in new areas. In the absence of any natural controls, such as pathogens or herbivores, these invasive species may continue to expand their range (Bedunah 1992).

Finally, the process of succession can affect the invasion cycle by altering the availability of resources over time. The change in species composition from a simple plant community composed of a few colonizing species to more complex plant communities over time is called succession. Succession is driven by stressors or disturbance, which can affect the availability of resources available to plants. These changes in resource availability influence which plants are able to persist in the ecosystem and may provide an initial opportunity for invasion. Over time, plants that are best adapted to the biotic and abiotic conditions replace the plants that are not well adapted to the conditions.

There are two general types of succession: primary and secondary succession. Primary succession occurs when plants gradually become established in areas not previously vegetated because of the lack of soil development. Examples of primary succession include plants which colonize a gradually filling bog or parent material such as granite (Barbour et al. 1987). In contrast, secondary succession occurs in areas that were previously vegetated, but have had the pre-existing vegetation destroyed. In the case of secondary succession, much of the soil and plant propagules (such as seeds and rhizomes) remain intact (Barbour et al. 1987). Disturbances such as fire, logging, or cultivation can initiate secondary succession.

Secondary succession is tightly linked to the availability of resources and the life history characteristics of the plants. For example, recent research in the Piceance Basin of western Colorado indicates that nitrogen availability in the soil is the key factor driving secondary succession (McLendon and Redente 1992). A commonly observed pattern of plant succession begins with the domination of annual species followed by perennial grasses or shrubs, followed by perennial grasses, and finally either shrubs or trees. The final dominant community of shrubs or trees is sometimes referred to as a climax community.

Changes in nitrogen availability over time will affect the species composition for that ecosystem. Immediately following a disturbance, nitrogen is often highly available. These conditions favor plants which readily exploit the available nitrogen, such as annual plants (sometimes called early seral species). The annual life history involves a relatively rapid rate of growth that requires high levels of nitrogen. Annual plants, such as Russian thistle, generally dominate a disturbed area as long as there is a surplus of available nitrogen.

Over time, the nitrogen from the soil becomes tied up in plant tissue and litter. In addition, the decomposition of litter (which contains organic nitrogen and carbon) is relatively slow during early succession. As a result, the amount of plant available nitrogen decreases over time. These conditions favor slower growing plants with lower nitrogen demands such as perennial forbs and perennial grasses (mid-seral species). During the middle stages of succession, perennial forbs and grasses gradually replace the annual plants. The mid-seral species tend to have slower growth rates, which reduces the amount of litter inputs. Fortunately, the rate of decomposition of litter increases during the mid-succession stages.

In spite of their slow growth rates, shrubs and trees increase in importance during late succession stages. Late seral species are able to tolerate low resource availability because they are good accumulators and competitors for resources. By efficiently exploiting limited resources, or by storing resources (and denying other plants access to resources), late seral species are able to survive in low resource conditions.

Relatively few exotic plants introduced to RMNP can be considered late seral species. However, species which possess traits similar to mid- or late succession species are generally much more persistent. For example, some perennial grasses such as smooth brome store a large amount

of resources in below ground tissues. These large food reserves make this plant very difficult to control because these reserves must be depleted before the plant becomes stressed. Many of these species are also capable of slowing down natural succession processes because of their ability to access the limited resources in the ecosystem. Plants which have high reproductive output along with mid to late succession characteristics are among the most threatening and difficult to control.

The invasion potential of an exotic species can be partially predicted by examining its life history characteristics, geographic distribution, and ecological distribution. Table 1 summarizes some of the life history characteristics that are closely related to the overall invasion potential and persistence of plants in ecosystems. The list presents a general "wish list" for the ideal weed adapted from some of the early work on colonizing species (Baker 1965). Fortunately, no single species possesses all these characteristics. However, plants that possess a number of these traits are often "pre-disposed" to being good invaders. In addition to life history characteristics, information on the ecological and geographical range of the species can also be used to help predict the potential distribution of a species in a given area. Species which are found in a wide range of habitat types will likely have a much wider potential range than those species restricted to a small geographic range or few habitats.

Table 1. Characteristics of the "Ideal Weed" (adapted from Baker 1965).

1. Has no special requirements for germination.
2. Has discontinuous germination (self-controlled) and great longevity of seed.
3. Shows rapid seedling growth.
4. Spends short time in vegetative condition before beginning to flower.
5. Maintains continuous seed production for as long as growing conditions permit.
6. Is self-compatible, but not obligatory self-pollinated.
7. When cross pollinated, can be achieved by non-specialized flower visitor or bywind.
8. Has very high seed output in favorable environmental conditions.
9. Can produce seed in a wide variety of environmental circumstances. High tolerance of (and often plasticity in face of) climatic and edaphic variation.
10. Has special adaptations to both long and short distance dispersal.
11. If perennial, has vigorous vegetative reproduction.
12. If perennial, shows ability to regenerate from severed rootstocks.
13. Has ability to compete by special means (rosette formation, choking growth, etc.)

Information on the life history and distribution of exotic species is certainly useful in a management context. For example, species that have wide distributions in their native systems and have traits that are characteristic of invasive species (such as adaptations for long distance dispersal, and the ability to compete for resources) should be closely monitored. Other species that have restricted ranges, specialized pollinator relationships, or limited seed dispersal potential may pose less of an immediate threat.

## APPROACH

National Park Service policy requires that all exotic species which pose a threat to natural areas or human health be managed. In agreement with park policy, this project was designed to examine the current and potential ecological impacts of known exotic plant species in RMNP. There were three general goals for this project. The first goal was to estimate the potential effects of non-native plant species on native plant communities in RMNP. Second, the known exotic plants were ranked based on their potential impacts on native plant species and communities. Finally, a management approach for corrective action was developed to help control exotic species in RMNP. A ranking system was modified from the *Handbook for Ranking Exotic Plants for Management and Control* (Hiebert and Stubbendieck 1993) to help accomplish these goals.

The *Handbook for Ranking Exotic Plants for Management and Control* was developed to provide land managers with a tool to effectively evaluate the potential impacts of known exotic plant species. The advantage to using this approach is that managers can objectively evaluate different management strategies based on information obtained from literature and field surveys. This approach encourages managers to consider the full range of the potential impacts for their management decisions (Hiebert and Stubbendieck 1993). The benefits of managing specific exotic plants can be weighed against the potential costs of different management actions. The ranking system provides a sound justification for management plans, and can also provide justification for future program authorization and funding (Hiebert and Stubbendieck 1993).

The ranking system uses numerical ratings in an outline format to evaluate the current and potential ecological impacts and distributions of species in the areas of concern. The ranking system also evaluates different control options for a given species. Information for the ranking system can be obtained from both literature reviews and field surveys. Once a list of known exotic plant species has been obtained for a given area, each individual species can then be ranked relative to the other species. Species which pose an immediate threat to natural areas can then be targeted for control efforts, while species which have small potential impacts are given a lower priority for management.

The *Handbook for Ranking Exotic Plants for Management and Control* incorporates information obtained from a literature review and field surveys. As a result, its usefulness is somewhat restricted to species that have currently been studied in the field. However, for many species extensive surveys would be costly and unnecessary because of their low potential ecological impacts. This posed a particular problem for RMNP because field survey information was unavailable for many of the known exotic plants. Because of limited resources and time, collection of additional field survey information for all species was an unrealistic option.

To provide RMNP with useful information without additional field surveys, the *Handbook for Ranking Exotic Plants for Management and Control* was modified so that information from a literature review could be used to estimate the potential ecological impacts of all known exotic plants. The Ranking System for RMNP (Appendix II) is divided into two general areas: an initial Screening Assessment section and a Final Assessment section. Information for the initial screening assessment can be obtained from literature reviews. If the species is identified as being a potential problem, then additional information and field surveys are conducted to provide a final assessment. Additional information on control methods and management considerations are also obtained for species which are identified as potential problems.

Figure 2 provides an overview of the ranking process. Initially, a list of known exotic plants is developed for an area. Once this list is complete, a general literature review is conducted for all species. After information has been collected for all species, an initial ranking is then performed using the Screening Assessment section. The screening assessment stage is designed to merely screen out those species which are not considered a potential ecological problem. For

example, species which have an overall low potential ecological impact and low potential ecological distribution are unlikely to become a threat to natural areas.

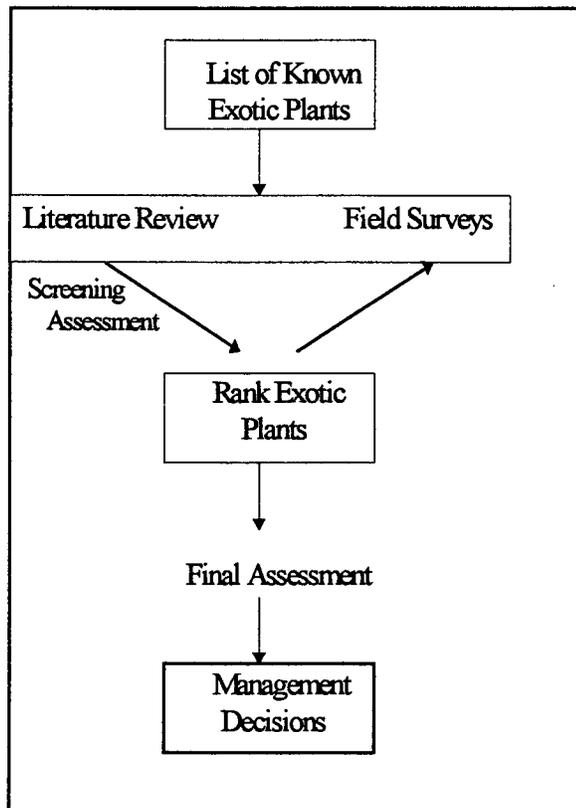


Figure 2. This figure provides a general outline of the ranking process. The initial screening assessment uses information from a literature review to rank all known exotic plants. Additional field surveys and literature reviews are then conducted for species which are identified as potential ecological threats.

Species which have a low potential impact and low ecological distribution can be screened out at this point. Species which pose a threat to native communities and/or have a high potential distribution are left on the list of species of concern. Additional information from literature and field surveys can then be collected for the remaining species of concern. This final assessment stage is designed to review information on different control options and on the overall feasibility of controlling the species of concern. Once the final assessment stage is completed, a management strategy can be developed for all species of concern.

The following example, using four exotic species found in RMNP, illustrates the ranking process. Canada thistle, dandelion, diffuse knapweed, and Russian thistle are four exotic species that are found in RMNP. A literature review was conducted for these species to determine their potential ecological impacts. The results of an initial literature review and screening assessment are illustrated in Figure 3. All four species were found to have a high overall potential distribution. However, dandelion and Russian thistle have relatively low potential ecological impacts. In contrast, both Canada thistle and diffuse knapweed have a high potential ecological impact. A

final assessment is necessary to evaluate management options for Canada thistle and diffuse knapweed.

		POTENTIAL ECOLOGICAL IMPACT	
		Minor	Serious
POTENTIAL DISTRIBUTION	Large	Dandelion * Russian thistle *	Diffuse knapweed * * Canada thistle
	Small		

Species	Common Name	Potential Distribution (15 total)	Potential Impact (40 total)
<i>Centaurea diffusa</i>	Diffuse knapweed	13	33
<i>Cirsium arvense</i>	Canada thistle	11	31
<i>Taraxacum officinale</i>	Dandelion	13	21
<i>Salsola iberica</i>	Russian thistle	11	19

Figure 3. Results of the Screening Assessment for Canada thistle, dandelion, diffuse knapweed, and Russian thistle.

The results for the final assessment for Canada thistle and diffuse knapweed are presented in Figure 4. Canada thistle currently has a high overall distribution and is a difficult weed to control. As a result, attempts to eradicate Canada thistle in RMNP may be very difficult. Diffuse knapweed is also a very difficult weed to control. However, diffuse knapweed currently has a much smaller distribution in RMNP. Diffuse knapweed has a much higher likelihood of being effectively controlled. As a result, efforts to control diffuse knapweed while populations are small should be given priority over attempts to control Canada thistle.

		POTENTIAL ECOLOGICAL IMPACT				
		Minor		Serious		
		Ease of Control				
POTENTIAL DISTRIBUTION		Large		Small		
		Easy	Difficult	Easy	Difficult	
POTENTIAL DISTRIBUTION	Large	Farrow	* Russian thistle	II.		I.
		Wide				Diffuse knapweed *
	Small	Wide		* Dandelion		Canada * thistle
		Farrow			IV.	

Figure 4. Results of the Final Assessment for Canada thistle, dandelion, diffuse knapweed, and Russian thistle. As these results illustrate, management efforts should focus on controlling diffuse knapweed because it currently is not widely distributed in RMNP.

## METHODS

### Objective 1: Identify Exotic Species

A list of known exotic species was initially prepared by park personnel. This list was compiled using the Romoflora database, herbaria records, the Catalogue of the Vascular Plants of Rocky Mountain National Park (Weber 1988), park research reports (Rocky Mountain National Park Resource Management Reports #1 and #13), and field surveys by the Denver Botanical Gardens (Yeatts, 1987, 1988, 1990, 1991). Species considered to be non-native to North America, native to North America but introduced into RMNP, or native to North America but not known to be native to RMNP, were all included on the list. Adventive (occasional occurrence, though not thoroughly naturalized), naturalized (well adapted and growing in region where plant is not native), cosmopolitan (having nearly worldwide distribution), cultivated (grown as a crop or ornamental), and escaped (formerly cultivated) species were considered to be exotic (Stubbendieck 1994). In addition, attempts were made to include exotic species that currently are not present in RMNP, but can be found near park borders.

### Objective 2: Rank Exotic Plant Species of RMNP

One of the objectives for this project was to assess the potential ecological impacts for the known exotic plant species of RMNP. To accomplish this objective, all species on the list of known exotic plants for RMNP were evaluated. A literature review was conducted to collect information on the basic life history traits for each species. The literature review primarily focused on obtaining information necessary for the Screening Assessment portion of the Ranking System

(Appendix II). General reference sources along with specific journal articles were used to construct a database for all exotic species. Appendix III contains a list of general references that were particularly useful sources of information. In some cases, little information was available on the life history characteristics. In these cases, information on species of the same genera or family was collected.

Once information was obtained from the literature review, the species were ranked according to the Screening Assessment portion of the Ranking System for RMNP (Appendix II). Species were assigned scores for each category of the Screening Assessment. Attempts were made to use conservative estimates for the scores assigned to each category, especially for areas where information was limited.

All species then received a total score for potential distribution and potential ecological impact. An important note is that all rankings for potential distribution and potential ecological impact are relative scores. The scores only represent the potential distribution and potential ecological impacts of each species relative to other species using life history information. These scores should only be used to make comparisons between species, and have little meaning outside of this context.

The scores for all species were compared to assess their overall potential ecological impact. Species that received a total potential ecological impact score equal to or greater than 24 (60 % of the total points possible) were identified as 'species of concern'. Species which received scores below 24 were believed to have a relatively low overall potential ecological impact, and no additional information was collected for these species. However, information from the initial literature review for species not believed to be potential problems is included Literature Review for Remaining Exotic Species section.

Additional information from a more thorough literature review was then collected for all species of concern. The second literature review concentrated on obtaining additional information on life history characteristics as well as management options for each species of concern. The species were then ranked again, using the Final Assessment section of the Ranking System for RMNP (Appendix II). Species that currently have a limited distribution in RMNP, but have a high potential distribution and a high potential ecological impact were identified as a 'high' priority for management. Species with large current distributions, or species that are relatively easy to control were identified as 'medium' priority for management.

## RESULTS

### Objective 1: Identify Exotic Species

A list of known exotic species was compiled for Rocky Mountain National Park. A complete list, along with synonyms and common names, can be found in Appendix I. Nomenclature follows McGregor et al. (1991).

### Objective 2: Rank Exotic Plant Species of RMNP

All known exotic plants of RMNP were evaluated to assess their potential ecological impact. The results for the initial Screening Assessment are displayed in Table 2. Table 2 contains information on the species origin, current distribution, potential distribution, and potential ecological impact. Species were given a score of 1-3 for origin (1=not native to North America, 2=native to North America, but not native to RMNP, 3=native to North America, not known to be native to RMNP). Scores from 1-4 were given to species based on the current known distributions

(1=few, scattered populations; 2=intermediate number of patchy distributed populations; 3=several widespread, dense populations).

In addition, species were ranked according to their potential distribution and potential ecological impact using the Screening Assessment section of the Ranking System for RMNP. Potential distribution (out of a total of 15) and potential ecological impact (out of a total of 40) was assigned to each species. Species which had a total potential ecological impact greater than 24 were identified as species of concern (marked with "\*" in Table 2).

The results of the Final Assessment for species of concern are illustrated in Table 3. Table 3 contains additional information on the current level of ecological impact for each species (out of a total of 50), and the relative ease of control (out a total of 100). Species were also assigned 'urgency scores' ranging from 'high' (delay in action will result in significant effort required for control) to 'medium' (delay in action will result in moderate increase in effort required for control) to 'low' (delay in action will result in little increase in effort required for successful control).

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Table 2. Summary of Screening Assessment

Species Name	Origin	Current Distribution	Potential Distribution	Potential Impact
	(1=non-native N. America) (2=ative N. America, non-native to RMNP) (3=not known native RMNP)	(1=few, scattered) (2= <i>intermed., patchy</i> ) (3=many, dense)	(15 possible)	(40 possible)
<i>Agropyron cristatum</i>	1	3	6	19
<i>Agropyron intermedium</i>	1	3	6	23
<i>Agropyron repens</i>	1	2	6	33 *
<i>Agrostis stolonifera</i>	1	3	8	22
<i>Alopecurus pratensis</i>	1	2	6	19
<i>Alyssum alyssoides</i>	1	--	6	16
<i>Amaranthus retroflexus</i>	1, 2	--	9	19
<i>Ambrosia tomentosa</i>	3	2	6	21
<i>Amsinckia menziesii</i>	3	--	6	14
<i>Arabis glabra</i>	3	2	6	17
<i>Asparagus officinalis</i>	1	2	4	14
<i>Barbarea vulgaris</i>	1	1	6	18
<i>Berteroa incana</i>	1	1	9	20
<i>Bromus inermis</i>	1	3	6	33 *
<i>Bromus japonicus</i>	1	--	9	17
<i>Bromus tectorum</i>	1	3	13	25 *
<i>Camelina microcarpa</i>	1	--	6	16
<i>Capsella bursa-pastoris</i>	1	2	9	17
<i>Carduus nutans</i>	1	3	9	26 *
<i>Carum carvi</i>	1	--	9	17
<i>Centaurea diffusa</i>	1	2	11	33 *
<i>Centaurea maculosa</i>	1	2	11	26 *
<i>Cerastium vulgatum</i>	1	--	11	18
<i>Chenopodium album</i>	1	2	9	19
<i>Chenopodium capitatum</i>	3	--	9	16
<i>Chenopodium glaucum</i>	1	--	9	19
<i>Cirsium arvense</i>	1	3	11	31 *
<i>Cirsium vulgare</i>	1	3	11	26 *
<i>Conium maculatum</i>	1	3	9	17
<i>Convolvulus arvensis</i>	1	2	6	26 *
<i>Conyza canadensis</i>	3	--	9	20
<i>Conyza schiedeana</i>	3	--	6	14
<i>Chrysanthemum leucanthemem</i>	1	3	9	29 *
<i>Cynoglossum officinale</i>	1	2	11	20
<i>Dactylis glomerata</i>	1	3	6	29 *
<i>Descurainia sophia</i>	1	3	9	18

Species Name	Origin	Current Distribution	Potential Distribution	Potential Impact
<i>Draba nemorosa</i>	3	--	6	14
<i>Dianthus armeria</i>	1	--	9	20
<i>Erodium cicutarium</i>	1	--	6	17
<i>Erysimum cheiranthoides</i>	1, 2	--	6	16
<i>Euphorbia esula</i>	1	3	11	38 *
<i>Euphorbia serpyllifolia</i>	3	--	6	19
<i>Festuca ovina</i>	1	3	9	21
<i>Festuca pratensis</i>	1	2	6	21
<i>Gypsophila paniculata</i>	1	--	9	26 *
<i>Hieracium aurantiacum</i>	1	2	6	20
<i>Hypericum perforatum</i>	1	1	13	38 *
<i>Iva xanthifolia</i>	3	--	6	14
<i>Lactuca serriola</i>	1	2	6	16
<i>Lappula redowskii</i>	3	--	9	19
<i>Linaria dalmatica</i>	1	3	9	31 *
<i>Linaria vulgaris</i>	1	3	11	27 *
<i>Lepidium campestre</i>	1	3	6	14
<i>Lepidium densiflorum</i>	1, 2	--	9	17
<i>Lepidium perfoliatum</i>	1	--	6	17
<i>Lolium perenne</i>	1	2	6	20
<i>Lychnis alba</i>	1	--	11	22
<i>Lythrum salicaria</i>	1	1	11	31 *
<i>Madia glomerata</i>	3	--	6	16
<i>Matricaria matricaroides</i>	3	3	9	19
<i>Matricaria perforata</i>	1, 2	--	9	17
<i>Medicago lupulina</i>	1	--	9	20
<i>Melilotus alba</i>	1	3	9	24 *
<i>Melilotus officinalis</i>	1	3	9	24 *
<i>Mentha spicata</i>	1	--	6	9
<i>Onobrychis viciaefolia</i>	1	--	7	15
<i>Phalaris arundinacea</i>	2	--	9	36 *
<i>Phleum pratense</i>	1	3	8	15
<i>Plantago major</i>	1, 2	2	9	22
<i>Poa annua</i>	1, 2	--	11	17
<i>Poa bulbosa</i>	1	2	6	15
<i>Poa compressa</i>	1	3	6	15
<i>Poa pratensis</i>	1, 2	3	11	27 *
<i>Polygonum arenastrum</i>	3	--	6	17
<i>Polygonum convolvulus</i>	1	--	6	22
<i>Potentilla norvegica</i>	1	2	6	16
<i>Psathyrostachys juncea</i>	1	--	6	18

Species Name	Origin	Current Distribution	Potential Distribution	Potential Impact
<i>Rheum rhabarbarum</i>	1	2	4	10
<i>Rumex acetosella</i>	1	--	9	22
<i>Rumex crispus</i>	1	3	9	23
<i>Salsola collina</i>	3	--	9	16
<i>Salsola iberica</i>	1	2	11	19
<i>Sisymbrium altissimum</i>	1	--	11	17
<i>Sisymbrium officinale</i>	1	--	6	16
<i>Solanum triflorum</i>	3	--	6	15
<i>Sonchus arvensis</i>	1	3	9	27 *
<i>Spergularia rubra</i>	1	--	6	13
<i>Taraxacum officinale</i>	1, 2	3	13	21
<i>Thlapsi arvense</i>	1	--	9	17
<i>Tragopogon dubius</i>	1	2	6	12
<i>Trifolium hybridum</i>	1	3	6	15
<i>Trifolium pratense</i>	1	3	6	15
<i>Trifolium repens</i>	1, 2	3	6	21
<i>Triticum aestivum</i>	1	2	6	13
<i>Triticum sp.</i>	1	2	0	0
<i>Verbascum thapsus.</i>	1	3	9	14
<i>Verbena bracteata</i>	3	--	6	11
<i>Verbesina encelioides</i>	3	--	6	12

\* Species of concern

Note: Species given two scores for Origin category are identified as non-native and native species of North America by different sources.

Table 3. Summary of Final Assessment for Exotic Plant Species of Concern

Species Name	Potential Distribution (Total=15)	Potential Impact (Total=40)	Current Impact (Total=50)	Ease of Control (Total=100) (0=Difficult)	Urgency
<i>Agropyron repens</i>	6	33	4	40	Med
<i>Bromus inermis</i>	6	33	25	18	Med/High
<i>Bromus tectorum</i>	13	25	17	24	Med
<i>Carduus nutans</i>	11	26	29	25	Med
<i>Centaurea diffusa</i>	11	33	22	26	High
<i>Centaurea maculosa</i>	11	26	22	31	High
<i>Cirsium arvense</i>	11	31	30	8	Med
<i>Cirsium vulgare</i>	11	26	25	34	Med
<i>Chrysanthemum leucanthemem</i>	9	29	8	33	Med
<i>Convolvulus arvensis</i>	6	26	6	22	Med
<i>Dactylis glomerata</i>	6	29	12	34	Med
<i>Euphorbia esula</i>	11	38	42	20	High
<i>Gypsophila paniculata.</i>	9	26	--	40	Med
<i>Hypericum perforatum</i>	13	38	-9	21	Med
<i>Linaria dalmatica</i>	9	31	37	27	Med
<i>Linaria vulgaris</i>	11	27	40	19	High
<i>Lythrum salicaria</i>	11	31	*	31	Med
<i>Melilotus alba</i>	9	24	9	30	Med
<i>Melilotus officinalis</i>					
<i>Phalaris arundinacea</i>	9	24	--	21	Med
<i>Poa pratensis</i>	11	27	23	26	
<i>Sonchus uliginosus</i>	9	27	--	31	

\* Currently not found in RMNP, but is found in areas adjacent to RMNP.

## Appendix I

### ROCKY MOUNTAIN NATIONAL PARK EXOTIC SPECIES LIST

Species Name	Synonym	Common name
<b>Amaranthaceae</b>		
<i>Amaranthus retroflexus</i> L.		Redroot pigweed
<b>Apiaceae</b>		
<i>Carum carvi</i> L.		Wild caraway
<i>Conium maculatum</i> L.		Poison hemlock
<b>Asparagaceae</b>		
<i>Asparagus officinalis</i> L.		Asparagus
<b>Asteraceae</b>		
<i>Ambrosia tomentosa</i> Nutt.	<i>Franseria discolor</i>	Skeletonleaf bursage
<i>Carduus nutans</i> L.		Musk thistle
<i>Centaurea diffusa</i> Lam.	<i>Acosta diffusa</i>	Tumbleknappweed
<i>Centaurea maculosa</i> Lam.	<i>Centaurea biebersteinii</i>	Spottedknappweed
<i>Chrysanthemum leucanthemem</i> L.	<i>Leucanthemum vulgare</i>	Ox-eye daisy
<i>Cirsium arvense</i> (L.) Scop	<i>Cirsium incanum</i>	Canada thistle
<i>Cirsium vulgare</i> (Savi) Ten	<i>Cirsium lanceolatum</i>	Bull thistle
<i>Conyza canadensis</i> (L.) Cronq.	<i>Erigeron canadensis</i>	Horseweed
<i>Conyza schiedeana</i> (Less.)	<i>Laehnnecia schiedeana</i>	
<i>Hieracium aurantiacum</i> L.		Orange hawkweed
<i>Iva xanthifolia</i> Nutt.	<i>Cyclachaena xanthifolia</i>	Marsh elder
<i>Lactuca serriola</i> L.	<i>Lactuca scariola</i>	Prickly lettuce
<i>Madia glomerata</i> Hook.		Tarweed
<i>Matricaria matricarioides</i> (Less.) Porter	<i>Chamomilla suaveolens</i>	Pineapple weed
<i>Matricaria perforata</i> Merat.	<i>Matricaria inodora</i>	
<i>Sonchus arvensis</i> ssp. <i>uliginosus</i> L.		Marsh sowthistle
<i>Taraxacum officinale</i> Weber		Common dandelion
<i>Tragopogon dubius</i> Scop.		Western salsify
<i>Verbesina encelioides</i>	<i>Ximenesia encelioides</i>	Crownbeard
<b>Boraginaceae</b>		
<i>Amsinckia menziesii</i> (Lenhmann)		Fiddleneck
<i>Cynoglossum officinale</i> L.		Hound's tongue
<i>Lappula redowskii</i> (Hornem. ) Greene		Beggar's tick
<b>Brassicaceae - Cruciferae</b>		
<i>Alyssum alyssoides</i> (L.) L.		Pale alyssum
<i>Arabis glabra</i> (L.) Bernh	<i>Turritis glabra</i>	Tower mustard
<i>Barbarea vulgaris</i> R. Br.		Winter cress
<i>Berteroa incana</i> (L.) DC.	<i>Alyssum incanum</i>	Hoary alyssum
<i>Camelina microcarpa</i> Andr. ex DC.		Smallseed false flax

**Brassicaceae - Cruciferae (cont.)**

<i>Capsella bursa-pastoris</i> (L.) Medic.		Shepherds purse
<i>Descurainia sophia</i> (L.) Webb ex Prantl.		Tansy mustard
<i>Draba nemorosa</i> L.		Yellow whitlowort
<i>Erysimum cheiranthoides</i> L.		Wormseed mustard
<i>Lepidium campestre</i> (L.) R. Br.	<i>Neolepia campestre</i>	Field peppergrass
<i>Lepidium densiflorum</i> Schrad.		Peppergrass
<i>Lepidium perfoliatum</i> L.		Clasping peppergrass
<i>Sisymbrium altissimum</i> L.		Jim Hill mustard
<i>Sisymbrium officinale</i> (L.) Scop.		Hedge mustard
<i>Thlapsi arvense</i> L.		Field pennycress

**Caryophyllaceae**

<i>Cerastium vulgatum</i> L.	<i>Cerastrium fontanum</i>	Mouseear chickweed
<i>Dianthus armeria</i> L.		Deptford pink
<i>Gypsophila paniculata</i> L.		Baby's breath
<i>Lychnis alba</i> Mill.	<i>Melandrium dioicum</i>	White cockle
<i>Spergularia rubra</i> (L.)		

**Chenopodiaceae**

<i>Chenopodium album</i> L.		Lamb's quarters
<i>Chenopodium berlandieri</i> Moq.		Netseed lambsquarters
<i>Chenopodium capittaum</i> (L.) Asch.		Strawberry blite
<i>Chenopodium glaucum</i> L.		Oak-leaved goosefoot
<i>Salsola collina</i> Pall.		Tumbleweed
<i>Salsola iberica</i> Senn. and Pau	<i>Salsola kali</i> , <i>Salsola australis</i>	Russian thistle

**Convolvulaceae**

<i>Convolvulus arvensis</i> L.	<i>Convolvulus ambigens</i>	Field bindweed
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**Euphorbiaceae.**

<i>Euphorbia esula</i> L.		Leafy spurge
<i>Euphorbia serpyllifolia</i> Pers.	<i>Chamaesyce serpyllifolia</i> Pers.	Thyme leafed spurge

**Fabaceae - Leguminosae**

<i>Medicago lupulina</i> L.		Black medic
<i>Melilotus alba</i> Medic.		White sweet clover
<i>Melilotus officinalis</i> (L.) Pall.		Yellow sweetclover
<i>Onobrychis viciaefolia</i> Scop.		Sainfoin
<i>Trifolium hybridum</i> L.		Alsike clover
<i>Trifolium pratense</i> L.		Red clover
<i>Trifolium repens</i> L.		White clover

**Hypericaceae**

<i>Hypericum perforatum</i> L.		Klamath weed, St. John's wort
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**Lamiaceae**

<i>Mentha spicata</i> L.		Spearmint
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**Lythraceae**

<i>Lythrum salicaria</i> L.		Purple loostrife
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**Plantaginaceae***Plantago major* L.

Broadleaf plantain

**Poaceae - Gramineae***Agropyron cristatum* (L.) Gaertn.*Agropyron intermedium* (Host) Beauv.*Agropyron repens* L. Beauv.*Agrostis stolonifera* L.*Alopecurus pratensis* L.*Bromus inermis* Leyss.*Bromus japonicus* Thunb. ex Murr*Bromus tectorum* L.*Dactylis glomerata* L.*Elymus cinereus* Scribn. & Merr.*Festuca ovina* L.*Festuca pratensis* Huds.*Lolium perenne* L.*Phalaris arundinacea* L.*Phleum pratense* L.*Poa annua* L.*Poa bulbosa* L.*Poa compressa* L.*Poa pratensis* L.*Psathyrostachys juncea* Fisch. Nevski*Triticum aestivum* L.*Triticum* sp.*Elytrigia intermedia**Elytrigia repens**Agrostis gigantea**Bromopsis inermis**Anisantha tectorum**Leymus cinereus**Lolium multiflorum**Phalaroides arundinacea**Elymus junceus*

Crested wheat grass

Intermediate wheatgrass

Quackgrass

Redtop

Meadow foxtail

Smooth brome

Japanese brome

Cheatgrass

Orchard grass

Great Basin wildrye

Sheep's fescue

Meadow fescue

Perennial rye grass

Reed canary grass

Timothy

Bulbous bluegrass

Canada bluegrass

Kentucky bluegrass

Russian wild rye

Wheat

Sterile wheatgrass

**Polygonaceae***Polygonum arenastrum* Jord. ex Bor.*Polygonum convolvulus* L.*Rheum rhubarbarum* L.*Rumex acetosella* L.*Rumex crispus* L.*Polygonum aviculare**Fallopia convolvulus**Acetosella vulgaris*

Devil's shoestrings

Black bindweed

Rhubarb

Sheep sorrell

Curly dock

**Rosaceae***Potentilla norvegica* L.

Norway cinquefoil

**Scrophulariaceae***Linaria dalmatica* (L.) Mill*Linaria vulgaris* Hill*Verbascum thapsus* L.*Linaria genistifolia* (L.) ssp. *dalmatica*

Dalmatian toadflax

Butter and eggs

Woolly mullein

**Solanaceae***Solanum triflorum* Nutt.

Cut leaved nightshade

**Verbenaceae***Verbena bracteata* Laq. and Rodr.

Prostrate vervain

## Appendix II Ranking System for Rocky Mountain National Park

### Section I Screening Assessment

#### Potential Distribution in Rocky Mountain National Park

1. Ability to complete reproductive cycle in various communities of RMNP
  - a. not expected to complete reproductive cycle in any communities 0
  - b. capable of completing reproductive cycle in a small range of communities 1
  - c. capable of completing reproductive cycle in a moderate range of communities 3
  - d. capable of completing reproductive cycle in a wide range of communities 5
2. Germination requirements
  - a. requires open soil and disturbance to germinate 0
  - b. can germinate in vegetated areas but in a narrow range or special conditions 3
  - c. can germinate in existing vegetation under a wide range of conditions 5
3. Dispersal ability
  - a. little potential for long distance dispersal 0
  - b. medium potential for long distance dispersal 3
  - c. great potential for long distance dispersal 5

*Total possible = 15*

#### Potential Impact on Communities of Concern

1. Ability to complete reproductive cycle in area of concern
  - a. low potential to complete reproductive cycle in area of concern based on literature 0
  - b. medium potential to complete reproductive cycle in area of concern based on literature 3
  - c. high potential to complete life cycle in area of concern based on literature 5
2. Mode of reproduction
  - a. reproduces almost entirely by vegetative means 1
  - b. reproduces only by seeds 3
  - c. reproduces vegetatively and by seeds 5
3. Vegetative reproduction
  - a. no vegetative reproduction 0
  - b. vegetative reproduction rate maintains population 1
  - c. vegetative reproduction results in a moderate rate of increase in population size 3
  - d. vegetative reproduction results in a rapid rate of increase in population size 5
4. Frequency of sexual reproduction for mature plant
  - a. almost never reproduces sexually in area 0
  - b. once every five or more years 1
  - c. every other year 3
  - d. one or more times a year 5
5. Number of seeds per plant
  - a. few (0-10) 1
  - b. moderate (11-1,000) 3
  - c. many seeded (>1,000) 5
6. Competitive ability
  - a. poor competitor for limiting factors 0
  - b. moderately competitive for limiting factors 3
  - c. highly competitive for limiting factors 5
7. Known level of impact in natural areas
  - a. not known to cause impacts in any other natural area 0
  - b. known to cause impacts in natural areas, but in other habitats and different climatic zones 1
  - c. known to cause low impact in natural areas in similar habitats and climate zones 3
  - d. known to cause moderate impacts in natural areas in similar habitats and climate zones 5
  - e. known to cause high impacts in natural areas in similar habitats and climate zones 10

*Total possible = 40 \**

\* Final Assessment is required for all species which receive a score equal to, or greater than 24 for this section.

## Section II Final Assessment

### Feasibility of Control

*(Information for this section obtained from literature review)*

#### Ease of Control

##### A. Ease of Control

1. Seed banks
  - a. seeds remain viable in the soil for at least 3 years 0
  - b. seeds remain viable in the soil for 2-3 years 5
  - c. seeds remain viable in the soil for 1 year or less 15
2. Vegetative regeneration
  - a. any plant part is a viable propagule 0
  - b. sprouts from roots or stumps 5
  - c. no resprouting following removal of aboveground growth 10
3. Level of effort required
  - a. repeated chemical or mechanical control measures required 1
  - b. one or two chemical or mechanical control efforts required 5
  - c. can be controlled with one chemical treatment 10
  - d. effective control can be achieved with mechanical treatment 15
4. Side effects of chemical/mechanical control measures
  - a. control efforts will cause impacts to communities 0
  - b. control measures will cause moderate impacts to communities 5
  - c. control measures will have little or no impact on communities 15
5. Effectiveness of community management
  - the following options are not effective 0
  - a. cultural techniques (burning, flooding or mechanical removal) can be used to control species 5
  - b. routine management of community or restoration or preservation practices (e.g. prescribed burning or controlled disturbance) effectively controls species 10
6. Biological control
  - a. biological control not feasible (not practical, possible or probable) 0
  - b. potential may exist for biological control 5
  - c. biological control feasible 10

*Sub-total = 75*

*(Information for this section obtained from field surveys)*

##### B. Abundance Within Park

1. Number of known populations (stands) based on available field data
  - a. several; widespread and dense 1
  - b. intermediate number; patchy 3
  - c. few; scattered 5
2. Areal extent of populations
  - a. > 50 ha 1
  - b. 11-50 ha 2
  - c. 5-10 ha 3
  - d. < 5 ha 5

##### C. Abundance and Proximity of Propagules to Park

1. many sources of propagules near park 0
2. few sources of propagules near park, but these are readily dispersed 5
3. few sources of propagules near park, but these are *not* readily dispersed 10
4. no sources of propagules are in close proximity 15

*Total possible = 100*

**Section II Final Assessment (cont.)**

**Significance of Impact**

*(Information for this section obtained from field surveys)*

**Current level of Impact**

<b>A. Distribution relative to disturbance regime</b>	
1. found only on sites disturbed within the last 3 years of sites regularly disturbed	10
2. found in sites disturbed within the last 10 years	1
3. found in mid-successional sites disturbed 11-50 years before present (BP)	2
4. found in late successional sites disturbed 51-100 years BP	5
5. found in high quality natural areas with no known major disturbance for 100 years	10
<b>B. Abundance</b>	
1. Number of populations (stands)	
a. few; scattered (<5)	1
b. intermediate number; patchy (6-10)	3
c. several; widespread and dense (>10)	5
2. Areal extent of populations	
a. < 5 ha	1
b. 5-10 ha	2
c. 11-50 ha	3
d. >50 ha	5
3. Effect on natural processes and character	
a. plants having little or no effect	0
b. delays establishment of native species in disturbed sites up to 10 years	3
c. long term (more than 10 years) modification or retardation of succession	7
d. invades and modifies existing native communities	10
e. invades and replaces native communities	15
4. Significance of threat to park resources	
a. threat to secondary resources negligible	0
b. threat to areas' secondary (successional) resources	2
c. endangerment to areas' secondary (successional) resources	4
d. threat to areas' primary resources	8
e. endangerment to areas' primary resources	10
5. Level of visual impact to an ecologist	
a. little or no visual impact on landscape	0
b. minor visual impact on natural landscape	2
c. significant visual impact on natural landscape	4
d. major visual impact on natural landscape	5

*Total possible = 50*

**Urgency:**

1. Delay in action will result in large increase in effort required for successful control.	High
2. Delay in action will result in moderate increase in effort required for successful control	Medium
3. Delay in action will result in little increase in effort required for successful contro	Low

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# **A NATURAL DISTURBANCE MODEL FOR THE RESTORATION OF GIANT FOREST VILLAGE, SEQUOIA NATIONAL PARK**

Athena Demetry

Sequoia and Kings Canyon National Parks  
Three Rivers, CA 93271

## **ABSTRACT**

Visitor facilities are being removed from a 25 hectare area of giant sequoia-mixed conifer forest in the Giant Forest Grove of Sequoia National Park. A natural disturbance model for restoring the vegetation was sought in the surrounding ecosystem. Forest canopy openings, or gaps, caused by prescribed fire are of similar scale to canopy openings caused by tree removal for buildings and parking lots. In 1994, regeneration of woody species within fire-caused gaps was quantified in order to define this restoration model. Density and height growth for many species were found to vary with the size of the gap and the position within gaps (edge or center). Gaps in the restoration site were surveyed; for each gap a prescription was made for species composition, density, and spatial pattern that falls within the range of variability for these properties in similarly-sized fire-caused gaps. An adaptive management approach, in which different degrees of active restoration are applied within gaps using several different treatments, is being used to determine the minimal amount of human intervention necessary to meet the standard reference condition of natural vegetation in fire-caused gaps. Smaller trials are being applied at the split-plot level to assess the effectiveness of soil restoration treatments.

## **INTRODUCTION**

The Giant Forest grove of giant sequoia-mixed conifer forest is one of the largest of *Sequoiadendron giganteum*'s 75 extant groves, all of which are located on the western slope of the Sierra Nevada (Rundel 1971). Beginning in the early part of this century, a small city complete with gas station, market, hundreds of cabins, campgrounds, and a sewage treatment plant was constructed in Giant Forest. By the 1930's, park managers understood the damage such intense use could cause the ecosystem and began to call for removal and relocation of visitor facilities from Giant Forest. After decades of management efforts, the infrastructure for the relocated development is near completion, the first phase of demolition in Giant Forest has begun, and ecological restoration will begin in 1998. Because Giant Forest is a highly valued natural area, a focal site for ecological research, and a pioneering site for the use of prescribed fire in the National Parks, it is important that the restoration have a sound basis in the science of ecology, i.e., based on a quantified natural model.

One approach to defining a model for ecological restoration is to look to the surrounding ecosystem for a natural disturbance condition which resembles the human

disturbance, then quantify the vegetation in the naturally disturbed area. After removal of buildings and pavement from Giant Forest Village, the forest canopy will consist of a matrix of mature forest interspersed with canopy openings, or gaps, where patches of mature trees were removed to make way for buildings and parking lots. This canopy disturbance condition is similar to areas in undeveloped portions of Giant Forest where prescribed fire has killed patches of mature canopy trees, creating a gap which is colonized by an even-aged patch of regeneration. Because the canopy disturbance caused by removal of development and the canopy disturbance caused by fire are of similar scale and pattern on the landscape, we quantified the vegetation within fire-caused gaps to use as a model for revegetation or as a reference to evaluate the success of other restoration treatments.

The goal of the restoration is to mimic the effects on the vegetation of a fire burning through this area of the forest. Because fire is the dominant disturbance condition shaping the species composition and structure of the giant sequoia-mixed conifer forest (Stephenson 1996), and because fire-caused gaps have an important role in the forest as favorable regeneration sites for giant sequoia and other pioneer species, restoring vegetation in development-caused gaps to a composition, density, and spatial pattern typical of vegetation in fire-caused gaps is an important first step in returning developed areas of Giant Forest to a natural state.

The degree of human intervention necessary to mimic this vegetation is being investigated through adaptive management. It is probable that a century of human impact to these sites has moved the forest past the threshold where it can recover on its own; formerly-developed sites in the area that have been abandoned for over 30 years show little natural recovery. The impacts mostly likely to hamper natural revegetation include: (1) topsoil erosion, loss of organic matter, and compaction; (2) absence or depletion of the soil seed bank; (3) absence or low density of understory seed sources (shrubs, forbs, and grasses); (4) absence of litter, duff, and fuels to carry a fire hot enough to release the canopy-stored seed of giant sequoia, the dominant species in many fire-caused gaps; and (5) the possibility of exotic species invasion, due to the presence of disturbed soil surfaces and human vectors carrying seed from the Valley. As an adaptive management approach, increasing degrees of active restoration are being applied in a coherent, experimentally-designed manner to determine the least intrusive but still effective means of restoring the area.

#### DEFINING THE NATURAL DISTURBANCE MODEL

In the summer of 1994, field work was conducted to provide a model of woody species composition, density, and spatial patterns for the ecological restoration of potential canopy gaps in Giant Forest Village by mapping and analyzing the vegetation within fire-caused gaps of various sizes in Giant Forest Grove. Gap size was used to categorize gaps because it was hypothesized that gap size would account significantly for the variation seen in the regeneration within gaps. The size of the gap in a forest canopy affects the light, moisture, temperature, and nutrient regimes in the forest floor beneath the gap (Forman and Godron

1981, Canham and Marks 1985, Runkle 1985). Different species will respond differently to these varying environmental regimes, causing different-sized gaps to contain different species, plants densities, and spatial patterns of regeneration (Drury and Nisbet 1973, Whittaker and Levin 1977, Noble and Slatyer 1980, Sousa 1984, Thompson 1985, Poulson and Platt 1989, Spies and Franklin 1989, Phillips and Shure 1990, Gray 1995). Thus, to use fire-caused gaps as a model for restoration in potential gaps in Giant Forest Village, it was important that the vegetation in a range of gap sizes in Giant Forest Grove be carefully documented.

## Project Area

Giant Forest is located on a plateau in the mixed conifer zone of the middle elevations (between about 1950 m and 2320 m) of the southern Sierra Nevada and covers an area of approximately 1012 ha. The most common tree species are white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), and giant sequoia (*Sequoiadendron giganteum*). The average annual precipitation, which falls mostly as snow during the winter months, is 113 cm. Average minimum air temperatures range from -6.7°C in February to 11.8°C in August. Average maximum air temperatures range from 3.4°C in December and January to 27.4°C in August. The soils in the Giant Forest Grove of Sequoia National Park are predominantly Pachic Xerumbrepts that are 0.5-1.5 m deep, well drained, acid soils formed in granitic rock residuum (Huntington and Akeson 1987). Typically, the soils are coarse sandy loams with an O horizon  $\geq 10$  cm thick (Stohlgren et al. 1991).

Prescribed fires have been conducted in Giant Forest since 1979 and have been accompanied by a standardized monitoring program. Consequently, fire dates and boundaries are well documented. The sites sampled in this study burned between 1979 and 1987. The scale, severity, and effects of prescribed fires in Giant Forest are thought to be within the range of historic fire behavior and its effects, despite the century-long accumulation of fuels resulting from fire suppression (Mutch 1994, Demetry 1995, Stephenson 1996). Therefore, it is believed that mimicking the effects of prescribed fire will perpetuate the forest composition, structure, and patch dynamics produced by the historic, or "natural," fire regime.

## Methods

Six fire-caused gaps within each of three size categories were selected systematically for a total of eighteen gaps. The size categories were small (0.05-0.1 ha), medium (0.1-0.3 ha), and large (0.3-1.2 ha); these categories were chosen to correspond to observed thresholds in vegetation response to gap size. The presence of scorch on standing dead and down trees was evidence that the gap was caused by fire rather than by other disturbances, such as windthrow. Gaps were selected to represent the variability in vegetation observed within a size category. Gaps were excluded if more than 25 percent of the gap area consisted of exposed rock or if the slope was greater than 20 percent. Gap age was determined from

prescribed fire records.

Gap boundaries were delineated using criteria similar to those used by Spies and others (1990) in forests of the Pacific Northwest. Gap boundaries were defined by canopy dominants or codominants which had crowns that were either touching or were within one average crown diameter of each other. In other words, if a tree of average canopy width (defined by the sum of the two half-crown widths) were placed between the two trees in question and the canopies were to touch or overlap, the two trees were considered boundary trees. A mature tree that was farther than one average crown diameter from a neighboring tree was considered part of the gap vegetation and not a boundary tree.

Woody plants within each gap were mapped by obtaining their exact x,y,z coordinates using a Topcon CTS-2 total station, which has sub-centimeter accuracy. All tree seedlings greater than 0.1 meters height were mapped, with the exception of red fir and white fir, which were mapped if greater than 0.2 meters height. This exception was necessary because of the establishment of high densities of fir seedlings following a mast year in 1991, accompanied by favorable climatic conditions. Heights of all mapped seedlings were measured.

All shrubs with canopy dimensions at least 0.1 by 0.1 meter were mapped. Because shrub stems, or individuals, could not always be readily differentiated, shrubs were mapped as elliptic clumps, and the length and width of the ellipse was measured as well as the height of the clump. When a continuous group of a shrub species was encountered which was not roughly elliptical, the perimeter of the shrub polygon was mapped. Shrub cover was later generated by calculating the area of the ellipse or obtaining the area of the polygon from an AutoCAD map.

## DESCRIPTION AND APPLICATION OF MODEL

In this section I present the data as it was used as a model for forming prescriptions for restoring the vegetation in development-caused (restoration) gaps. The study also investigated whether species composition, density, and spatial arrangement of trees and shrubs in gaps varied with gap size and in different positions within gaps. Because gap size was found to account for significant variability in the density and growth rates for many species (see Demetry 1995 for methods and results of statistical analyses), gap size was used as the principal criterion for identifying a natural analogue for each restoration site.

The goal of the restoration is to mimic the effects on the vegetation of a fire burning through this area of the forest. For gaps where planting will be conducted, "fire-plus-ten," or the mimicking of species composition, density, and spatial patterns within gaps ten years following fire, is the objective. The ten-year goal was chosen because the mean age of the model gaps was just over ten years. Once the desired vegetation is established, which may entail a period of post-planting care, natural processes (fire, self-thinning/mortality) will be allowed to proceed. Although most of the seedlings planted to mimic the "fire plus ten"

vegetation will not survive to be recruited into the canopy, we prefer that natural processes do the thinning rather than managers planting fewer seedlings to account for future mortality (i.e., creating a “fire plus twenty” vegetation).

### Restoration Gaps

Restoration gaps (development-caused gaps) were identified and their boundary trees mapped. The size of each gap was determined and each gap classified by size using the same methods as for model gaps. A prescription was formed for each gap, based on the range of variability of the comparable properties in the 6 model gaps of the same size category (small, medium, large). Prescriptions included species of trees and shrubs, the density (total number) of each species, and the spatial arrangement of plants within gaps (proportion in edge vs. center, compass position if applicable, number of clumps, size of clumps, and stem spacing within clumps). Grasses and forbs were minor components of most gaps and were not included in the model, but will be seeded or planted as plugs at low densities into most gaps.

### Prescribing Species Composition

The number of tree and shrub species prescribed for each restoration gap was based on the number of species found in the same size category model gaps (Table 1). The individual species prescribed were based on the relative frequency of each species in the model gaps (Table 2, Table 3). Table 2 shows that white fir was present in 83 percent of the small gaps, 67 percent of the medium gaps, and 100 percent of the large gaps. Thus, when the prescriptions are completed for all the development-caused gaps, approximately 83 percent of the small gaps, 67 percent of the medium gaps, and 100 percent of the large gaps should contain white fir. For each individual gap, decisions were made based on the surrounding vegetation, aspect, elevation, soil type, topographic position, and similarities to individual model gaps. Thus, gaps located on shallow soils on steep south to west-facing slopes with little to no white fir in the surrounding canopy would not have white fir prescribed, while gaps located on mesic, deep soils on fairly level, north to east-facing slopes with abundant white fir in the surrounding canopy would have white fir prescribed.

### Prescribing Species Densities

The model gaps were used to define the range of variability of a species' density within each gap size category, based on a normal distribution (Figure 1). The parameters of the normal distribution, mean and standard deviation, are shown for trees in Table 4 and shrubs in Table 5. Within the limits of this range, factors such as surrounding vegetation, aspect, elevation, soil type, topographic position, and similarities to individual model gaps were considered in order to locate where in the distribution the value for a particular species in a gap should be. For example, the restorationist may have three medium gaps and needs to determine the density of incense cedar desired for each gap. Gap A is located on a shady, north-facing slope with no surrounding incense cedar; Gap B is located on a relatively flat

**Table 1.** Number of tree and shrub species found in small, medium, and large gaps (range and values for individual model gaps shown).

Gap Size	Number of Tree Species		Number of Shrub Species	
	Range	Gap Values	Range	Gap Values
Small	1-3	1, 2, 2, 3, 3, 3	0-7	0, 3, 4, 5, 7, 7
Medium	3-5	3, 3, 3, 4, 5, 5	4-11	4, 5, 6, 6, 8, 11
Large	4-7	4, 4, 4, 5, 7, 7	7-12	7, 9, 10, 11, 12, 12

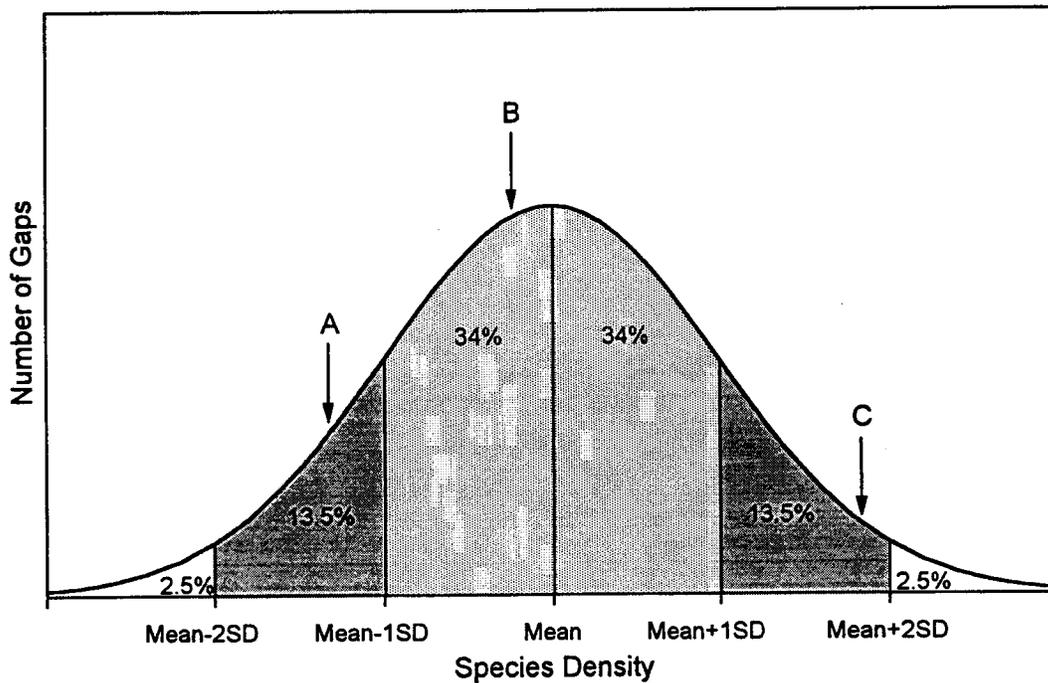
**Table 2.** Tree species frequency (presence in number of gaps), followed by relative frequency (percent) in parenthesis, for small, medium, and large gaps, and total. Species classifications are from the Jepson Manual (Hickman 1993).

Scientific Name	Common Name	Frequency			
		Small	Medium	Large	Total
<i>Pinus lambertiana</i>	sugar pine	5 (83)	6 (100)	6 (100)	17 (94)
<i>Sequoiadendron giganteum</i>	giant sequoia	4 (67)	6 (100)	6 (100)	16 (89)
<i>Abies concolor</i>	white fir	5 (83)	4 (67)	6 (100)	15 (83)
<i>Calocedrus decurrens</i>	incense cedar	0	4 (67)	3 (50)	7 (39)
<i>Pinus jeffreyi</i>	Jeffrey pine	0	1 (17)	5 (83)	6 (33)
<i>Abies magnifica</i>	red fir	1 (17)	1 (17)	2 (33)	4 (22)
<i>Pinus ponderosa</i>	ponderosa pine	0	1 (17)	2 (33)	3 (17)
<i>Quercus chrysolepis</i>	canyon live oak	0	0	2 (33)	2 (11)
<i>Quercus kelloggii</i>	black oak	0	1 (17)	1 (17)	2 (11)
Total number of species present		4	8	9	9

swale with a few incense cedar on the boundary; and Gap C is located on a steep, southwest-facing slope with rocky, shallow soil and many incense cedar on the boundary. Incense cedar density in medium gaps has a mean of 62 trees/ha and a standard deviation of 78 trees/ha. For Gap A, the restorationist might choose an incense cedar density on the low end of the distribution, between 1 and 2 standard deviations below the mean (e.g., 0 trees/ha, see point A, Figure 1). For Gap B, the restorationist might choose an incense cedar density near the mean (e.g., 60 trees/ha, see point B, Figure 1). For Gap C, the restorationist might choose an incense cedar density on the high end of the distribution, between 1 and 2 standard deviations above the mean (e.g., 190 trees/ha, see point C, Figure 1). When all incense cedar densities in all medium gaps have been chosen, a histogram of these densities should be

**Table 3.** Shrub species frequency (presence in number of gaps), followed by relative frequency (percent) in parenthesis, for small, medium, and large gaps, and total. Species classifications are from the Jepson Manual (Hickman 1993).

Scientific Name	Common Name	Frequency			
		Small	Medium	Large	Total
<i>Ceanothus cordulatus</i>	whitethorn	5 (83)	6 (100)	6 (100)	17 (94)
<i>Arctostaphylos patula</i>	greenleaf manzanita	4 (67)	6 (100)	6 (100)	16 (89)
<i>Ribes roezlii</i>	Sierra gooseberry	4 (67)	6 (100)	6 (100)	16 (89)
<i>Ribes nevadense</i>	Sierra currant	2 (33)	5 (83)	5 (83)	12 (67)
<i>Ceanothus parvifolius</i>	littleleaf ceanothus	3 (50)	4 (67)	3 (50)	10 (56)
<i>Chrysolepis sempervirens</i>	bush chinquapin	3 (50)	2 (33)	5 (83)	10 (56)
<i>Symphoricarpos rotundifolius</i> var. <i>parishii</i>	creeping snowberry	3 (50)	2 (33)	5 (83)	10 (56)
<i>Cornus nuttalli</i>	mountain dogwood	1 (17)	2 (33)	2 (33)	5 (28)
<i>Ribes viscosissimum</i>	sticky currant	1 (17)	1 (17)	3 (50)	5 (28)
<i>Sambucus mexicana</i>	elderberry	0	1 (17)	4 (67)	5 (28)
<i>Prunus emarginata</i>	bitter cherry	0	0	4 (67)	4 (22)
<i>Apocynum androsaemifolium</i>	spreading dogbane	0	1 (17)	2 (33)	3 (17)
<i>Rubus glaucifolius</i>	raspberry	0	1 (17)	1 (17)	2 (11)
<i>Rubus parviflorus</i>	thimbleberry	0	0	2 (33)	2 (11)
<i>Salix</i> sp.	willow	0	1 (17)	1 (17)	2 (11)
<i>Amelanchier alnifolia</i> var. <i>pumila</i>	smooth serviceberry	0	1 (17)	0	1 (6)
<i>Ceanothus integerrimus</i>	deer brush	0	0	1 (17)	1 (6)
<i>Chamaebatia foliolosa</i>	bear clover	0	0	1 (17)	1 (6)
<i>Corylus cornuta</i> var. <i>californica</i>	hazelnut	0	1 (17)	0	1 (6)
<i>Penstemon newberryi</i>	mountain pride	0	0	1 (17)	1 (6)
<i>Prunus virginiana</i>	western chokecherry	0	0	1 (17)	1 (6)
<i>Rosa</i> sp.	rose	0	1 (17)	0	1 (6)
Total number of species present		9	16	19	22



**Figure 1.** Normal curve, showing how this study defines the range of variability for species density. Such a curve would be used for one species in one gap size category, for which the mean and standard deviation (SD) are defined. 68% of the restoration gaps should have densities within 1 SD of the mean, and 95% of the restoration gaps should have densities within 2 SD of the mean. Points A, B, and C show single density values for a particular restoration gap (see text).

approximately normal with a mean near 62 trees/ha, with approximately 68% of the densities between 0 and 140 trees/ha ( $62 \pm 78$ ), and with approximately 95% of the densities between 0 and 218 trees/ha ( $62 \pm (2 * 78)$ ).

To approximate these distributions when prescribing species densities, I generated random numbers from normal distributions with the means and standard deviations specified, then chose densities from these lists. For example, we expect to restore about 40 medium gaps, so 40 random normal densities for each species were generated and used as a guide when forming prescriptions for medium gaps.

The assumption of a normal distribution was moderately supported by the data for most species. The distribution of the 6 density values within a gap size category was often skewed to the right, as when most gaps contained a low density of a species, but one gap had an

**Table 4.** Mean density and standard deviations (SD) for conifers in small, medium, and large gaps (n=6).

Species	Density (trees/ha)					
	Small		Medium		Large	
	Mean	SD	Mean	SD	Mean	SD
Giant sequoia	<b>653</b>	962	<b>612</b>	1250	<b>2956</b>	3084
White fir	<b>62</b>	51	<b>70</b>	136	<b>107</b>	128
Sugar pine	<b>50</b>	61	<b>58</b>	42	<b>114</b>	76
Incense cedar	<b>0</b>	--	<b>62</b>	78	<b>5</b>	10
Jeffrey pine	<b>0</b>	--	<b>2</b>	4	<b>6</b>	6
Red fir	<b>29</b>	65	<b>90</b>	220	<b>39</b>	70
Ponderosa pine	<b>0</b>	--	<b>7</b>	17	<b>2</b>	3

**Table 5.** Mean cover and standard deviation (SD) for shrubs in small, medium, and large gaps (n=6).

Species	Mean Cover (m <sup>2</sup> /ha)					
	Small		Medium		Large	
	Mean	SD	Mean	SD	Mean	SD
Whitethorn	<b>48</b>	63	<b>275</b>	255	<b>1134</b>	841
Littleleaf ceanothus	<b>96</b>	133	<b>190</b>	281	<b>211</b>	410
Greenleaf manzanita	<b>2</b>	4	<b>5</b>	8	<b>60</b>	58
Sierra gooseberry	<b>7</b>	13	<b>10</b>	14	<b>97</b>	120
Sierra currant	<b>0.4</b>	1	<b>7</b>	15	<b>7</b>	12
Sticky currant	<b>0.9</b>	2	<b>2</b>	5	<b>31</b>	35
Mountain dogwood	<b>0.2</b>	1.5	<b>5</b>	12	<b>118</b>	288
Elderberry	<b>0</b>	--	<b>5</b>	13	<b>7</b>	11
Bush chinquapin	<b>120</b>	194	<b>576</b>	1381	<b>46</b>	37
Bitter cherry	<b>0</b>	--	<b>0</b>	--	<b>0.8</b>	1
Creeping snowberry	<b>0.6</b>	1	<b>31</b>	67	<b>15</b>	18
Spreading dogbane	<b>0</b>	--	<b>0.4</b>	0.9	<b>19</b>	45

extreme high density. In this case, the range above the mean produced by the normal distribution will be large but realistic, whereas a portion of the range below the mean will be meaningless because negative values are produced. To correct for this and reproduce the right-skew of the model gaps' distribution, any randomly-generated negative values were given densities below the mean or zero.

### Prescribing Spatial Patterns

Within-gap spatial patterns were examined by dividing gaps into regions where density or growth rates were expected to differ because of gradients of environmental factors within gaps. An edge versus center division was made because moisture is generally higher in centers of gaps, and a compass position division was made because light availability is higher in northern regions of gaps. The distance from each tree seedling to the nearest gap boundary was calculated; the division between edge and center was made at half the maximum distance from edge. The north, south, east, and west divisions were made with offset quadrant axes through the geometric center of the gap.

Results showed that many species, particularly the pioneer-type species, tended to grow with higher densities in gap centers than at gap edges (see Figures 2 and 3 for results for giant sequoia and whitethorn, respectively), while others, such as bush chinquapin and creeping snowberry, had higher densities at gap edges than centers. There were few cases where density varied with compass position. Based on these data, density in gap edge vs. center was prescribed for each species in each restoration gap using a similar process as described for species density. Density in north, south, east, or west quadrants was prescribed if compass position was significant for a species.

Patchiness of growth within gaps was examined using Ripley's  $K(t)$  analysis (Moeur 1993). The analysis showed that tree species within gaps grew in clumped patterns in all gap sizes and at all spatial scales. A pattern of hierarchical clumping, with clumps of a few stems positioned within larger-scale clumps, was shown by the analysis (Demetry 1995). With this analysis, which showed at what spatial scale the clumping patterns were strongest, as well as simple examinations of stem plots, prescriptions were made for number of clumps, a range of clump sizes, and a range of stem spacings for each species in each restoration gap. Figure 4 shows a stem map of giant sequoia seedlings and whitethorn cover in one large gap (total area 0.34 ha), and illustrates the clumped patterns of growth as well as the tendency to have higher density (and higher rates of growth, see Demetry 1995) in gap centers.

### Non-Gap Areas

In the relatively natural ecosystem surrounding Giant Forest Village, areas between gaps that have sustained fire generally do not contain patches of even-aged regeneration. For this reason, no planting or seeding is planned for disturbed, non-gap areas of Giant Forest Village. However, restoring the natural topography and mitigating soil compaction

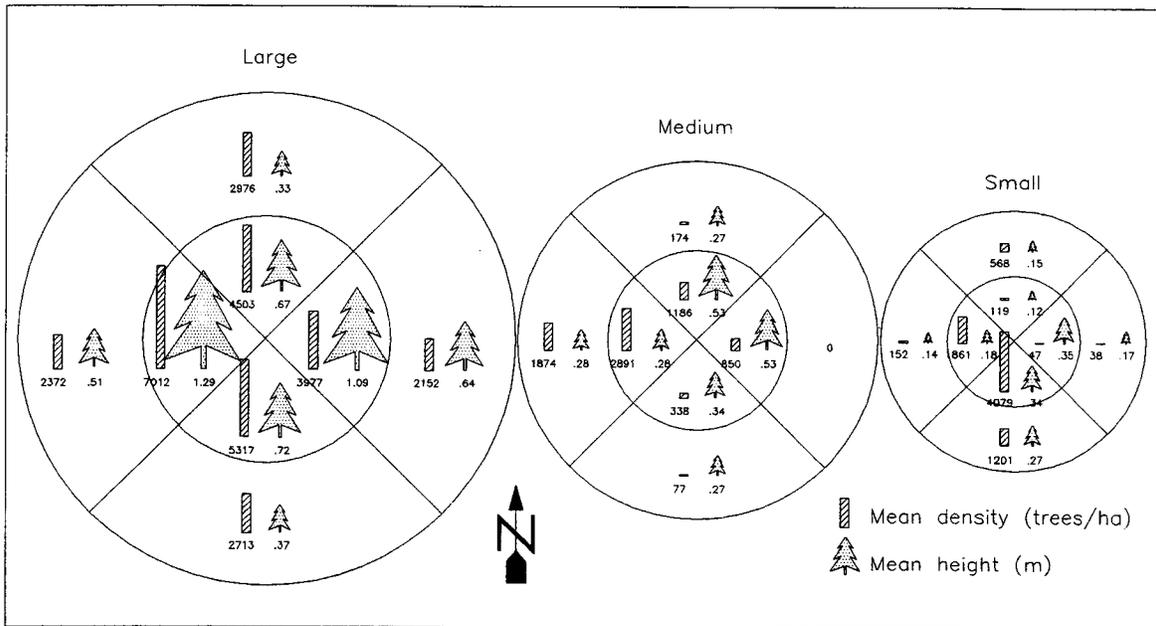


Figure 2. Giant sequoia mean density and height by within-gap position and gap size. Mean density is shown as a bar symbol scaled to density in trees per hectare, and mean height is shown as a tree symbol scaled to height in meters.

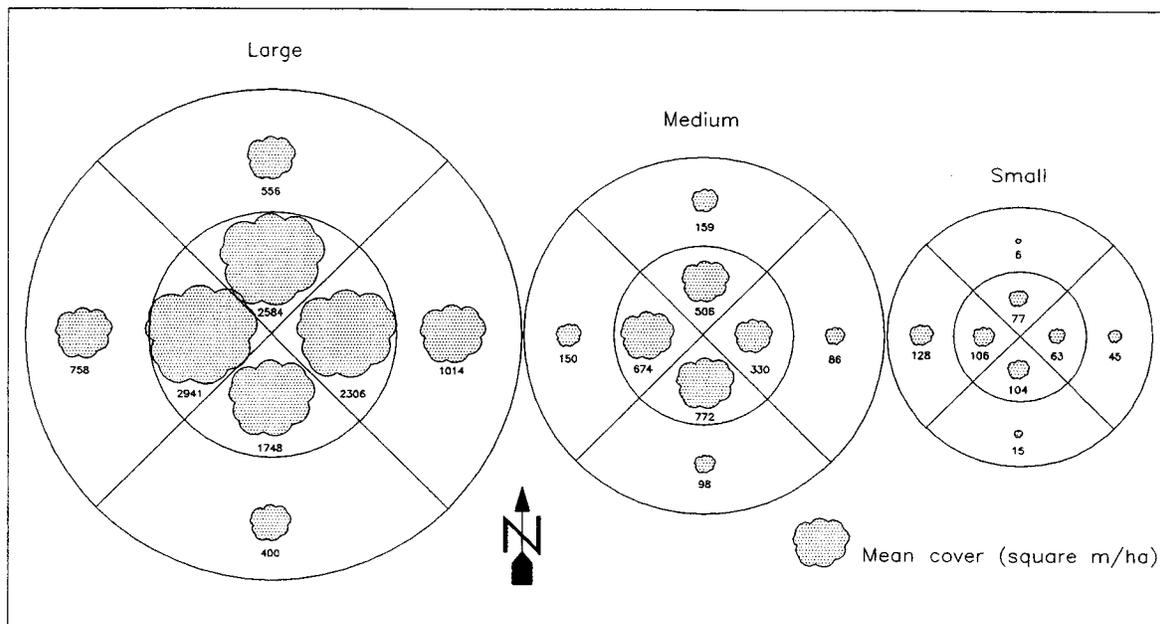


Figure 3. Whitethorn mean cover by within-gap position and gap size. Mean cover is shown as a shrub symbol scaled to cover area in square meters per hectare.

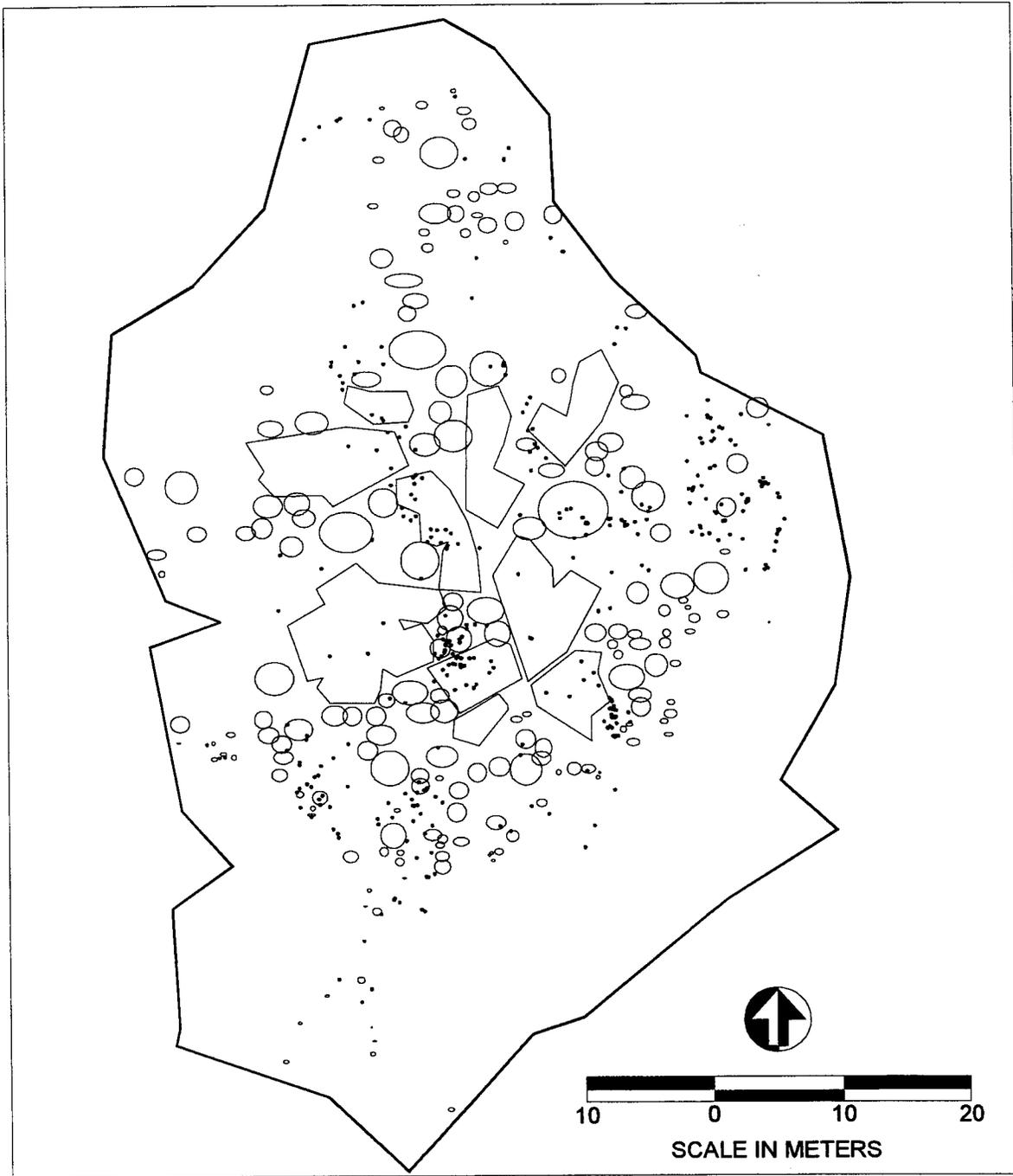


Figure 4. Stem map of giant sequoia seedlings, shown as points, and whitethorn cover, shown as ellipses and polygons, in a large gap. Large irregular polygon is the gap boundary.

(cultivating) are planned in order to allow natural revegetation to occur. Restored vegetation within gaps should provide islands of seed sources for shrub, grass, and forb recolonization into non-gap areas.

### Soil Impacts and Mitigation

To assess impacts to the soil in the developed areas, chemical and physical properties of soil profiles were compared with profiles in natural areas (gaps) that had sustained fire. Results showed that the primary impacts in developed-site soils are compaction of the A horizon, depletion of organic matter in the A horizon, and loss or alteration of natural aggregate structures. Compaction in natural soils, as measured by a soil penetrometer, ranged from 50 to 200 p.s.i., while compaction in developed-site soils ranged from 409 to 600 p.s.i. Surface compaction was highest in soils beneath pavement (mean=586 p.s.i. at 3 sites) and lowest in sites where development has been removed for 30 years, but no restoration conducted (mean=437 p.s.i. at 3 sites). Organic matter (O.M.) content in the top 25 cm of disturbed-site soils was below the range of O.M. shown by natural soils (5.4% to 17.1%) for 11 of 14 disturbed-site soils sampled. This reduced O.M. content was due both to topsoil erosion and to a combination of increased decomposition due to trampling disturbance, loss of fine O.M. particles in suspension, and decreased O.M. inputs (e.g., from decreased litter inputs from the reduced overstory and understory). Finally, the A horizons of natural soil profiles contained fine crumb structural aggregates, while disturbed-site soils contained subangular blocky and platy aggregate structures.

To mitigate both soil compaction and restore crumb soil structure, we plan to cultivate (with rototiller-type equipment) soils in the developed areas to a depth of about 25 cm and outside the driplines of mature trees. Because soils must be moist to restore soil structure during cultivation, cultivation will be conducted in the spring after snow-melt, or soils will be sprinkler-moistened prior to cultivation if done in the fall. Organic matter loss and topsoil erosion would best be mitigated by spreading a layer of local, borrowed topsoil on the surface of the most highly impacted sites. However, no borrow source for topsoil exists within Giant Forest. Two alternate methods will be tried in an experimental approach described below, involving amendment with forest bark humus during cultivation, and using low-intensity fire.

### ADAPTIVE MANAGEMENT APPROACH TO RESTORATION

Because of the duration and severity of impacts to developed areas of Giant Forest, managers believe that some degree of human intervention is necessary for the recovery of the site. However, an acceptable restoration product might be achieved through less intensive means than the seed collection, propagation, planting, seeding, and irrigation process traditionally practiced in the Park's frontcountry revegetation projects. To address this possibility, an adaptive management approach is being taken. The term "adaptive management" refers to "an iterative approach to decision making involving a cycle of planning, implementation, monitoring, research, and subsequent reexamination of

management decisions based on new information that may alter existing plans and priorities” (Interagency Ecosystem Management Task Force 1995). Adaptive management explicitly recognizes that managed ecosystems are complex and inherently unpredictable, and that incomplete knowledge of ecosystems is the rule rather than the exception. Experimentation is integrated into management actions not as basic research, but to learn which actions will meet management goals, because no other source for this knowledge exists.

Everett et al. (1994) provide nine steps for adaptive management of forested ecosystems:

- (1) Establish measurable goals for management
- (2) Explicitly define cause-and-effect relations for natural and management-induced processes
- (3) Design sets of actions that will achieve the goals of management.
- (4) Implement management actions
- (5) Periodically assess progress and cause-and-effect relations
- (6) Compare actual system performance with forecasted performance
- (7) Evaluate the appropriateness of goals and forecasts of system performance; refine the conceptual model, redesign goals, and develop new management actions if the model and goals require adaptation
- (8) Implement new actions
- (9) Return to step 5 for reiterative evaluation

The goal of an adaptive management approach in Giant Forest is to apply different degrees of active restoration in a coherent experimental design, so that the minimal amount of human intervention necessary to meet the standard reference condition of natural vegetation in fire-caused gaps can be determined. Because restoration goals have been quantified based on fire-caused gaps, a solid reference condition exists for comparison and evaluation of alternative treatments, making Giant Forest an especially good candidate for adaptive management. Adaptive management will be most important in the early phases of the restoration so that rapid feedback on different restoration treatments can be gathered and new knowledge applied to later phases.

Three basic treatments for restoration gaps in Giant Forest Village are being used, in order of increasing human intervention, with the first two treatments ideally applied in the minimum number of gaps necessary for statistical replication:

- (1) No action other than regrading, cultivation, and mulching with litter and duff.
- (2) Regrade, cultivate, import light fuel bed and 2 to 3 large slash piles, and burn with the intent of releasing sequoia seed, scarifying the seed bank, and improving the soil. No propagation, soil amendments, mulch, planting, or irrigation.

(3) Propagate; regrade; cultivate; mulch with wood chips; plant tree and shrub seedlings and grass and forb plugs; and irrigate. Use organic matter amendment to the topsoil in one-half of selected gaps in a split-plot design. Use low-intensity burning in one-half of selected gaps in a split-plot design.

The first treatment mitigates the most severe and consistent soil impact in Giant Forest Village, soil compaction, and protects newly decompacted, loose soil from surface erosion. It relies on natural seed dispersal as a source of propagules in gaps. It does not actively put the ecosystem on a trajectory similar to an ecosystem response to fire.

The second treatment adds to the first by providing a source of propagules in the heating and releasing of canopy-stored sequoia seed and the scarifying of soil-stored shrub and forb seed, and by burning with variable, heterogeneous intensities within a gap to provide possible soil benefits (pulse of mineralized, plant-available N; a source of partially decomposed organic matter from incomplete fuel combustion; and a friable, mineral seedbed, required for the germination of giant sequoia). It actively puts the ecosystem on a trajectory similar to an ecosystem response to natural fire, but does so with minimal intervention.

The third treatment aims to simulate the effects of fire on vegetation; it mimics the species composition, density, and spatial patterns of regeneration in different-sized fire-caused gaps by actively planting tree, shrub, forb, and grass seedlings. It is the most active, highest-intervention method of putting the ecosystem on a trajectory similar to an ecosystem response to natural fire.

None of the methods described above directly mitigate the destruction of the topsoil. One sub-treatment within Treatment 3 would mitigate loss of organic matter in the topsoil and topsoil erosion by amending the top 25 cm of soil in half of selected gaps with forest bark humus and nitrogen to rebalance the C:N ratio; the other half of the gap would remain unamended as a control, to see if the added expense of soil amendment is justified with a substantial improvement in plant establishment and growth. A second sub-treatment within Treatment 3 would attempt to indirectly mitigate topsoil destruction by using low-intensity burning to provide possible soil benefits.

Monitoring is an essential and integral component of adaptive management. The purpose of monitoring is to quantify the results of the various treatments in a way that they can be meaningfully compared with each other and with the standard reference condition of vegetation in fire-caused gaps. If monitoring and data analysis reveal that certain treatments are not producing vegetation that is within the range of variability for fire-caused gaps, altering or abandoning these treatments can be considered in the iterative planning, implementation, monitoring, and evaluation cycle of adaptive management. If monitoring indicates that a less intensive treatment produces acceptable results (vegetation within the range of variability for fire-caused gaps), this treatment may be used in gaps in later phases of restoration.

The first phase of demolition in Giant Forest Village will be completed in the fall of 1998, with restoration to follow and continue through spring of 1999. There are 13 gaps to be restored in this first phase, and all are included in an experimental design to compare the effectiveness of the different treatments. Although there are not enough gaps to provide the replicates that a power analysis indicated would be necessary for a fair level of statistical confidence (gaps originally included in the first phase of restoration were removed from the contract package due to funding constraints), there may be enough differences seen among the treatments to indicate their relative effectiveness.

### SUMMARY

Finding and quantifying an analogous model or reference condition is an important first step in ecological restoration. Natural disturbance models, in which the early stages of recolonization and community development following natural disturbance are mimicked, are appropriate when the scale and pattern on the landscape of the human disturbance are similar to the natural disturbance. This study provided an example of using regeneration within fire-caused canopy gaps as a natural disturbance model for patchy, development-caused disturbance in a forested ecosystem. In addition to fire, natural disturbances that might be used as models in other ecosystems include hurricanes, wind storms, ice storms, cryogenesis, landslides, avalanches, coastal erosion and dune movement, flash floods, and various biotic processes such as insect outbreaks, disease, and browsing and burrowing animals (White and Pickett 1985, Attiwill 1994). Particularly in ecosystems where the health, diversity, and sustainability of the plant community are dependent on a particular disturbance regime, this approach is ecologically sound, and may be more appropriate than using a mature community type as a model or reference.

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## CRATER LAKE NATIONAL PARK LODGE LANDSCAPE RESTORATION: UPDATING AN HISTORICAL LANDSCAPE USING 1990'S RESTORATION TECHNIQUES

Theresa Flessner<sup>1</sup>, Joan Trindle<sup>1</sup>, Nancy Dunjkle<sup>2</sup>, Terri Urbanowski<sup>2</sup>, and  
Sandra Klepadlo<sup>3</sup>

<sup>1</sup> USDA-Natural Resources Conservation Service, Plant Materials Center, 3415  
NE Granger Avenue, Corvallis, Oregon 97330

<sup>2</sup> USDI-National Park Service, Denver Service Center, 12795 West Alameda  
Parkway, Denver, Colorado 80225

<sup>3</sup> USDI-National Park Service, Crater Lake National Park, Crater Lake, Oregon  
97604

### ABSTRACT

In 1994, the landscape surrounding the historic Crater Lake Lodge at Crater Lake National Park, Oregon was replanted, following major renovation of the lodge. The landscape plan incorporated design elements from the original lodge planting from the 1930's and utilized locally collected plant materials more suited to the harsh environment at the lake rim. These plant materials were collected and increased as part of a cooperative agreement between Crater Lake National Park and the Natural Resources Conservation Service Plant Materials Center, Corvallis, Oregon. Plantings were established, maintained, and monitored by Crater Lake National Park personnel and contract crews. Survival and growth of plant materials were recorded in 1995, 1996, and 1997; mean survival and growth vary with plant species and microclimate, but overall are good to excellent. Using native vegetation and restoration practices such as erosion control blanketing and organic soil amendment, the landscape is now well-established and requires very little human interference ("maintenance") to flourish. The success of this project may be attributed to several items, with the most crucial being a good working knowledge of the local ecosystem and adapted plant materials, excellent working relationships between agencies, production/use of quality plant materials, and the use of appropriate planting, establishment, and monitoring techniques.

### INTRODUCTION

The Crater Lake Lodge is situated on the southwest rim of the caldera at an elevation of 7100 feet. The lodge aspect is generally south-southwest; however, portions of the rehabilitated landscape occur on the east and northeast sides of the Lodge where little or no sun is received. Annual precipitation, which falls mostly as snow in the winter months, averaged 71.8 inches for the years 1992-1997 (U.S. Department of Commerce-National Oceanic and Atmospheric Administration, 1992-1997). Ground snowload can reach 500 pounds per square foot. Snow typically falls at Crater Lake as soon as September and

generally persists into late June and July resulting in a very short growing season of two to three months. The northwest and southeast edges of the Lodge landscape tend to blow clear of snow, exposing vegetation and subjecting it to frost and strong desiccating winds. Average yearly number of frost-free days for the years 1992-1997 was 130 (U.S. Department of Commerce-National Oceanic and Atmospheric Administration, 1992-1997). Like many Pacific Northwest environments, Crater Lake experiences a summer dry period. Total average precipitation for the period June through August is about 4 inches (NPS, 1978). The soil on the rim is composed of a high percentage of volcanic tuff and may be described as relatively infertile and well-drained.

The plant community of this site and other comparable sites on the rim include open canopy forests of white bark pine (*Pinus albicaulis*) and subalpine fir krummoltz (*Abies lasiocarpa*) in association with mountain ash (*Sorbus* spp.), oceanspray (*Holodiscus discolor*), and sedges (*Carex* spp.). Intermixed are deep-drained pumice, late-lying snowfields composed of spreading phlox (*Phlox diffusa*), Klamath knotweed (*Polygonum newberryi*), alpine pussypaws (*Spraguea umbellatum*), mountain buckwheat (*Eriogonum mariflorum*), western needlegrass (*Stipa occidentalis*), and Cascade aster (*Aster ledophyllus*). Species such as mountain brome (*Bromus carinatus*), blue wildrye (*Elymus glaucus*), squirreltail (*Elymus elymoides*), lupine (*Lupinus* spp.), and goldenbrush (*Ericameria bloomerii*) are common to the flora as well.

## DEVELOPMENT OF CONCEPTUAL PLAN FOR LODGE LANDSCAPE RESTORATION

### Historical Landscaping/Naturalization Practices

Prior to the 1930's, it was common practice for motorists to park automobiles anywhere along the rim, as there was no road from the cafeteria to the Lodge. The result of this practice combined with sandy soil rendered the area between the road and the rim devoid of vegetation (Sager, 1932). So, from 1930-1938, certain landscaping or naturalization practices were implemented to address this problem. These practices included sodding with native grasses and sedges, seeding grasses (both native and introduced species) and wildflowers, transplanting native, root-pruned trees and shrubs, and installing crosswalks for pedestrians; most plantings around the Lodge were completed from 1931 to 1933 (Gilbert and Luxenberg, 1990). Work on the rest of the rim continued until 1938. Large quantities of sedge peat and top soil mined from within Park boundaries were incorporated in areas of the rim landscape prior to planting. Sodding was described as most effective as "its appearance could be controlled" (Sager, 1932). Seeding did not meet aesthetic standards and was unpredictable. Transplanted native trees (root-pruned) and shrubs "came through in good shape" (Sager, 1932).

The design intent was to create a "romantic" landscape which appealed to perceived aesthetic values. Native plant communities were used as models to a certain extent, but from a visual rather than an ecological standpoint. For example, Merel Sager, landscape architect on site during the 30's, cited Sun Notch, a meadow east of Garfield Peak, as an example of his vision for the

"naturalized" rim. He believed the wetter areas of the meadow represented the rim area's "original lush appearance" (Gilbert and Luxenberg, 1990). Plant materials were chosen for visual qualities and availability, not for their natural distribution or typical association with other species. Adaptability was determined by trial and error. Civilian Conservation Corps volunteers watered, replaced dead plants, and picked up trash. It was assumed that this level of maintenance would be ongoing. With the beginning of World War II, the supply of inexpensive labor was depleted, and the landscape was virtually neglected for decades.

Over the years, the Lodge landscape changed in response to the harsh environment. Subalpine fir, mountain hemlock and 8-10 hardy shrub species, the backbone of the landscape design, survived. The composition of the groundcover moved toward the drier end of the spectrum. Nevertheless, when Gilbert and Luxenberg (1990) studied and evaluated the landscape, it had sufficient integrity to be eligible for the National Register of Historic Places. This designation obligated the National Park Service restoration team to observe the historic design concept (as interpreted in the Gilbert and Luxenberg study).

#### Challenges Faced in Development of Restoration Plan

Although the design team's intent was to preserve as much of the historic landscape as possible, about two acres of vegetation were cleared around the Lodge during the 1994 renovation. Among the losses were the 20-30 foot historic trees planted within 10 feet of the building and large shrubs massed around the foundation. Revegetation needs included 1) replacing historic trees with specimens of the same species, 2) replanting shrubs in historic patterns, 3) establishing site-adapted groundcover that would fit the historic concept, but would also control erosion and eventually be self-sustaining.

Accomplishing these goals was not merely a matter of copying the 1930's design because of the changes that had occurred in the intervening 50 years. Speaking at a 1995 conference on "Balancing Nature and Culture in Historic Landscapes", design team landscape architect Terri Urbanowski commented that the proposed design, in responding to current conditions, "...precipitated conflicts between natural and cultural resources, between past approaches and present ideals" (Urbanowski and Dunkle, 1995). The historical goal of a "romanticized landscape...", "...altered to create focal points, views and a varied experience..." had to be reconciled with contemporary goals and policy of working with ecosystem processes, native site-adapted plant materials, and sustainable site restoration. Current NPS policy also generally discourages practices like large-scale mining of topsoil, peat, and sod within Park boundaries; practices that were key elements in establishing the historic landscape (Gilbert and Luxenberg, 1990). Even if such practices were allowed today, NPS could not afford them because of the current high cost of labor, compared with the cost of using Civilian Conservation Corps volunteers during the Depression. Finally, the salient characteristics of the Park's natural systems and their vulnerability to increased visitor use are far better understood than they were in the 1930's.

The potential difficulties of restoration plantings in these severe, variable environments had been highlighted by a disappointing attempt to restore several abandoned campground loops at the Mazama campground in the late 1980's. Only 10-15% of the installed specimen trees (4-6 foot) and tree seedlings survived (Tabor, 1989). Visual examination of seeded areas revealed healthy colonization by lodgepole pine and native sedges, but very poor establishment of the seeded grass mix. Limited survival was attributed to 1) an exceptionally dry year and limited supplemental water, 2) lack of soil structure and low soil fertility, 3) poor adaptation of imported plant materials, and 4) possible lack of seed/soil contact resulting from using a one-step hydroseeding process (Tabor, 1989). Recommendations drawn from the Mazama project included 1) performing soil tests within proposed revegetation area, b) using supplemental irrigation with fertilizer injection capability during establishment period, c) amending soil as appropriate, d) mulching trees and shrubs, e) transplanting smaller material, f) mechanically drilling seed where possible, and g) developing a well-documented vegetation management/maintenance program (Tabor, 1989). These recommendations were carried forward into the Crater Lake Lodge landscape restoration. Analysis of the Mazama project made it clear that, in the harsher environment of the rim, all components of the restoration - selecting seed and plant sources, handling plant materials before and after planting, soil preparation and timing - had to be done carefully and correctly. Because the NPS could not afford intensive ongoing maintenance, the landscape needed to be self-sustaining after two or three years of post-planting care. Therefore, successful establishment would depend on carefully timed and coordinated management practices before and during installation.

## ACQUISITION OF NATIVE PLANT MATERIALS AND TECHNOLOGY

### Development and Revision of Interagency Agreement

The plan for obtaining native plant materials and related technology for restoring the Lodge landscape was initiated in 1990 and resulted in the development of an agreement between Crater Lake National Park (CRLA) and the USDA Natural Resources Conservation Service (NRCS) Plant Materials Center, Corvallis, Oregon in 1991. NRCS agreed to collect, plant, and evaluate establishment and increase potential of locally collected grasses, sedges, forbs, and shrubs, as well as harvest, clean, and increase plant material for revegetation needs within the Park. CRLA assisted NRCS by monitoring seed maturity in the Park and by collecting additional seed and cuttings in 1994 for continued production of seed, tubelings, and transplants. The agreement was revised in 1993 according to initial propagation, establishment, and plant/seed increase results obtained in 1992. The species list, numbers of plants, container size for delivery, and required seed poundage were revised and refined. Targeted revegetation needs focused on six grass and sedge, four forb, and nine woody species with deliveries of 14,000 tubelings, 2000 containers, and a maximum of 140 pounds of seed scheduled in 1994 and 1995. Information on propagation, establishment, and increase was provided by NRCS to CRLA in 1993, and projected delivery information (plant species, numbers, container size, seed lot size) was reviewed and revised twice yearly in 1994 and 1995. This frequent, in-depth communication facilitated landscape planting plan revision

and timely planning for shipping, development of holding/hardening-off facilities, and obtaining trained planting crews and necessary supplies and equipment.

#### Planning and Installation of *In situ* Revegetation Test Plots

Another important component of the cooperative agreement between CRLA and NRCS (Corvallis Plant Materials Center) was the planning and installation of *in situ* revegetation test plots. Because of previous seeding failures, it was necessary to evaluate success of both seeding local ecotypes and select revegetation practices under "near-site" conditions prior to installation and planting of the Lodge landscape. Plots were installed in October, 1991 at CRLA, near Park headquarters, to determine the effect of species and soil treatment on stand establishment using locally collected grass, sedge, and forb seed. Soil treatments included a) control, b) incorporation of peat moss, c) incorporation of slow-release fertilizer, d) addition of erosion-control netting, e) b & c, f) c & d, and g) b & c & d. Species included 1) *Elymus glaucus*, 2) *Stipa occidentalis*, 3) *Elymus elymoides*, 4) *Festuca* sp., 5) *Carex* spp., 6) *Lupinus latifolius*, and 7) mix of 1-6. Treatments were randomized and replicated within blocks. Data was recorded from spring 1992 through fall 1994 by NRCS staff; the plots continue to be monitored by CRLA staff. Overall, species and soil treatment interacted to affect stand establishment in plots. Also, incorporation of peat moss and slow-release fertilizer promoted stand establishment and growth of certain grass species and lupine. (*Carex* spp. performed poorly in all treatments.) The effect of application of erosion control netting to plots on stand establishment and growth was mixed and species dependent.

As planned, the results (data) of the test plots were utilized in the development of seeding and planting specifications for the Lodge landscape project. Specifications defined seeding rates, use or proportion of seed versus transplants per species, organic matter application, fertilizer use and limitations, and application (type) of erosion control netting. Also, the need to anticipate and plan for wildlife use of the landscape was identified.

### REVISION OF DESIGN AND INSTALLATION OF PLANT MATERIALS

#### Factors Influencing Final Planting Plan

The success of seed and plant propagation of the different species as identified in the 1990's planting plan were not known at the time the original plan was prepared. Thus, it was inevitable that as the propagation trials proceeded, the planning/design team would need to take stock of actual availability of the different materials and adjust the plan accordingly. As the project evolved, the actual areas of disturbance were adjusted somewhat from the original estimates. In early 1994, the senior design team landscape architect visited the Plant Materials Center (PMC) to view the size and condition of the plants. He reported this visit aided him greatly in determining final plant spacing and effectively using available materials.

Seed production for this project was limited due to both inherent and climatic factors. As for many "native ecotypes", they often do not depend on a high level of fecundity to persist in their environment. For example, PMC staff have grown different populations of *Elymus glaucus* from various origins in the Pacific Northwest in the same year at the PMC and obtained yields ranging from 12 to over 200 pounds per acre. In some areas of the Park we found that even robust populations of select species yielded little or no sound seed in a given year of collection. Environmental factors affecting seed production at the PMC included the lower elevation, more mild maritime climate, and seasonally saturated soils. Thus, in the final planting plan cone-tainers of grasses, sedges, and forbs were produced to interplant into the direct-seeded areas and the shrub beds nearest to the Lodge.

### Plant Preparation for Outplanting

In preparing both the larger containers of shrubs and the cone-tainers for shipping to the Park, the plants were preconditioned as much as possible for their transition to the site nearly 6,500 feet higher in elevation, with its drier, cooler, and sunnier climate. Plant production practices were timed to allow for earlier spring growth, during which the plants were kept in an outdoor, shade-cloth covered nursery, well-watered and fertilized to accumulate biomass and carbohydrate reserves. In early summer the hardening-off process was initiated by reducing and then suspending fertilization, removing the shade cloth to expose the plants to full sun, and gradually reducing watering. Plants were top-pruned as needed to avoid an overabundance of foliage which would leave the plant more susceptible to the damaging effects of drying winds. Top pruning had to be carefully timed to promote maximum root production *and* to avoid stimulating bud break and lush new growth which would be less able to withstand the sudden transition to a harsher climate. Some root pruning also was done on the shrubs in 1-gallon cans; the 10" cone-tainers of course were "air-pruned" as a function of the container design. Finally, in August the plants were shipped to the Park in a refrigerated semi-truck and further hardened off at the Park in a shade-covered frame for a few weeks prior to transplanting.

Compared to the campground planting in 1987, seed and plants were outplanted later in the season, and soil moisture levels were higher as irrigation was implemented prior to planting. As the roots had a shorter time period to "settle in" to the soil, frost heaving did occur on some cone-tainer stock - mostly to plants in areas not covered by erosion control blanketing. In this later-season planting, the timing of the plants' seasonal cycle was crucial to ensuring overwinter survival and regrowth the following spring. Carbohydrate reserves had to be maximized to prior to outplanting, and at the same time the plants had to be early enough into their "rest" or vernalization period that they would not start active regrowth in the event of a warmer, milder fall.

### Preparation for Transplanting Larger Trees

Because the foundation of the Crater Lake Lodge had to be totally rebuilt, the 20-30 foot historic firs and hemlocks growing close to the building could not be saved, but replaced in kind with smaller trees. The 5-8 foot size range was

selected as trees this size were more likely to survive transplanting than larger specimens, and purchasing or moving trees was affordable. The poor survival of purchased trees in the 1987 Mazama campground planting led NPS to consider treespading a limited number of trees from selected sites within the Park. The Mazama trees had been dug at a high elevation site in Idaho and transported to Crater Lake, sustaining undetermined stress in digging and transport. As project time frames would not allow custom propagation and high-elevation stock was not available in larger sizes from regional nurseries, NPS had to settle for trees dug in the wild. Larger trees were dug from an old quarry and from a stand of hemlocks bordering Rim Village, and were root-pruned in October, 1992. By July, 1994, after an unusually early snowmelt and continuous dry weather, the root-pruned trees showed signs of drought stress. Supplemental water was applied at least once a week from mid-July until fall rains began late September, 1994. Eighteen of the root-pruned trees were moved to their permanent location around the Lodge during the first week of October.

### Installation of Plant Materials

Planting specifications were written to incorporate recommendations from the Mazama project and results of revegetation test plots. Close communication between the design team, the NPS construction supervisor, Park staff, NRCS (PMC) staff, and the landscape contractor during installation was a key element in project success. Members of the design team were on site for consultation during treespading, landscape layout, and other critical periods. During the 1995 installation, a seasonal employee was hired by the Park as a full-time construction inspector to assist with the revegetation and landscape work.

To ensure the specifications were followed carefully and thoroughly, NPS hired a separate landscape firm. Although having two unrelated contractors at the construction site made coordination more difficult, it successfully ensured all vital aspects of the project received appropriate attention from experienced contractors. The contractor's responsibilities included providing and erecting a shade house, caring for plants being acclimated in the shadehouse, preparing and amending soil, cultipacking, applying native seed with a hand-held fertilizer spreader, installing erosion control blanketing and composted bark mulch, treespading 18 5-10 foot firs and hemlock, and planting native grass, sedge, forb, and shrub species in cone-tainer and gallon sizes. About 1100 gallons and 24,000 cone-tainers were installed. During the second (1995) planting season, Park staff filled in the initial plantings with approximately 15,200 cone-tainers and 1000 gallon containers.

### Fertilizer Specifications

A potentially divisive issue arose during preparation of specifications for the revegetation contractor. Because Crater Lake is the most oligotrophic lake in North America and harbors a unique microbiota in submerged volcanic vents (Phinney, 1989), the Park's resources management staff had serious reservations about using fertilizer on its rim. Further, the soils around Crater Lake are very permeable, and preliminary analysis suggested a high probability of nitrogen leaching. On the other hand, the revegetation test plots clearly

indicated a positive fertilizer effect. Treatments that used only peat amendments were not significantly different from the control (seeding alone). Seeding without adding fertilizer might result in poor groundcover establishment on a site that is quite vulnerable to wind erosion. Consultation with aquatic biologists at Crater Lake and the Oregon State University Cooperative Park Studies Unit (CPSU) resulted in the following compromise: the design team proposed a fertilization rate of 40 pounds usable nitrogen per acre. This rate was lower than that used in the test plots, but, because it approximated the amount of nitrogen removed from the system by destroying vegetation during construction, this addition was expected to have a minimal effect on the lake. The CPSU tested this rate in its mathematical model of the lake's nitrogen budget and found the rate represented less than a tenth of a percent of the nitrogen added to the lake each year from the atmosphere. Thus, fertilization proceeded at the specified lower rate. The availability of good baseline information helped the team and the Park find a satisfactory solution.

## MONITORING AND MAINTENANCE OF LODGE LANDSCAPE

### Monitoring and Maintenance Activities

Park personnel monitored revegetation efforts by evaluating survivorship (1995, 1996, and 1997), establishing permanent plots for comparative analysis of disturbed and undisturbed sites (1996 and 1997), and establishing photopoints for yearly visual comparisons. Plant density, canopy cover, and frequency per species was recorded in five meter-square plots in the seeded/planted area and in five meter-square plots in an adjacent undisturbed area.

Maintenance activities in 1995 included chaining off revegetated areas, irrigation as needed with a low-volume irrigation system from mid-July through mid-October, replacement of plants that had died, and eradication of exotic plants (*Taraxacum* spp.). Maintenance activities in 1996 included irrigation (as needed), replacement of plants that had died, eradication of exotic plants (*Lepidium campestre* and *Trifolium repens*), and installation of snow fence around select beds to trap and retain snow as an insulating blanket.

### Plant Growth and Survival

Overall survivorship of 1994 planting (except *Carex* spp., for which original numbers were unavailable) was estimated to be 87% in 1995 (table 1). In 1996, only shrub survival (80%) was determined since it was not possible to distinguish between "original" and "replacement" grasses and forbs. Shrub survival in 1997 was good overall, with some exceptions, such as *Ribes erythrocarpum* (table 2), which was apparently affected by harsh winds, intense sunlight, and high visitor impact in select beds. In comparison, *Spirea densiflora* exhibited excellent survivorship under various microclimates (table 2). The larger, transplanted trees placed in protected locations exhibited good survival and growth in 1997; some plant loss and stunted growth of surviving trees have occurred in areas receiving high winter winds without insulating effect of snow.

Table 1. First-year overwinter survival of shrubs and forbs transplanted around Crater Lake Lodge in fall 1994.

Species	# planted Fall '94	# surviving Spring '95	Percent Survival
<b>I. Woody species</b>			
<i>Acer glabrum</i>	17	17	100%
<i>Arctostaphylos nevadensis</i>	16	14	87%
<i>Ericameria bloomeri</i>	40	27	67%
<i>Lonicera involucrata</i>	148	145	98%
<i>Ribes cereum</i>	56	35	62%
<i>Ribes erythrocarpum</i>	97	95	98%
<i>Salix orestera</i>	17	17	100%
<i>Sambucus racemosa</i>	15	15	100%
<i>Sorbus sp</i>	31	28	90%
<i>Spiraea densiflora</i>	255	251	98%
<b>II. Forbs</b>			
<i>Anaphalis margaritacea</i>	184	107	58%
<i>Aquilegia formosa</i>	155	121	78%
<i>Erigeron peregrinus</i>	350	350	100%
<i>Eriogonum marifolium</i>	150	111	74%
<i>Lupinus latifolius</i>	8	8	100%
<i>Penstemon rupicola</i>	19	19	100%
<i>Polygonum newberryi</i>	5	5	100%
Overall survival:			87%

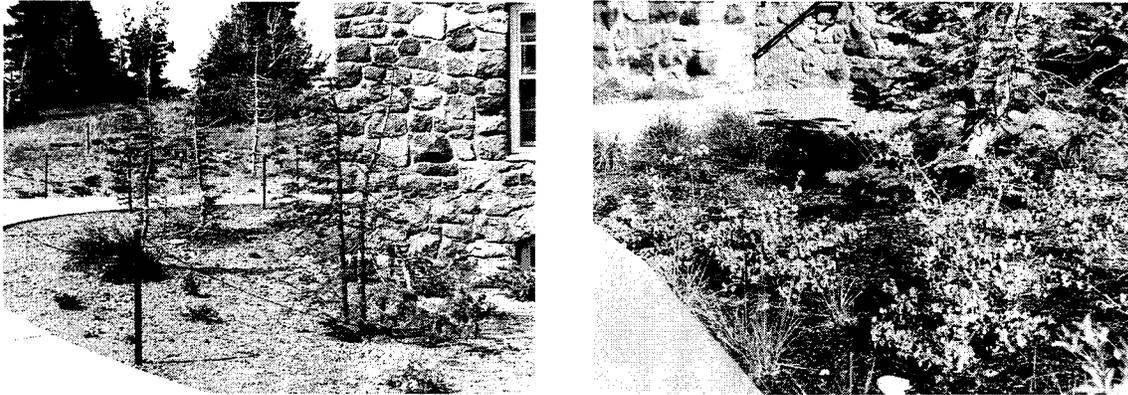
Table 2. 1997 survival comparisons of selected shrub species planted in 1994 to 1995 in 3 different beds surrounding Crater Lake Lodge.

Bed:	harsh winds; little snowpack; late afternoon direct sun	harsh winds; intense sun; high visitor impact	Little sun; sheltered; low visitor impact
Species			
<i>Ribes cereum</i>	79%	83%	--
<i>Ribes erythrocarpum</i>	30%	17%	86%
<i>Sorbus sp</i>	71%	--	82%
<i>Spirea densiflora</i>	100%	92%	95%
<i>Salix orestera</i>	--	75%	100%

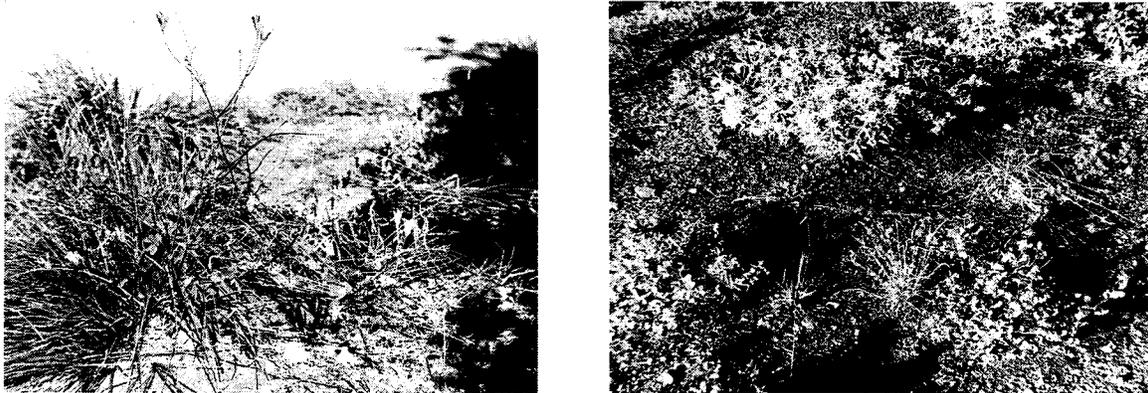
Forb and sedge survival was also affected by bed location or microclimate; species survival ranged from poor to excellent in 1997 (table 3, figure 1). Crown diameter of monitored forbs and sedges ranged from 7 to 66 cm in protected beds to 4 to 33 cm in beds receiving harsh winds, intense sun, and/or high visitor impact. *Anaphalis margaritacea*, *Eriogonum marifolium*, *Aquilegia formosa*, and *Carex* spp. were apparently sensitive to harsh sites; *Anaphalis margaritacea* may be more tolerant of visitor impact or trampling (table 3). Lush growth of several species in protected beds is illustrated in figure 2. Several seedlings of four forb species and two shrub species were observed in select beds in 1997, also indicating successful establishment and reproduction (recruitment) of these planted species.

Table 3. 1997 survival comparisons of selected forb and sedge species transplanted in 1994-95 in 4 different beds surrounding Crater Lake Lodge.

Bed:	sunlight: wind: visitor impact:	full day high minimum	afternoon low minimum	morning high high	morning low moderate
Species					
<i>Anaphalis margaritacea</i>		43%	100%	92%	95%
<i>Eriogonum marifolium</i>		60%	100%	58%	86%
<i>Aquilegia formosa</i>		53%	100%	58%	86%
<i>Carex spp</i>		--	97%	--	71%



**Figure 1. Effect of harsh conditions (left) versus protected conditions (right) on plant growth and establishment of shrubs, grasses, sedges, and forbs in Lodge landscape two to three years after planting.**



**Figure 2. Establishment of select shrubs, sedges and forbs in protected beds two to three years after planting.**

Seeding and planting grasses, sedges, forbs, and shrubs in beds near the Lodge with amended soil and protected with erosion control blanketing resulted in good plant establishment and cover (figure 3). Plant community compositions

of revegetated plots versus undisturbed "natural" plots at the rim were significantly different in terms of mean density and canopy cover in 1996 (table 4). A few species, *Bromus carinatus* particularly and *Elymus* spp., comprised the majority of seedlings (plants) and cover of revegetated plots, while several species, including *Gaophytum* sp., *Eriogonum* spp., *Bromus carinatus*, *Stipa occidentalis*, *Elymus* spp., and others) comprised the majority of plants in undisturbed plots (table 4). Interestingly, *Eriogonum* spp., provided significantly greater mean canopy cover in undisturbed plots than other species (table 4). Total mean canopy cover was less than 8% in revegetated plots in 1996, versus approximately 66% in undisturbed plots (table 4). However, canopy cover (in conjunction with erosion-control blanketing) was effective in terms of controlling erosion and promoting seed germination and seedling establishment (figure 4), and canopy cover and species diversity is expected to increase with time.

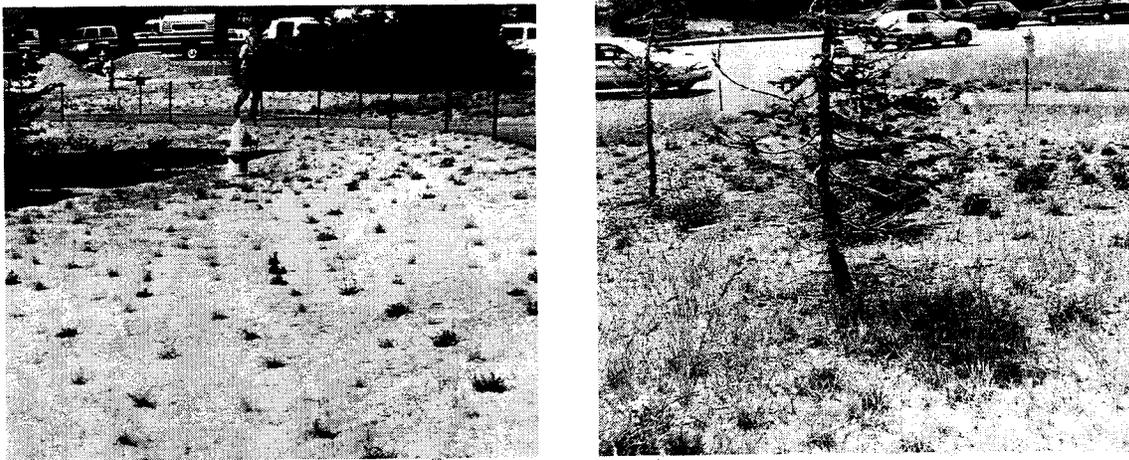


Figure 3. Seeding and planting amended beds in conjunction with erosion-control blanketing in 1994-1995 near Lodge (left) resulted in good plant establishment and cover in September, 1997 (right).

Table 4. Mean density and canopy cover of species in seeded versus "natural" area plots in 1996 at Crater Lake National Park.

Species	Mean Density (#/m <sup>2</sup> )		Mean Canopy (Percent)	
	Seeded	Natural	Seeded	Natural
<i>Anaphalis margaritacea</i>	0.1	0.0	0.05	0.05
<i>Bromus carinatus</i>	84.8	8.2	6.98	1.23
<i>Carex spp</i>	1.1	3.6	0.06	1.50
<i>Elymus spp</i>	16.8	5.2	0.12	0.89
<i>Eriogonum spp</i>	0.2	8.7	0.14	52.31
<i>Castilleja spp</i>	0.0	1.3	0.00	0.10
<i>Gaophytum spp</i>	0.0	13.1	0.00	0.02
<i>Phacelia sp</i>	0.0	3.8	0.00	0.96
<i>Phlox diffusa</i>	0.0	4.8	0.00	0.25
<i>Polygonum newberryi</i>	0.0	1.2	0.00	0.25
<i>Stipa occidentalis</i>	2.0	7.9	<0.01	2.30
	<u>105.0</u>	<u>57.8</u>	<u>7.36</u>	<u>65.62</u>



Figure 4. Seeding and planting disturbed area near Lodge in 1994 (left) has resulted in adequate plant establishment and canopy cover in 1997 (right).

## SUMMARY

Success of the Crater Lake Lodge restoration planting depended on flexibility in planning and implementation as much as development of appropriate objectives and planting plan or design. The final design blended ecological restoration techniques and principles with more conventional horticultural practices to achieve a stable landscape in a relatively short time frame. Finally, it is hoped the documentation of decisions reached and reasoning for these decisions will be useful to those responsible in the continued care and development of the Lodge landscape.

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## **STREAM RESTORATION AT DENALI NATIONAL PARK AND PRESERVE**

Roseann V. Densmore  
U.S.G.S., Biological Research Division  
1011 East Tudor Rd.  
Anchorage, AK 99503

and

Kenneth F. Karle  
National Park Service  
P.O. Box 9  
Denali National Park and Preserve, AK 99755.

### **ABSTRACT**

Placer mining for gold has severely disturbed many riparian ecosystems in northern regions. We are conducting a long-term project to test methods to promote restoration of a placer-mined watershed in Denali National Park and Preserve. The project included hydrological restoration of the unstable and excessively confined stream with heavy equipment. We stabilized the floodplain with bioengineering techniques, including alder and willow brush bars anchored laterally to the channel and willow cuttings along the channel. A moderate flood near the end of construction showed that the brush bars provided substantial protection, but some bank erosion and changes in slope and sinuosity occurred. Subsequent refinements included greater sinuosity and channel depth, pool/riffle construction with stone weirs, and buried alder and willow brush projecting from the bank. The reconstructed stream and floodplain have remained stable for five years, but have not been re-tested by another large flood. The willow/alder riparian plant community is naturally revegetating on the new floodplains, but vigorous willows which sprouted from branches in brush bars and banks still provide the erosion protection.

### **INTRODUCTION**

Placer mining for gold has severely disturbed many riparian ecosystems in northern regions. Placer mining involves removing vegetation and topsoil, excavating gravel down to bedrock from the active floodplain, old terraces, and/or the active stream channel, and processing the gravel to remove the gold. Placer-mined streams in the Kantishna Hills region of Alaska's Denali National Park and Preserve have unstable or excessively confined streambeds and over-steep floodplains along many reaches. Piles of mine tailings have replaced much of the native streambed material. Some floodplain soil was stockpiled, but most was buried beneath tailings or washed downstream. Riparian vegetation is sparse or absent, and habitat value has been severely reduced.

With such a disturbed riparian ecosystem, recovery through natural processes is hindered. In channel reaches where the stream bed is incised and straightened, bed scouring continues to occur. During annual flooding, erosion of over-steep banks results in excessive sediment loading of the stream. This sediment load is then deposited in the channel downstream in areas of shallower gradient, resulting in additional problems such as cementing of substrates and clogging of benthic

invertebrates. Incised stream channels also prevent flooding, thus interrupting the natural process of floodplain sediment deposition.

The National Park Service (NPS) is conducting long-term multi-disciplinary research on methods to promote riparian ecosystem recovery. The primary study site is abandoned placer claims on lower Glen Creek in the Kantishna Hills. Projects include studies of natural plant succession and revegetation methods on areas above the active floodplain, the role of mycorrhizae and other soil microflora, benthic invertebrate populations, water chemistry, and suspended sediment (Densmore, 1994; Karle et al., 1996; Landolt et al., 1992; Treu et al., 1996). This paper addresses our research on techniques to restore the active floodplain and stream channel which would (1) reduce erosion, (2) allow the stream to develop floodplains, sinuosity, and pools and riffles similar to premining conditions, and (3) minimize construction needs. We focus on bioengineering techniques for stabilization of reconstructed floodplains and streambanks.

## STUDY AREA

The Glen Creek watershed study area is located in the Kantishna mining area, a group of rugged hills within Denali National Park and Preserve (Fig. 1). The watershed is 16.7 km<sup>2</sup>, with elevations ranging from 648 m at the mouth to 1372 m near Spruce Peak. The Glen Creek watershed is in the continental climatic zone of interior Alaska, but the continental pattern is modified by cooler summers and higher precipitation because of the greater maritime influence and a higher elevation. July averages 12° C, while January averages -18° C. Precipitation averages 48 cm annually with 72% occurring from June through September.

The bedrock geology of the Glen Creek watershed is faulted and folded quartzite and hornblende schist of the Birch Creek formation. The study area on lower Glen Creek was covered in the middle Wisconsin with glacial ice from the Alaska Range, and gravel and rocks deposited by the glacier are mixed with bedrock material in the alluvial gravels.

The study area is at treeline, and trees are confined to favorable sites on alluvial terraces and south-facing slopes. Tall shrubs dominate riparian vegetation on the floodplain and younger terraces, and low shrubs and herbs form the tundra vegetation on colder, more exposed sites. The mining severely disturbed the vegetation on the study area, but the predisturbance vegetation can be inferred from remnants and adjacent less-disturbed watersheds. On these watersheds the floodplain is dominated by feltleaf willow (*Salix alaxensis*) (Viereck and Little, 1972) 3-4 m tall, mixed with varying amounts of American greenleaf alder (*Alnus crispa*) 1-2 m tall, and an understory that usually includes the low shrub cinquefoil (*Potentilla fruticosa*), bluejoint reedgrass (*Calamagrostis canadensis*) (Hulten, 1968), and dwarf fireweed (*Epilobium latifolium*). The floodplain is vegetated to the bankfull stream level; natural flood or ice events which remove vegetation and initiate primary riparian succession are infrequent. Higher areas have balsam poplar (*Populus balsamifera*) and younger white spruce (*Picea glauca*), and old terraces have open stands of white spruce with an understory of dwarf birch (*Betula glandulosa*) and diamondleaf willow (*Salix planifolia*).

The Glen Creek watershed was hand-mined from 1906 to 1941. The stream was diverted and dammed, and topsoil and fines were washed away, but the areal extent of disturbance was limited relative to later mining. In the 1970's, the study area on lower Glen Creek was extensively mined with the bulldozer/washplant method. In 1988, 9-15 years after mining had ceased, the study area was dominated by unstable gravel and rock spoil piles 3-8 m tall. Spoil piles differed in particle size distribution, depending on whether the excavated alluvial material had been processed and on the type or stage of processing, but most of the topsoil was gone.

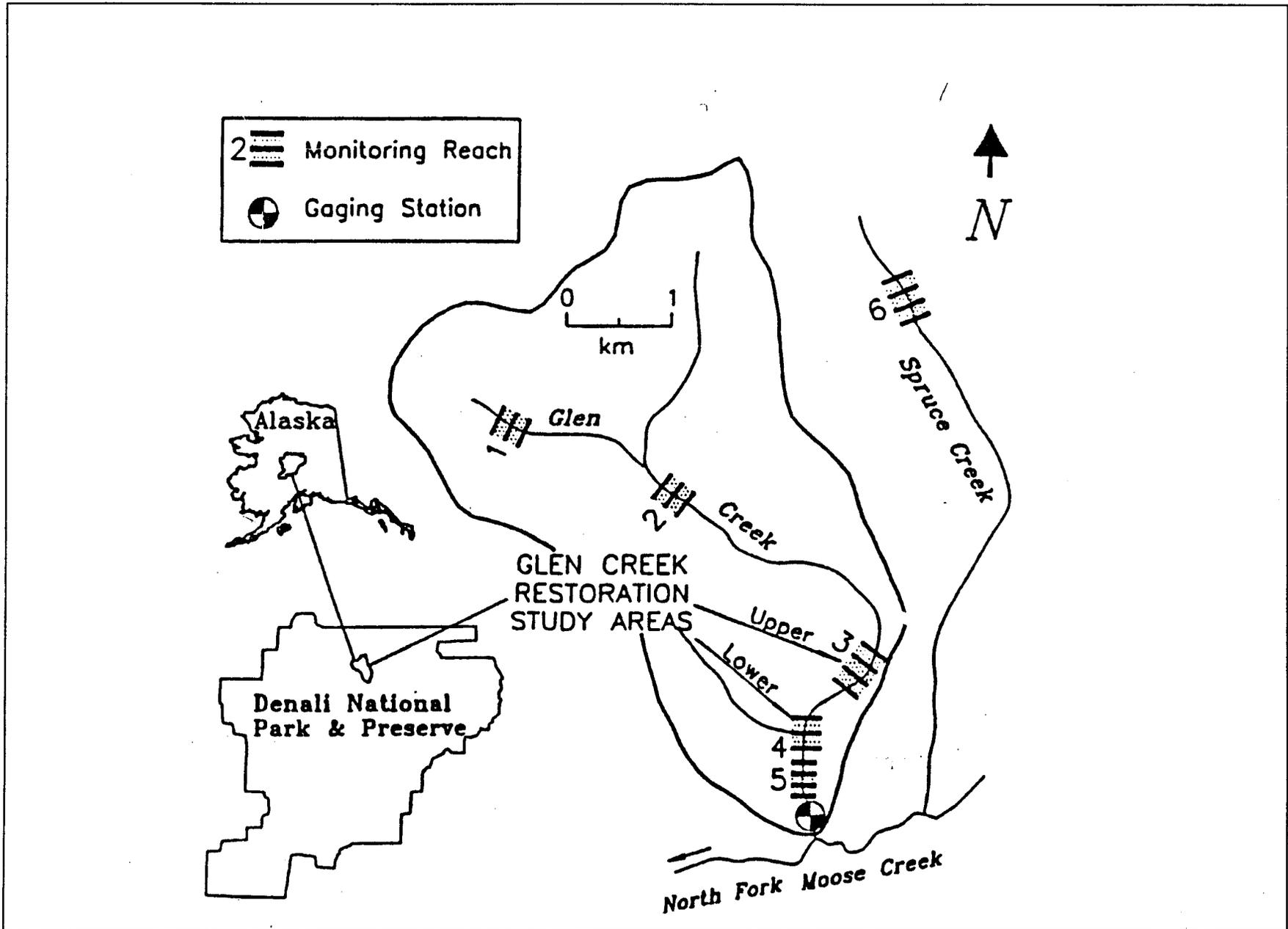


Figure 1. Location of the study area.

Reclamation of the study area began in August 1988, when the area above the active floodplain was recontoured (Schramm, 1988). The recontouring redistributed spoil to reduce and stabilize slopes, but left the stream channel incised and unstable.

## METHODS

Design parameters for channel and floodplain reconstruction are described elsewhere (Karle and Densmore, 1994a,b). We used a crawler-dozer, articulated front-loader, and dump truck to reconstruct a 425 m reach of Glen Creek (upper study area) in 1991, and a 925 m reach (lower study area) in 1992. The two study areas were separated by a relatively undisturbed reach in a narrow canyon. Most of the work involved recontouring raised tailings to a shallow sloping floodplain, leaving the existing channel undisturbed except for minor bank modifications. On the lower study area, a 110 m section of channel was repositioned from the valley wall to the center of the floodplain.

We predicted that serious damage could occur to the new floodplains if a major flood occurred before natural revegetation took hold. On undisturbed floodplains, vegetation anchors the substrate, decreases water velocity, catches organic debris, and promotes sediment deposition. We designed a brush bar to slow flood water velocity and encourage sediment deposition. The brush bars were bundles of cut alder, approximately 0.5 to 0.75 m in diameter and 4 to 5 m in length. Bars included one 4 to 5 m long feltleaf willow branch buried in the lower half of the bundle, and five feltleaf willow cuttings planted into the downstream side of the bundle. We used as little feltleaf willow as possible because few mature willows were left after mining, and we wanted to limit damage to the remaining habitat. Alder, on the other hand, was very abundant along old mining roads. The bundles were installed by first digging a trench into the floodplain perpendicular to the channel. Several manila rope lengths were placed across the open trench, the lower half of each bundle was set into the trench, and the trench was then backfilled, the top half of the bundle was added, and the ropes were tied around the bundle to anchor the bundle in place. We fertilized the brush bars with time-release Osmocote fertilizer (13-13-13 NPK) at a rate of 500 kg/ha. One-half of the fertilizer was spread in the bottom of the trench, and the other half was spread on the backfill. In 1991, we installed 26 brush bars on the upper study area. The bars were spaced two channel widths apart. For the 1992 project, we installed 30 brush bars on the lower study area, with the spacing at one channel width apart.

We also planted feltleaf willow cuttings and alder seedlings to anchor the substrate and catch organic debris. In 1991, on the upper study site, cuttings were planted on two newly-constructed floodplains, one protected by brush bars and one unprotected by brush bars. Each floodplain planting site was divided into three replicate blocks. Each block was divided into two plots. We collected feltleaf willow cuttings near the site and planted 25 seedlings in each plot in rows of five perpendicular to the stream in a 0.5 m wide band bordering the stream channel. In each replicate block, the upstream plot was fertilized with Osmocote 13-13-13 NPK at a rate of 500 kg/ha by spreading the fertilizer in the trench dug for each row of cuttings. In 1992, on the lower study area, we collected feltleaf willow cuttings near the site and planted 15 seedlings in each space between bars. Cuttings were planted in rows of five perpendicular to the stream in a 1.0 wide band bordering the stream channel. Each cutting was fertilized with one teaspoon of Osmocote (13-13-13).

A moderate flood occurred in the Glen Creek watershed just as the 1992 stream and floodplain work was completed. The effects of this flood provided important data which was used to refine the design and develop new techniques. We describe the flood effects in this section to provide

sufficient background for our post-flood methods, but details of changes in channel and floodplain morphometry are presented in Karle and Densmore (1994a,b), and bioengineering results are expanded in the Results section. On the upper section, the flood eroded the floodplains which were not protected by brush bars. Brush bars provided substantial protection, but high water ran behind the brush bars, undercut the stream ends of some bars, washed out one bar, and cut a new channel between bars in a floodplain area with unconsolidated material. In the new channel section in the lower study area, the unarmored channel bed contributed to extensive erosion on the unprotected side of the channel. On the other side of the channel, water ran behind the first bars and undercut the stream ends of some bars, but most of the floodplain was protected. Overall, stream slope decreased and sinuosity increased.

To address these problems, we tested modifications and new techniques in 1994. These included construction on the upper study site of a point bar to create a meander with a deeper channel, reconstruction of eroded floodplains, and construction of a series of pools and rock weirs between the reconstructed floodplains. In the lower study area, we redesigned the channel structure with a deeper, narrow channel. A point bar and meander were also constructed. We deliberately bulldozed some soil and vegetation from adjacent areas with mature willow and alder into the new point bars and reconstructed floodplains. Design details are not included here but may be obtained from the author (Karle, unpublished data).

We addressed the problem of floodwater flowing around bars by extending the first four bars to reach a steep slope on the upper study area and to reach the second terrace on the lower study area.

To protect the streambank itself, we buried willow and alder branches along 31 m of the bank of a reconstructed floodplain. We constructed the floodplain to a height just above the mid-season water level, placed branches 3-4 m long perpendicular to the stream with the ends projecting approximately 0.5 m from the bank, and bulldozed additional material over the branches. Branch density was 1-2 feltleaf willow and 2-3 alder branches/m of streambank. Feltleaf willows and one-half of the alders were buried with the branch tip projecting from the bank. The remaining alders were buried with the branch base projecting from the bank.

We evaluated bioengineering structures and plantings and natural revegetation on the upper study area in August 1995, and on lower study area in August 1996; on each site this was four growing seasons after the initial stream and floodplain reconstruction. We mapped the position of the brush bars in relation to the stream channel. We classified willow cuttings planted between bars as live, dead, or washed out, and measured the height of each willow plant. On the lower section, we counted the number of willows sprouting from the bars, and measured the height of each sprouted willow.

For the brush buried in the new floodplain, we mapped the location of each branch, recorded the species and whether the branch tip or base projected from the streambank, and the distance the branch projected from the bank. In 1995, we recorded the number of sprouts on each branch.

We established permanent plots for long-term monitoring on the reconstructed floodplains in 1993, and analyzed soil samples from these plots for texture and nutrients. We measured natural revegetation in these permanent plots by establishing line transects in the upper study area in 1995 and in the lower study area in 1996. On the upper study area, we established three 5 m line transects in each permanent plot, one transect perpendicular to the stream channel in the middle of the space between brush bars, one transect adjacent to the downstream side of a brush bar, and one transect on the upper slope of the floodplain above the brush bars. On the lower study area, we established four line transects in each permanent plot, one 6 m transect parallel to the stream between brush bars, two 4 m transects adjacent to the downstream sides of two brush bars, and one 5 m transect on the upper slope of the floodplain above the brush bars.

We measured cover in 1-cm increments along the line transects. Vascular plant cover was measured by species, and ground cover was measured as rock, soil, cryptogamic crust, moss, or litter. Cryptogamic crust is a mixture of algae and lichens growing on the soil surface. It appears as a blackish crust on the surface between stones on rocky sites and as spots or a continuous cover on areas with more soil. We measured species composition in a 0.5 x 5 m plot adjacent to one side of the transect on transects which were not next to a brush bar. On transects next to the brush bar, the line transect ran lengthwise down the center of the plot. All vascular plant taxa present in this plot were recorded. To measure woody plant density and growth, we subdivided the plot used to measure species composition into 0.5 x 0.5 m subplots. In each subplot, we measured the height of the tallest feltleaf willow seedling and the tallest alder seedling, and recorded the number of seedlings of all woody plant species.

## RESULTS

### Brush Bars

In the 1992 flood, most of the bank and floodplain erosion occurred on areas which were not protected by brush bars. For example, on the new channel section, serious erosion occurred on the unprotected west bank, as compared to minor erosion on the east side with the brush bars (Fig. 2). The first few bars on each reconstructed floodplain took the brunt of the flood. On the upper study area, the floodwater eroded the floodplain in front of and under the end of some of these bars, and bent the bar around the resulting corner. This configuration prevented further erosion and has remained stable, with the stream flow channeled against the front of the bar, and a pool formed on the downstream end of the bar. On the lower study area, the first bar washed out entirely and the second bar wrapped around. On the new channel section, the first bar remained in place and cobbles (to 20 cm) and gravel were deposited in front of and on top of the bar to a depth of 0.5 m.

Floodwater cut behind most of the brush bars in the upper study area. The main problem was not the formation of a high-water channel, but water flowing back into the channel in the areas between brush bars. This not only decreased deposition but eroded the existing floodplain material. On the lower study area, floodwater cut behind only the first few bars (Fig. 2). The remaining bars encouraged sediment deposition, as planned, with 5-10 cm of fines deposited between bars and large amounts of silt deposited within bars.

After four years, the manila ropes holding the brush bars had disintegrated, as planned. The willow branches and cuttings within the bars had sprouted and grown vigorously, and now held the bar together. Along the new stream channel in the lower study area, there were  $4 \pm 0.3$  (mean  $\pm$  SE) willow plants sprouting per bar from 25 bars. Most plants from brush bar sprouts were 0.5-1.5 m tall, with a mean height of  $90 \pm 5.1$ .

### Willow Cuttings

The willow cuttings planted along the stream bank provided little or no erosion protection during the 1992 flood. At the time of the flood, the cuttings on the upper study area had grown for one year and the cuttings on the lower study area had just been planted. On the upper study area, all the cuttings planted on a floodplain which was not protected by brush bars were washed out, while only 14% of the willows planted between brush bars on both sites were washed out.

Four years after planting, overall survival of cuttings which were not washed out was 80% (Fig. 3). On the upper study site, the fertilization treatment had no effect on survival, but fertilized cuttings were twice as tall as unfertilized cuttings (Fig. 3).

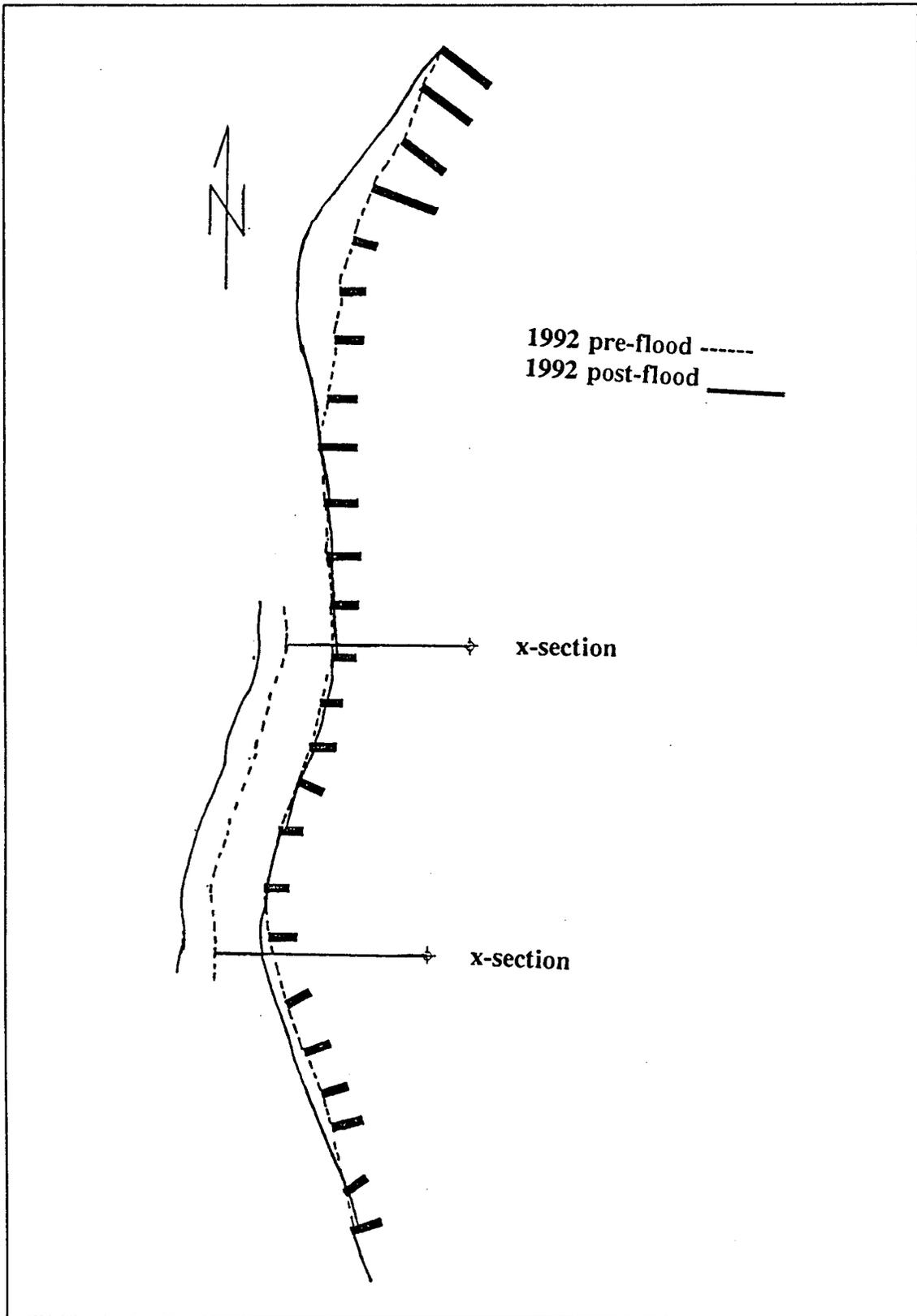


Figure 2. Map of the new stream channel section in the lower study area, showing brush bars, the location of east streambank before and after 1992 flood, the estimated location before and after the 1992 flood of the section of the west streambank between surveyed cross-sections, and the new brush bar extensions and new point bar constructed after the 1992 flood.

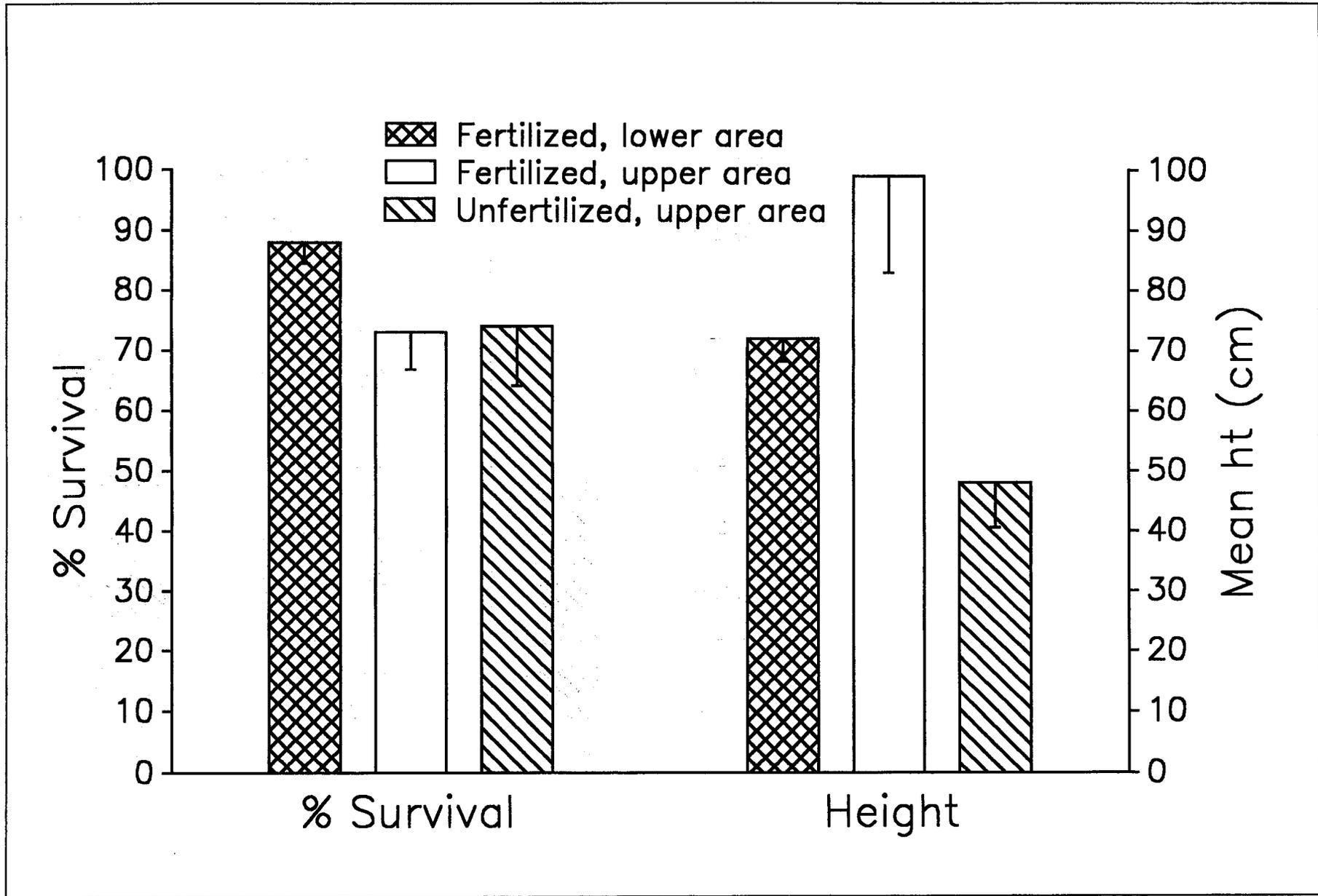


Figure 3. Survival and growth of planted feltleaf willow cuttings after four years, with and without time-release fertilizer on the lower study area.

## Natural Revegetation

Natural revegetation of the reconstructed floodplains was relatively slow on both study areas, with the exception of islands of vigorous growth around brush bars. After four years, vascular plant cover on the floodplain above the brush bars was 10% on the upper study site and only 2% on the lower study site, with similar cover levels for nonvascular plants (Fig 4). Almost all of the nonvascular plant cover on the study areas was cryptogamic crust, a thin blackish layer on the soil surface composed primarily of two nitrogen-fixers, the cyanobacteria *Microcoleus vaginatus* and the soil lichen *Collema tenax* (J. Belnap, personal communication). On the lower study site, vascular and nonvascular plant cover between bars was higher than on the floodplain above the bars. On both sites, the highest cover and most vigorous vegetation was adjacent to the brush bars (Fig. 4).

The woody plants colonizing the reconstructed floodplains included feltleaf willow, other willow species, alder, balsam poplar, and white spruce. The density of all woody taxa, measured as seedlings/m<sup>2</sup> (mean ± SE), was 23 ± 3.7 on the floodplain above the brush bars, 23 ± 2.4 between brush bars, and 38 ± 4.7 adjacent to brush bars. Seedling density was similar in all areas of the lower study area (31 ± 5.4 on the floodplain above the brush bars, 33 ± 7.4 between brush bars, and 30 ± 3.4 seedlings/m<sup>2</sup> adjacent to brush bars).

All floodplain areas of both study sites were well stocked with feltleaf willow, the dominant riparian species (Fig. 5). However, only seedlings adjacent to brush bars were growing rapidly (Fig. 6). Seedlings on the remainder of the floodplain were growing relatively slowly (measured seedlings were three or four years old) (Fig. 5). Stocking of alder was relatively high on all areas of the upper site (Fig. 5). On the lower site, alder stocking was high only adjacent to the brush bars, and there were very few alder seedlings on the floodplain above the brush bars.

## Post-Flood Experiments

On the lower study area, the new meander constructed with deeper channels and a new point bar has remained stable, but the new meander on the upper study area increased in length, eroding the cut bank. The rock weirs partially maintained the pool and riffle sequence, but the pools partially filled with gravel. On the reconstructed floodplain where we buried willow and alder branches which projected from the streambank, 93% of the willow branches had sprouted by 1995. By the end of the 1997 growing season, we observed that these willow sprouts had grown vigorously and the streambank appeared to be fully vegetated.

## DISCUSSION

The moderate 1992 flood demonstrated that the brush bars protected unvegetated floodplains. In fact, the brush bars stabilized the channel so effectively that we were concerned that they prevented needed channel adjustments in some spots. After four years, the ropes had decayed, and the bars were held together by vigorous feltleaf willow plants which had sprouted from the willow branches planted in the bars. In addition, the 1992 flood filled the brush bars with silt, and vegetation established within the bars. The growth of vegetation within and adjacent to the bars was stimulated by the time-release fertilizer placed in the bars, and also by nitrogen from decomposition of the alder leaves on the branches buried under silt.

The brush bars on the upstream end of floodplains were too short to prevent erosion from the

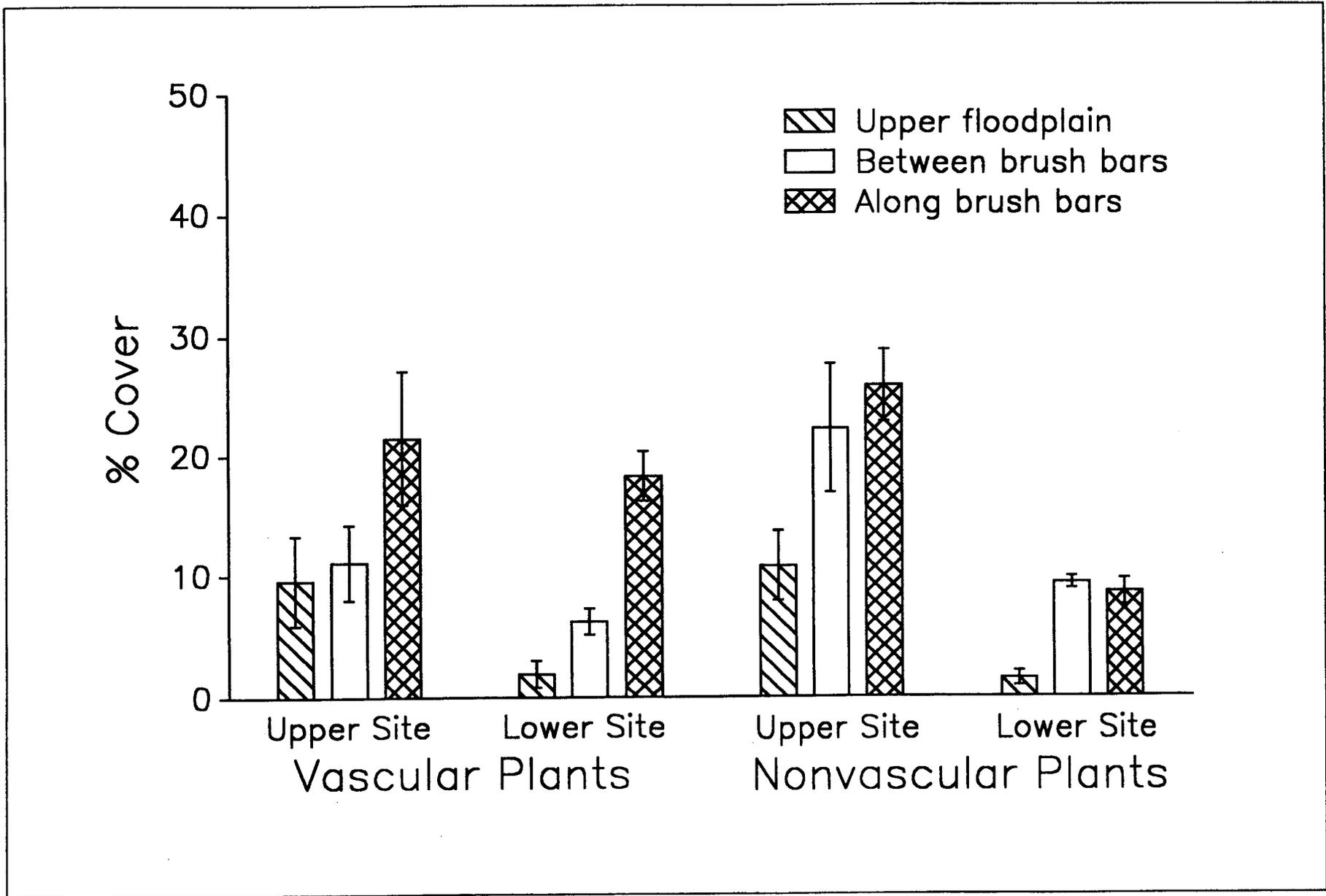


Figure 4. Vascular and nonvascular plant cover after four years on the reconstructed floodplains above the brush bars, between the brush bars and adjacent to the brush bars on upper and lower study area.

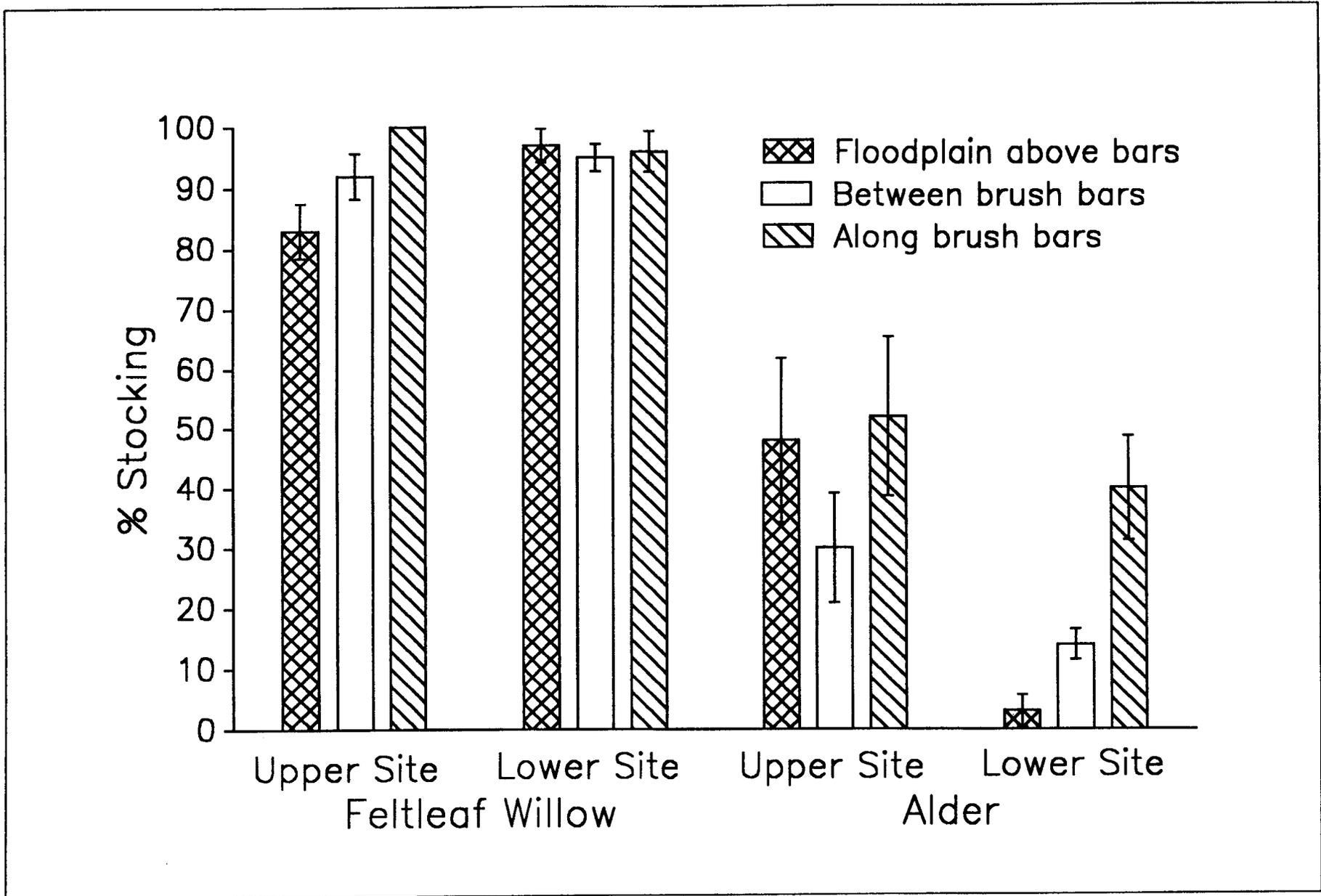


Figure 5. Natural revegetation of feltleaf willow and alder after four years on the reconstructed floodplains above the brush bars, between the brush bars, and adjacent to the brush bars. Stocking levels were measured as the percentage of 0.25m<sup>2</sup> plots with at least one seedling.

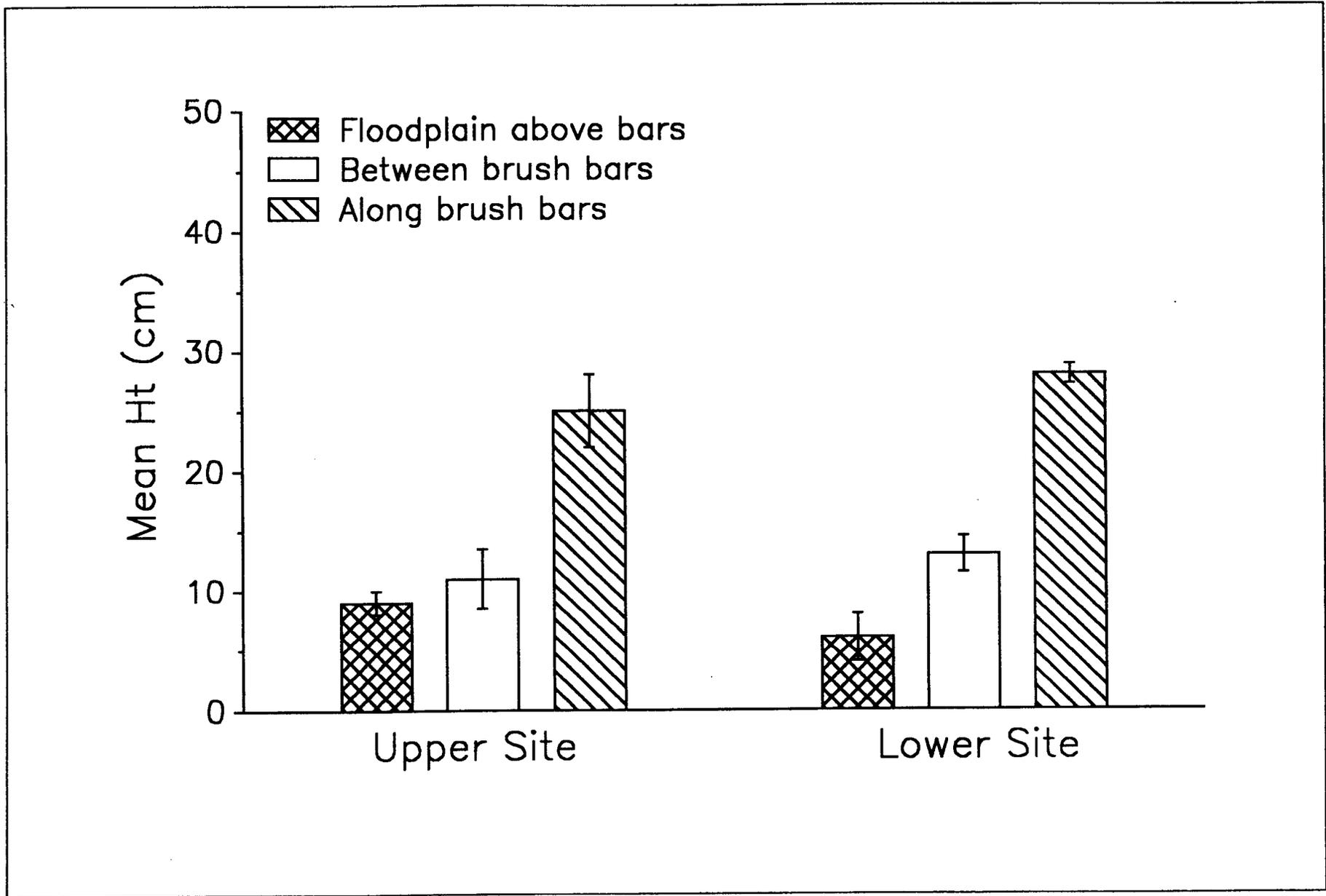


Figure 6. Growth of feltleaf willow seedlings after four years on the reconstructed floodplains above the brush bars, between the brush bars, and adjacent to the brush bars.

floodwater cutting behind bars. We extended the bars to reach higher terraces or slopes adjacent to the floodplain, and willows in these extensions have also grown vigorously. The rock weirs on the upper study area have successfully directed water flow toward the center of the channel and away from the erodible streambank. However, the weirs have not been able to maintain the desired pool/riffle sequence, and the constructed pools have mostly filled with gravel. The streambank protection design with buried alder and willow branches projecting from the streambank successfully revegetated the streambank with feltleaf willow. The post-1992 flood design modifications, including the modified channel design, extended brush bars, rock weirs, and streambank plantings have tested only by annual high water levels, but have not been subjected to another large flood.

The 1992 flood eroded both freshly planted feltleaf willow cuttings and cuttings which had been growing for one year. After four years, the willows from fertilized cuttings were vigorous and provided a band of vegetation along the streambank. Our experiments showed that the time-release fertilizer was essential on low-nutrient placer mine tailings, as the unfertilized cuttings were stunted and not vigorous. A temporary lack of mycorrhizae contributed to the need for fertilizer. Laursen (unpublished data) investigated mycorrhizal development on planted feltleaf willow cuttings on our study site. He found that development of mycorrhizal associations was delayed on cutting roots for one to two growing seasons. We strongly recommend using time-release fertilizer in subarctic riparian areas. In previous work, we found that almost all of the nitrogen from regular fertilizer leached rapidly from the root zone and into the water table, and had little effect on the planted cuttings (Densmore et al., 1987; Neiland et al., 1981). Fertilizer release in the time-release fertilizer we use is temperature-dependent, meaning that in the subarctic climate of our study area fertilizer release is usually spread over more than one growing season.

Our design relied on natural revegetation for restoration of riparian revegetation on the reconstructed floodplains. After four years, all floodplain areas had been colonized by the dominant riparian species. The species composition was similar to successional communities on nearby unmined streams (Densmore, 1994). However, the growth rate of feltleaf willows was optimal only adjacent to brush bars. The growth rate of willows was slow on the upper part of the floodplain above the brush bars, particularly on the lower study area. In previous work in this study area, we have found that low levels of nitrogen in the mine tailings were a major factor limiting growth of feltleaf willow and other species. Feltleaf willow seedling growth was better between bars because of fertilizer on cuttings, silt deposition, and perhaps because seedlings were closer to water table.

On the lower site, very few alder seedlings established on the floodplain above the brush bars. The alder seed source was adequate, so we attribute the lack of alders to the lack of adequate fines and nutrients in the mine tailings used to construct this floodplain. We found in other work on this site that coarse, well-drained, nutrient-poor substrates limit alder seedling establishment, but not the growth of established plants (Densmore, 1994).

We predict that all areas of the reconstructed floodplains on the upper study site, and the streamside areas with brush bars on the lower study site will naturally revegetate to riparian tall shrub communities. Because of the slow growth of feltleaf willow and the absence of alder, we speculate that the upper part of the reconstructed floodplains on the lower study area may eventually regenerate to a sparsely vegetated subalpine community rather than to tall riparian shrub. In view of the slow growth of natural revegetation, our temporary floodplain stabilization techniques, particularly the brush bars, still provide most of the floodplain protection.

## ACKNOWLEDGEMENTS

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## **THE PHILOSOPHY OF WEED MANAGEMENT AND ITS PRACTICAL APPLICATION**

Eric M. Lane  
Colorado Department of Agriculture  
700 Kipling Street, Suite 4000, Lakewood, CO 80215-5894

### **ABSTRACT AND INTRODUCTION**

Noxious weed management, as a philosophy, focuses heavily upon the use of integrated pest management (IPM) techniques to provide a desired degree of control of targeted noxious weed populations. However, achieving this desired degree of control relies on much more than a simple selection and application of biological, chemical, cultural, or mechanical control methods. Concepts and strategies that emphasize a thoughtful, practical approach to managing plant populations are essential to accomplishing management objectives such as eradication, control, and restoration. In recent years, the concept of weed management has been articulated as efforts to shift the species composition of degraded plant communities to that of desired, or healthy, plant communities. This concept provides a more productive framework for the successful and practical application of IPM techniques. In addition, strategies that weigh the life history characteristics of targeted species as well as the means by which invasive plant populations spread and expand have been used to target limited resources more cost-effectively and successfully. Finally, a growing variety of management techniques can now be selected and used to produce, in additive or synergistic fashions, the desired degree of control of noxious weed populations. If restoration efforts are to succeed in a timely and cost-effective manner, our simple reliance on an IPM-based weed management philosophy must be expanded to include the practical application of these concepts and strategies.

### **WEED MANAGEMENT - WHAT IS IT?**

As a concept, a conventional, or traditional, understanding of weed management encompasses several important aspects:

1. Goals related to the reduction or elimination of targeted noxious weed populations,
2. A focus on a common denominator: the undesired presence of noxious weeds, and
3. An emphasis on reducing weeds to a level or threshold at which a level of harm is acceptable.

Consequently, a conventional definition of weed management might be: efforts to eliminate or substantially reduce targeted noxious weed populations through the use of techniques designed to cause plant mortality or suppress plant growth and reproduction.

Not only does weed management focus attention upon the weeds themselves but also upon the techniques that help us to combat them.

### The Role of Integrated Pest Management

There are a variety of tools weed managers use to eliminate or reduce noxious weed populations. They include numerous techniques that are typically categorized as biological, chemical, cultural, and mechanical. In fact, it is a common understanding that effective weed management can best be accomplished by selecting a combination of techniques from a "toolbox" of all possible weed management tools. Integrated pest management (IPM) may be defined as the selection and use of a variety of management techniques in combination to reduce targeted weed populations through additive or synergistic effects.

Weed management, as currently practiced, focuses heavily upon the use of IPM to provide a desired degree of control of targeted noxious weed populations. As a result, many weed managers emphasize the use of tools to resolve society's noxious weed problems. Unfortunately, the substantial emphasis placed on the use of tools may be preventing natural resource managers from implementing effective, long-term weed management plans. Weed management is a very complex task and it will require a more complex solution than simply selecting and applying biological, chemical, cultural, or mechanical control methods. Concepts and strategies that emphasize a thoughtful, practical approach to managing plant populations are essential if management objectives such as eradication, control, and restoration are to be accomplished.

### STRATEGIES - BEYOND THE TOOLS

The emphasis of our conventional understandings of both weed management and IPM, as articulated above, is on the impact to noxious weed populations. In fact, the very concept of weed management relies upon the tools used to inhibit the spread and establishment of noxious weeds. It exhibits our human tendencies to think tactically rather than strategically; to think of how we can solve our problems by focusing on the tools available to us rather than on our own assessment of the problem itself.

In recent years, however, the concept of weed management has been articulated as efforts to shift the species composition of degraded plant communities to that of desired, or healthy, plant communities. This unconventional concept provides a more productive framework for the successful and practical application of IPM techniques by changing the focus of noxious weed management. With this new understanding of weed management, the evolution of plant community composition and structure becomes the goal rather than a reduction of targeted weed populations. Similarly, the focus of weed management becomes the presence of desired species rather than the presence of undesired noxious weeds. Also, the concept of a threshold emphasizes the improvement of ecosystem

function and health rather than the reduction of harm posed by the presence of noxious weeds. These altered views of the various aspects of our understanding of weed management coalesce in a new definition of weed management: efforts to manipulate and transform the existing plant community to that of a more desirable state through the use of techniques designed to alter site availability and disturbances, control colonization events, and control species performance (Sheley, Svejcar, and Maxwell 1996).

While weed management will undoubtedly continue to rely upon the tools and techniques created to manage weed populations, the role of IPM can also be transformed to fit this unconventional understanding of weed management. IPM will still include the use of a variety of biological, chemical, cultural, and mechanical tools selected and applied in a combined manner for best effect but its express purpose in weed management can now be to shape the composition and structure of the plant community and improve ecosystem health and function. Perhaps this new understanding of weed management and the role and purpose of IPM will benefit our efforts to achieve healthy and productive natural and agricultural systems where noxious weed populations are reduced to mere components of the systems rather than dominant features.

#### Using risk assessment techniques

In an effort to think strategically rather than tactically, weed managers should utilize strategies such as risk assessment to help prioritize tasks and resource allocation. There are only so many hours in a day and only so much money in the budget with which to accomplish a program's weed management objectives. Applying the tools of risk assessment to noxious weed management can identify where resources can best be used to achieve maximum effectiveness and long-term success. A familiar example of applied risk assessment is the U.S. Environmental Protection Agency's (EPA) Superfund program. This program assesses the environmental and human-health risks posed by the nation's worst toxic contaminated sites and prioritizes them for cleanup to minimize the risks, achieve maximum effectiveness, and promote long-term success.

A similar risk assessment protocol has been developed in recent years to help weed managers assess the risk posed by a variety of noxious weeds present at any one given site. Developed by Hiebert and Stubbendieck (1993), this risk assessment protocol identifies and prioritizes target species by assessing for each noxious weed its life history characteristics, the potential degree of ecological harm it may cause, and the feasibility of its control. This strategy allows weed managers to systematically prioritize tasks according to weed species. While it has not been widely used in Colorado, the National Park Service recently utilized this strategy to prioritize weed management efforts at Rocky Mountain National Park (Rutledge and McLendon 1997).

### Prioritizing target weed populations

Once target species are selected, another strategy can be employed to help weed managers develop a management plan based upon the extent of spread and distribution for each species. Developed by mathematical modelers Moody and Mack (1988), this strategy emphasizes the detection and elimination of new, small populations rather than management of larger, more well-established populations. Young populations tend to be less difficult to control since individual plants are less mature, may have significantly smaller root reserves, and have developed minimal seed banks in the surrounding soil. Larger, more mature populations frequently have massive seed banks, very substantial root systems, and contain individuals that will be difficult to kill.

Using this strategy, noxious weed populations should be prioritized based upon the extent of spread and degree to which targeted weeds have altered a plant community. If the community has not been significantly altered and the noxious weed population is suitably small or young, eradication efforts have a good chance of restoring the plant community to its former composition. In addition, emphasis should be placed upon the management of populations with significant potential for rapid spread to new locations due to vectors such as water, wind, trails, or roads. The management of species in such areas can significantly reduce the ability for targeted species to spread to new, uninfested areas.

### Implementing IPM in a more ecological fashion

In any system, there are ecosystem processes such as fire events, hydrology, and nutrient cycles to which native species are typically well adapted. Invasive species often alter these processes or take advantage of anthropogenic changes to invade and change the plant community. IPM techniques that work to restore these ecosystem processes may help to turn the competitive advantage back to natives that have been marginalized by invasive species.

In addition, IPM techniques that work in concert with natural processes may help to directly impact target species. For example, recent research in Boulder County, Colorado, is focusing on the use of prescribed fire to stimulate the germination of a large percentage of an invasive species' seedbank which can be subsequently killed with an herbicide application. Other research conducted by Colorado State University has focused on the use of grazing to not only impact targeted species but stimulate the production of grasses. New research in 1998 will focus on the use of herbicides to selectively thin noxious weed populations to promote the acceleration of biocontrol agent production and accelerate the rate at which noxious weeds and biocontrol agents attain a desired steady-state in equilibrium.

The use of IPM techniques in new and innovative ways, particularly in concert with natural processes, promises to provide new methods that not only impact targeted noxious weeds but also benefit the health of affected plant communities. The new definition of IPM, as the selection and use of a variety of management techniques in combination to shape the composition and structure of the plant community and improve ecosystem health and function, would seem to be of particular usefulness in this fashion.

## CONCLUSIONS

The concept of weed management is growing to include a stronger focus on the restoration of healthy and functioning ecosystems. However, to restore the composition of plant communities, weed management must include less of a tactical approach and reduce its reliance upon a simple collage of IPM techniques designed to kill weeds. Weed management must incorporate strategic approaches that apply techniques within the context of an overall management plan and promote efficient and effective use of limited resources. Using a strategic rather than a tactical, tool-oriented approach will help to improve cost-effectiveness and long-term success.

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# **HISTORY OF REVEGETATION IN THE WESTERN U.S. - HOW THE WAY WE WERE AFFECTS THE WAY WE ARE**

David L. Buckner, Ph.D.

ESCO Associates Inc.  
P.O. Box 18775  
Boulder, CO 80308

## **ABSTRACT**

Concern with vegetational replacement and, indeed the concept of conservation of natural resources in general, is a comparatively recent concern for we humans. In western history, we have traditionally viewed natural landscapes as, if not antithetical to the progress of civilization, then at least an inconvenient impediment to the advance of our welfare. To a large degree, the luxury of being allowed to be concerned with environmental preservation / restoration relates directly to the harnessing of the vast energy stored from ages before human existence in the form of fossil biomass.

Large scale disturbance of Western U.S. landscapes predated the advent of plant ecologists and even the birth of the science itself. Earliest motivations to encourage vegetational reestablishment were related to cases of massive environmental degradation -- the grazing "holocaust" of the late 19th century and the drought / "Dust Bowl" conditions of the 1930's are the prime examples. Although use of native species was given early attention, the advent of aggressive introduced species was a timely fit with the emergency circumstances of the Dust Bowl era. Concepts of "restoration" of pre-settlement plant communities are relatively recent. Focus on native species and exclusion of non-native species in restored landscapes is not without social controversy. Establishment of greater species and lifeform diversity on revegetated landscapes will require alteration of the "garden" model of plant ecology and changes in certain regulations.

## **INTRODUCTION**

It is appropriate and, I believe, productive to occasionally examine the historical roots of any human undertaking, including this subject of revegetation that brings us together at this conference. If the subject of revegetation is close to our hearts, and even has passing familiarity with the general public, it has not been so for long.

### **Historical Interest / Opportunity**

Throughout most of the few million years of human existence, our actions were directed toward the day to day necessities of survival. Although the argument is often made that human culture of prehistory was "closer" to nature, it was in my opinion, a closeness of necessity inseparable from the obvious lack of any alternative. It is the development of a concern for nature and natural features in the face of a viable alternative to ignore it that interests me here.

Prior to the advent of agriculture, human effects on the environment and specifically the vegetational component of the environment were certainly, by comparison to the present, small. We may have modified fire regimes in certain parts of the world and thereby affected vegetation structure and composition, but fire was most likely already an important ecological process in most of the affected ecosystems and sources of ignition were far more abundant than humans. Natural vegetation, even after the advent of agriculture and the subsequent rise of civilizations, was at least in western societies, viewed at most as an unexploited opportunity for replacement with agricultural land use. Natural landscapes were often viewed as malevolent, untamed, and in general incompatible with the best interests of humankind. Removal of the great forests of the primeval world not only provided structural material for ancient humans, but also opened land to controlled human use in the form of crop cultivation and husbandry of domestic livestock. Consequent environmental degradation either escaped notice or simply did not register in the priorities of the governing system of the time. In any case, the early history of western civilization was strongly facilitated by the existence, extensive use, and incremental destruction of vast forests from North Africa around the Mediterranean Sea through Europe to the British Isles. The central role of wood as fuel, and, especially as a structural material has been well-documented in Perlin (1989). As most of us remember from history courses, civilization came early to rely on the use of metals in everyday commerce and, especially, warfare. Early (Bronze Age) development was largely supported by finds of deposits of native (metallic) copper. Later technology of smelting of oxidized copper, tin and lead to metallic state was developed and the energy required was, of course, supplied by the burning of wood. With the advent of the Iron Age, the energy required to reduce the oxidized metal (i.e. iron ore) grew to huge proportions, and by the early 18th Century, the forests of Britain had been decimated by harvest to supply the ironworks, the output of which were nonetheless limited to the highest priority of that time, as in the present, armaments. The potential of iron as a structural material and as an everyday household material was rendered physically and economically impossible by the sheer lack of sufficient energy to reduce enough iron ore to metallic state. The pressure on forests of Britain had been intense for centuries and their decline was well-documented. It was apparently a great rarity, given the importance of the harvest of wood to the everyday (fuelwood and lumber) and the military (materials for ships) life of the time, to suggest any approach other than unrelenting harvest, but in 1660, John Evelyn, a member of the Royal Society, set forth "A Discourse of Forest-Trees and the Propagation of Timber in His Majesties Dominions." His impassioned efforts to conserve and restore devastated forest resources were rewarded in at least one small tract for a short period of time, but before long the point view that the sooner deforested, the sooner Britain would be truly civilized reasserted itself and the overall forest losses continued (Perlin 1989).

Although coal had been used for centuries already in heating and cooking, and in certain industries such as salt and glass production, its use in smelting iron had repeatedly failed due to the inevitable addition of impurities, especially sulfur, to the iron rendering it unusable. In about 1720, a man by the name of Abraham Darby devised a means of coking coal to produce a combustible material of sufficient purity that allowed the vast energy of the coal deposits of the world to fuel the reduction of iron ore, thereby facilitating its common and absolutely critical role in the infrastructure of civilization from that time to the present. The point of discussing this perhaps seemingly irrelevant historical event here is this: so long as the basic functioning of a society depended on the all-out exploitation of the natural landscapes (forests in this case), no such luxury as conservation or

revegetation could be conceived. We must realize that our opportunity to spend much of our lives concerned with reestablishment of vegetation on disturbed lands is a luxury afforded by the support of societal function and infrastructure through the use of fossil fuels.

In the western U.S., heavy forest cover in general was not, at the time of settlement, the most prominent landscape feature. Rather, it was the vast expanses of herbaceous cover in the form of grasslands and mountain meadows that attracted the earliest economic exploitation, with the possible exception of gold mining. Whereas the familiar landscapes of the eastern U.S. (and of Europe in centuries before) had been covered by heavy tree growth, requiring laborious clearing to produce open lands for livestock grazing, the West was already clear and huge expanses were covered with grass-dominated vegetation in seemingly unlimited amount. The potential for entrepreneurial gain was immense and the response in the form of large cattle and sheep "industry" funded largely by British speculators is well-documented. From the 1860's through the 1890's huge herds of cattle and sheep had been run on western landscapes, and by the 1890's the depletion of western rangelands was very apparent. This depletion left large areas nearly devoid of vegetation.

It should be noted that this is the condition in which the earliest plant ecologists saw the West. Plant ecology was not "born" until the 1880's and the earliest observers with ecological background were not on the scene until the after the turn of the century. This, I believe has skewed some perceptions of the nature of our native vegetation.

The U.S. Department of Agriculture Division of Agrostology and its successor the Bureau of Plant Industry, as well as the U.S. Forest Service all were involved with the real economic problems of the greatly decreased productivity of western rangelands and sought to remedy them by whatever the most economic means might be (Lamson-Scribner 1897, Sampson 1908, 1913, Griffiths 1907, Cotton 1908). In the late 1890's and the early 1900's investigation was made of the efficacy of 1) resting depleted lands and allowing revegetation to occur on its own, 2) the seeding of native plant species, and 3) the seeding of domesticated (or "tame" plants, as they referred to them). Generally most the most severely abused lands were so far depleted that natural regeneration was nil or very slow. Efforts to collect the seeds of natives ran into problems of low seed set and viability that would not be addressed at that time. By comparison, the familiar pasture plants of Europe mainly in the form of timothy (*Phleum pratense*), redtop (*Agrostis gigantea*), and white Dutch clover (*Trifolium repens*) had been bred over centuries to produce large amounts of highly germinable seed. The government researchers found to their surprise that these species, especially the grasses, could not only establish on depleted range with minimal seeding procedures but also could compete very well where native species were still present. In the initial studies, timothy and redtop were generally most successful but Kentucky bluegrass (*Poa pratensis*), smooth brome (*Bromus inermis*), tall fescue (*Festuca arundinacea*) and orchardgrass (*Dactylis glomerata*) were all used with varying and generally lesser degrees of success.

Out of the initial effort to reclaim depleted rangelands developed an enthusiastic point of view that native grasslands and meadows should be converted to "tame pasture" at the earliest opportunity, again demonstrating the prevailing frame of mind that land use was best conceived in the terms of controlled (and, of course, European) agriculture and that native species did not have a place in that context. Besides the low germinability of native seeds observed in the early studies, the

practice of sowing them on bare compacted ground sometimes without any harrowing at all produced very poor results. Meanwhile the high seedling vigor of the introduced species allowed them often to succeed under such conditions.

The next milestone occurrences in revegetation was of course, the effort to stabilize the marginal cropland that had little or no vegetational cover during the drought and "Dust Bowl" conditions of the 1930's and early 1940's. The response to this crisis rather naturally centered on the use of introduced species, given the experience with rangeland reseeding around the turn of the century and the introduction of since then of several Asian species including standard crested wheatgrass (*Agropyron desertorum*), Fairway crested wheatgrass (*Agropyron cristatum*), and intermediate wheatgrass (*Agropyron intermedium*). Given the emergency nature of the need to stabilize the denuded and badly blowing lands, it was natural and responsible to use plant materials that would respond rapidly. It should be noted that the nearly all of the adapted introduced species were cool season plants and many stabilization projects did include native warm season species, especially blue grama (*Bouteloua gracilis*) and sand dropseed (*Sporobolus cryptandrus*).

With the advent of large scale surface coal mining in the came the passage and implementation of laws at in the states of Wyoming and Montana and later at the federal level with the Surface Mine Control and Reclamation Act of 1977. This was an important step for two reasons. First, whereas previous efforts had focused on establishment of protective vegetation cover capable of controlling erosion and the reestablishment of livestock forage, in addition the new laws included for many situations, the requirement that woody plant establishment and the overall reestablishment of a cover of diverse species composition be accomplished. Second, the requirements for revegetation included quantitative performance standards that addressed the parameters of cover, forage production, woody plant density, and species diversity. Up to this time, the undertaking of revegetation was primarily an activity to be accomplished by a government agency in repair of imprudent private sector practice. Now the burden of revegetation was shifted to the private sector and very specific requirements were made applicable to the results.

With regard to the use of introduced species, not only were there, under some conditions, requirements that native species be used, but also the rapid establishment and exceedingly vigorous growth of the introduced species was not entirely advantageous anymore because, as a consequence, only the highly competitive species in a seed mix could survive and this usually did not include woody plants and most forbs. Seed mixes with aggressive non-natives were slowly changed to include less of the introduced species, but again and again, even small amounts of smooth brome, meadow brome, and intermediate wheatgrass in seed mixes have expanded to dominate resulting stands and the desired development of natives has been severely restricted.

Improvements in the establishment of woody plants and overall species and landscape diversity is not limited by the presence of introduced species alone. The requirement for replacement of topsoil at more or less uniform depth across large areas of reconstructed landscape greatly advantages grasses. The uniformly unconsolidated nature of topsoil-covered spoil approximates an ideal growth scenario for grasses whose fibrous root systems can evenly penetrate and thoroughly dominate the vast runs of fine material. Given this setup, the competitive superiority of grasses, be they native or introduced, tends to, at least in the short term, limit the establishment and growth of less aggressive grasses and forbs, as well as most shrubs in their younger stages. Revegetated

communities that are to ultimately be shrub-dominated need to be provided with the rocky, discontinuous substrate that characterizes the natural habitats of many shrub species.

In parallel, the interest in native species has initiated, largely through USDA Natural Resource Conservation Service Plant Materials Centers breeding programs, the development of named varieties of native species that have, among other things, predictable high seed production, germinability and seedling vigor, the lack of which frustrated the turn of the century attempts to incorporate native species in revegetation. Recent interest in use of local genomes in preserving adapted strains faces the same lack of conformance with a convenient "garden model" for plants in which seeds are harvested, sown, and establish on command. Although the arguments for preservation of local genetic races are persuasive, the difficulty in actually causing local genomes to become established on particular restoration sites is daunting. Perhaps the most practical approach is use of a "base amount" of dependable named varieties in the seed mix along with locally collected materials. This allows the potential for any viable propagules from local sources to assert site-specific superior adaptations that they may have.

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**THE GALLOPING FORESTER'S GUIDE TO SEXUAL PROPAGATION**  
**OR**  
**SO MANY SEEDS, SO LITTLE TIME**

Stephen J. Spaulding, Forest & Landscape Consultant  
Ute Pass Christmas Trees, Inc.  
P.O. Box 96  
Green Mountain Falls, CO 80819  
(719) 684-2333; upct@worldnet.att.net

**ABSTRACT**

Many plants used in revegetation efforts reproduce themselves readily by seed. The basic principles of propagation by seeds are the same whether one is growing one or one thousand plant species. This paper will highlight techniques and materials readily available for low volume plant production.

**INTRODUCTION**

Propagation from seed is the most practical way to obtain local plant species for use in reclamation efforts. The process of growing plants from seed is relatively simple; it is the "details" that can drive one crazy.

This paper provides a brief exploration of some of the processes and details required to successfully grow plants from seed. A short list of local woody plants and propagation tips is included. It should be understood that many of the suggestions provided here are geared toward a small, local use propagation operation.

**FACTORS AFFECTING SEED PRODUCTION**

Obviously in order to get started, you need seed with which to grow a plant. So it should be no problem to walk outside right now and start gathering seed up, right? Well, not quite.

For starters, there may not be a whole lot of seed out there to collect. Many factors influence the development of seed. Sometimes seeds are just aborted by a plant for no obvious reason. This is a physiological factor and is not well understood.

Weather is major player in the scheme of seed development. Freezing temperatures, strong winds and drought are a few examples. The timing of these weather incidents can cause pollination not to occur, destroy the flower structures of the plant or physically kill the seed embryo.

As if weather was not enough of a challenge, insects and diseases can attack at any point during the reproductive process. Insects are most notorious for feeding on the seed itself. Weevils boring into cones or acorns is an example of this type of damage.

Diseases can attack at any time also. Molds or fungi can attack the flowers of a plant destroying them. More importantly, they can piggy-back on the seed coat and kill the seedling as it germinates.

Most frustrating is predation by birds and mammals. There is nothing so heart warming as scouting out a potential seed collection area and then having it gobbled up by squirrels and blue jays prior to your harvest.

But in spite of all the hurdles plants must get over, there are seed crops of most plant species somewhere. The key is to keep your eyes open and scout out favorable areas where seed collection is promising. Be sure to inspect these locations regularly to monitor development so when the time for harvest arrives, there is sufficient seed to collect. With many plant species, there is usually a very small window of opportunity in which to gather seed. Make sure your effort is rewarded.

## COLLECTION & STORAGE

Collection is the fun part for it requires getting out of the office and into the big outdoors. It is assumed that most of the collection will be done by hand. If you require large amounts of seed, plan accordingly. For example, a timber harvest may provide an excellent means of obtaining large quantities of conifer seed.

A reminder, in some instances, you are not actually collecting the seed, but harvesting the fruit of the plant wherein the seed is contained. These structures have names such as cones, capsules, pods, (starting to sound like a space project isn't it?) strobiles and catkins.

These fruit structures are then treated to harvest the seed itself. Generally this involves drying the fruit until it opens and the seed is released. In most instances, placing the fruiting body in a paper bag and keeping it at room temperature will do the trick.

Fleshy fruits need to be cleaned immediately after harvesting as the pulp can heat up and kill the seed. An easy way to process fleshy seeds is to place them in a blender. The fruit is then mashed and the pulp can be extracted by adding water. The pulp will float on top while the seed will settle to the bottom. It may be necessary to cover the blades of the blender with rubber tubing to prevent damage to the seeds.

Many seeds have a woody appendage or 'wing' attached to it. These assist in dispersal of the seed. In a small scale operation, it is not necessary to remove this wing prior to storage.

Now that all this seed has been collected, what do you do with it until you are ready to sow it?

It is assumed that the collected material will be used the following season. So in many instances, all that is required is to dry the seed and place it in a sealed container. Be sure that there

is adequate air circulation during the drying period. The container should then be stored at approximately 36 - 41<sup>o</sup> F.

Are there exceptions to this recommendation? Of course! Some seeds will not require anything but being placed in a paper bag and kept at room temperature. Others will require elaborate procedures for proper storage. Fortunately, most species will fall within the refrigerated technique.

It should be mentioned here that several species of wood plants cannot be stored and should be sown right after they mature. Seeds of aspen, cottonwoods, elms, willows and some maple species lose their viability very quickly after they ripen and should be planted immediately.

While it may seem silly to mention this next item, it is critical to your eventual success in propagating the seed you have collected. Always, always, always, be sure to identify and label your seed collection!

## DORMANCY

Dormancy is one of many survival mechanisms developed by seed bearing plants. This particular mechanism retards or blocks the germination of seeds until outside conditions are most favorable for survival.

Dormancy occurs in most plant species, but its strength varies from very weak to extremely strong. For example, most of the white oak group sprouts readily upon maturing no matter what the conditions of growth are. Some juniper species must complete an elaborate set of triggers before germination can occur even when outside conditions are extremely favorable for survival.

Dormancy can be broken down into two very broad types, physical and physiological dormancy. Both can occur at the same time. Physical dormancy is the presence of a physical or chemical structure that inhibits germination. This exhibits itself in the form of a hard seed coat which prevents the movement of water into the seed or physically prevents the seed from germinating. It may also contain a chemical within the seedcoat that must be leached away before the seed can germinate.

Physiological dormancy is internal in nature to the seed itself. The seed cannot germinate until a series of physiological changes are triggered. These required physiological changes are not well understood at present. However, techniques developed through trial and error allow the germination of these type of dormant seeds.

Seeds are not restricted to one type of dormancy. Nor are they not limited to a single example within that particular type. It may take several different treatments to break dormancy in any given species.

## BREAKING DORMANCY

### Scarification

There are a number of different ways to break dormancy in seeds. For those that have a thick walled seed coat, it is only necessary to create an opening in the seed coat itself. This occurs naturally through the weathering of the seed coat from outside environmental factors. This can happen over a few months or a few years.

Some type of artificial weathering must be used to speed this process along. This artificial weathering is commonly referred to as scarification. Some common scarification techniques are mechanical scarring of the seed coat, soaking in water and the use of acids.

If you are not working with a large number of seeds, the use of an emery board is an inexpensive and safe way to open a thick seed coat. Not to mention that ones' nails will be very smooth after a few hours.

If this technique is not practical you can soak the seeds in water for up to 48 hours. Water is very effective in removing or softening thick seed coats. If the seed is a little tougher than most, it may require a short soak in boiling water and then subjected to a cold water rinse.

Acids are also very effective but are not readily available for use by most people. In addition, the use of acids is very hazardous to ones' health and well being. If the difficulty of disposal of the acid is also considered, it makes the use of acids not practical. I do not recommend this technique.

If a chemical inhibitor is suspected, the seed can be soaked in water. This usually causes the inhibiting chemical to leach from the seed coat. Be sure to change the water frequently so that the chemical inhibitor is thoroughly removed. This treatment will typically take no more than a day. If you are a busy person who cannot wait around all day changing water, the seed can be placed in a shallow pan under lightly running water.

### Stratification

Stratification is used to describe a technique of subjecting seed to an environment of moist conditioning prior to being placed in conditions favorable for germination. This process allows seed to complete the physiological requirements needed to trigger germination.

Many seeds require periods of cool, moist conditions in order to germinate. Seed can be allowed to soak for 24 hours in water, drained and then placed in sealed container. The container is then stored at temperatures ranging from 33 - 41<sup>o</sup> F. The length of time the seed must be kept at low temperature can range from 20 - 180 days. This type of stratification can take the place of storage. technique.

Some species respond to a period of warm, moist storage. The temperature can range from 59 -77<sup>o</sup> F. Typically, the period of time required to break dormancy is much shorter.

Finally, some species require a combination of warm, moist and cold moist conditions before being able to properly germinate. Germination success in other species can be enhanced by exposing the seed to periods of light.

At first appearance, stratification requirements can be overwhelming. However, much work has been done on the stratification requirements for many plant species is available. I have included a list of references to help with such research.

However, if one is working with a seed from a species that has not been closely experimented with, familiarity with the different means of completing seed dormancy can be helpful.

### Chemical Treatments

There has been work done with the use of chemical treatments to break dormancy. Gibberellic acid can be used to replace the chilling requirement in some cases. The use of hydrogen peroxide has been successful in stimulating germination in dormant seeds. In addition, hydrogen peroxide has been found to be a very effective agent in killing pathogens on thick coated species of seeds.

### GROWING - CONTAINERS, SEED BEDS & SOIL MIXES

There are a number of ways in which to grow seeds. If you are not germinating a tremendous number of seeds, you may wish to plant them in individual containers. This eliminates the step of germinating seed in a flat and then transplanted into a larger container.

For those on the bottom of the budget scale, small milk containers are an economical choice as a planting pot. These can be obtained from a local school. Just have the students save the containers. The only investment required is to collect and clean the milk containers.

Another possibility, is newspaper. This technique is used at the Joshua Tree National Monument in their native plant nursery program. A newspaper is folded into a cylinder approximately 3 inches in diameter and 11 inches in height. These are covered with a plastic cling wrap and filled with a potting soil.

Increased pressure by consumers is forcing commercial and retail nurseries to recycle their plastic pots and containers. A storage problem for the nursery is created as they may not reuse these containers. This may provide a free source of containers just for the asking.

Be sure to disinfect used containers prior to using them. This can be done by dipping them in a mild solution of ammonia bleach for a few seconds. Be sure to wear gloves and goggles to protect the hands and eyes from prolonged contact with the solution.

If you have a little space around the office or your yard, creating a seed bed is another avenue in which to grow seedlings. This could be on the ground or in raised beds. In either event, these areas must be prepared early enough to become a favorable environment for seed growth.

It may be necessary to provide shade, irrigation and protection from wind to the developing seedlings. In the open ground, the soil may need improvement to obtain favorable seedling

establishment. This can be very time intensive but once properly developed, a seedbed can be used over and over again.

As far as soil goes, it is important that it drains well and is friable so roots can penetrate easily. It must retain enough moisture for the plant without providing an environment for fungi.

Sand is an important component of any potting mix. The addition of sphagnum peat improves the water holding capacity of the soil and decomposed sawdust or compost adds fertility and structure to the potting mix.

A general potting mix would contain 1 part sand, 2 parts loam soil and 1 part peat or compost. This can be mixed together in a wheelbarrow with a shovel at least a day ahead of time. Be sure that the mix is slightly moist so that it does not crumble.

Initial development of the seedling is fueled by its storage tissues. However, once the seed has germinated and the first immature leaves appear, these storage tissues are spent. So some type of fertilization must be provided.

Remember, that the seedlings are extremely immature and will be sensitive to drastic changes in their growing environment. The less fertilizer used the better.

I suggest a fertilizer composed of 4 pounds blood meal, 4 pounds superphosphate and one pound potassium sulfate. Add approximately two teaspoons for every #1 container that is planted. This formula will prepare approximately one half yard of soil mix or 138 # containers (for those that are mathematically challenged).

A dilute solution of a 10-06-04 inorganic fertilizer can be incorporated into the watering schedule. This will provide nutrients to the developing plant without damaging the young roots.

## FINAL THOUGHTS

The information supplied here will not answer every question nor cover every detail required to grow every plant. Much of the information provided here was ultimately developed through trial and error. So be sure to research as many information sources as possible before trying to propagate a specific plant species.

However, if you want to try and propagate some plants from seed, it is hoped that the information provided will keep you on track and result in success for your efforts. Growing plants from seed need not be intimidating and can be done without any elaborate setup.

## Appendix 1 General Species Guidelines\*

The following list gives general information on collecting, storing and germinating local woody plant species.

**Abies concolor** (white fir) dormancy: physical & physiological; 7-14 days air drying; moist stratification at 34 - 41<sup>o</sup> F for about 21 days

**Acer glabrum** (Rocky Mtn. maple): to store, air dry; warm 68 - 86<sup>o</sup> F for 180 days then cold period at 37 - 41<sup>o</sup> F for 180 days

**Alnus** (alders) - pick fruit at first sign of opening, air dry. Store in sealed container at just above freezing. No further treatment needed.

**Artemisia** (sagebrush) -collect in fall or early winter, moist stratification for 10 days at about 36<sup>o</sup>F

**Atriplex** (saltbush) - harvest and store in a permeable bag (cloth). Requires afterripening period of 3 - 10 months depending on the species, germinates between 55 & 75<sup>o</sup> F

**Betula glandulosa** (birch) - pick green capsules in the fall, then air dry, seed is extremely small; light is used as a pretreatment

**Chrysothamnus** (rabbitbrush) - fruit heads are gray to light brown in color when ripe, hammer to break up seed heads, store in sacks at room temperature; stratification can speed germination but is not necessary

**Juniperus** (Rocky Mtn. juniper) - collect seed that is blue black to reddish brown in color and covered with a white waxy bloom; insects can feed on seeds pretty heavily; macerate and clean seeds; pretreatment may require warm stratification for up to 90 days with cyclical temperatures of 68<sup>o</sup> F and 86<sup>o</sup> F. Follow with a cold stratification period of 120 days at 41<sup>o</sup> F. Untreated seed may take up to 16 months to germinate

**Picea** (spruces) - harvest cones when spongy to the touch; air dry but protect from high temperatures; seed coat is very thin and damaged easily; store in sealed container at 33 - 38<sup>o</sup> F; seed may be presoaked in water for a couple of hours but otherwise they are good to go

**Pinus** (pines) - collect cones when cracking open; immediately air dry, serotinous cones can be opened by dipping in boiling water; soak in water for 1-2 days then cold, moist stratification for up to sixty days, can also use hydrogen peroxide pretreatment

**Populus** (aspen) collect in spring; pick catkins when seeds are a light straw color; dry for 2-3 days and then sow; germinates in 2-3 days; seed is extremely small in size; seed does not store for any great length of time

**Quercus** (Gambel oak) - collect seed as soon as ripe, very susceptible to weevil attack, float seed in water to remove bad seed; will germinate readily upon collection; store under cool moist conditions

**Ribes** (currants) - collect seed as soon as ripe; use a blender to separate the pulp from seed; store seed in sealed container; requires lengthy cool - moist stratification period

**Robinia** (New Mexican locust) - collect seed pods before open in fall; place in paper and allow to dry; flail pods in bag and collect seed; store seed in closed containers at 36<sup>o</sup> F; soak in hot water or mechanically scar seed coat prior to planting

**Salix** (willows) - collect seed pods as they turn from green to yellow; need to watch this closely; must be planted quickly or it dies do not store

\* Condensed from the Seeds of Woody Plants in the United States, USDA - FS

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## CAMPSITE RESTORATION IN HIGH SUBALPINE FORESTS, EAGLE CAP WILDERNESS, OREGON

David N. Cole  
Jeffrey A. Comstock  
David R. Spildie

Aldo Leopold Wilderness Research Institute, Rocky Mountain Research Station,  
Forest Service, U.S. Department of Agriculture, PO Box 8089, Missoula, MT 59807

### ABSTRACT

Results of the first two years of revegetation research on closed wilderness campsites are described. Experimental treatments involved soil scarification, an organic soil amendment (a mix of locally-collected organic materials and peat moss, and an inoculation of native undisturbed soil), an organic matter and composted sewage sludge treatment, and surface application of commercial mulch (Bionet). Half of the experimental plots received native seed and transplants; the other half did not. Seeding and transplanting were highly successful. The organic and compost soil amendment greatly increased seedling growth and increased transplant growth somewhat. Scarification increased seedling establishment of volunteer seedlings.

### INTRODUCTION

On federal lands designated by Congress as Wilderness, management objectives stress protection of natural conditions. Despite this emphasis on protection and preservation, wilderness areas are typically open to recreation use and resultant impacts can be severe, particularly on campsites. Most campsite impact is accepted as necessary if recreation use is to be allowed. However, in some situations campsite impacts are deemed to be either excessive or inappropriate in that particular location. In these situations, wilderness managers close sites to camping so they can return to conditions approximating those that existed prior to disturbance. Where recovery rates are slow, managers often employ various restoration treatments in an attempt to accelerate successional processes (e.g. Lester 1989). These efforts are often costly, in terms of time and money, and frequently are not very successful (e.g. Moritsch and Muir 1993). In many wilderness ecosystems, little is known about factors that limit the rate of natural recovery or about the effectiveness of techniques designed to accelerate recovery. Consequently, we designed a study to assess the effectiveness of several common restoration treatments on closed campsites in high subalpine forests in the Eagle Cap Wilderness, in northeastern Oregon. Specific objectives were to assess the influence of (1) amending soils with organic matter, composted sewage sludge, and a native soil inoculum, (2) transplanting and seeding with local, native species, and (3) applying a surface mulch on the establishment, survival, and growth of vegetation.

## STUDY SITES

The study is being conducted in the Lakes Basin portion of the Eagle Cap Wilderness, Wallowa-Whitman National Forest, northeastern Oregon. This area, located between 2170 m and 2320 m, contains a number of subalpine lakes and attracts large numbers of wilderness campers. Campsite impacts around these lakes are substantial and numerous (Cole 1981, 1993). Early efforts to close and restore campsites began in the 1970s. These efforts were largely unsuccessful. Campsites that have been closed to use have experienced little recovery over a period of more than a decade (Cole and Hall 1992).

Six campsites were selected for restoration in 1995. All are in a subalpine forest consisting of Abies lasiocarpa, Picea engelmannii, Pinus contorta, and Pinus albicaulis. The most common groundcover plants, in undisturbed places, are Vaccinium scoparium, Phyllodoce empetriformis and Carex rossii. All are within 70 m of lakes and, therefore, have been illegal campsites for more than 15 years. However, all these sites received some camping use over this period, had virtually no groundcover vegetation, and had not been revegetated in the past. These sites have probably exhibited high levels of impact (soil compaction, lack of vegetation, and minimal soil organic horizons) for at least 50 years.

## METHODS

Each campsite was divided into two whole plots, one with and one without a surface mulch application. The whole plots were subdivided into six subplots which received combinations of the two factors: soil amendments (organics/inoculum; organics/inoculum/compost; or nothing) and planting (transplanted/seeded; or nothing). All 12 of these 1.5 m by 1.5 m subplots were scarified. An additional plot, the control, received no treatment at all. The six campsites provide six replicates.

### Treatments

Scarification utilized shovels, picks, pitchforks, hoes, and hand kneading to break up compaction and clods to a depth of about 15 cm. We tried to avoid turning over the soil but substantial mixing of soil horizons was unavoidable in our attempt to develop a crumb texture. On several sites, numerous tree roots were cut and removed during scarification. Treatments that received the organics/inoculum treatment were covered with a mix of peat moss and well-decomposed locally-collected organic matter to a depth of about 2.5 cm. The dry peat moss was mixed with water before application. This material was then mixed with mineral soil to a depth of 7.5 cm. Inoculum came from the rooting zone of local transplants that were being transplanted onto the site. About 1.2 liters of soil were mixed with about 20 liters of water to make a slurry. Three liters of this slurry were sprinkled over each plot and raked into the soil. Compost treatments had organic matter and inoculum added in an identical manner. In addition, we added 2.5 cm

of composted sewage sludge (Ekocompost from Missoula, MT), wetted with water and raked into the top 10 cm of organic and mineral soil.

Half of the plots were seeded and transplanted. Seeding involved (1) collecting seed locally from several species with mature seed; (2) division of available seed into equal quantities for each seeded plot; (3) pinch-broadcasting seed over the plot; and (4) raking seed into the upper 2.5 cm of soil. Seeded species varied between campsites and included Antennaria lanata, Aster alpigenus, Danthonia intermedia, Juncus parryi, Penstemon parryi, Phleum alpinum, Sitanion hystrix, and Sibbaldia procumbens. One of the campsites was not seeded due to a lack of mature seed in the vicinity.

Transplanting involved (1) digging up enough transplants in the vicinity to plant equal numbers of each species in each plot; (2) digging a hole and placing transplants in the hole, along with Vita-start (vitamin B-1) to reduce transplant shock; and (3) giving each transplant 0.6 liters of water. Plots that were not planted were given an equivalent amount of water. Most transplant plugs were between 5 and 25 cm in diameter and most plots received 5-6 plugs. Although most plugs contained only one species, some contained more than one. Transplanted species varied between campsites and included Abies lasiocarpa, Achillea millefolium, Antennaria alpina, Antennaria lanata, Aster alpigenus, Calamagrostis canadensis, Carex rossii, Danthonia intermedia, Gaultheria humifusa, Hypericum formosum, Juncus parryi, Luzula hitchcockii, Oryzopsis exigua, Phyllodoce empetriformis, Pinus contorta, Polemonium pulcherrimum, Sibbaldia procumbens, Spiraea betulifolia and Vaccinium scoparium. All seeding and transplanting occurred in the central 1 m<sup>2</sup> of each plot. Measurements were also confined to this central area, leaving a 1 m buffer between the measured portion of each treated plot.

Half of the plots were covered with a biodegradable erosion control blanket made of straw interwoven with cotton string and jute (Bionet). The blanket was held in place with rocks. Where there were transplants, string was cut to allow the transplants to penetrate the strands of straw. Each campsite was closed to use by blocking main access points with string and an obvious sign. No evidence of camping use has been observed since campsites were closed to use. In 1996, plots were watered several times, when it appeared that soils were extremely dry. When this was done, all plots were given an equal amount of water. No supplemental watering was done in 1997. In all three years of the study the late snowpack was unusually deep, suggesting that conditions were much less droughty than normal.

## Measurements

For each transplant we measured areal extent of canopy cover (using a 1-m square PVC frame with a 5-cm by 5-cm grid) and maximum height. Measurements were taken immediately after transplanting (Sept. 1995) and in September of 1996 and 1997.

Seedling establishment was assessed beginning in early July of 1996. Every two weeks, from early July to early September, all established seedlings were mapped. Each seedling was identified by species and a colored toothpick was placed next to it to denote date of establishment. This made it possible to assess period of establishment and death,

if mortality occurred. In 1997, seedlings that germinated in 1996 were identified on the basis of their size, location, and species. New seedlings (the 1997 cohort) were identified in the surveys conducted every two weeks. In some plots, seedlings were so numerous that they were assessed in subplots. Ten individuals of a seeded species were randomly selected on each plot and their height was measured in September of 1996 and 1997. Another four individuals of the same species were carefully excavated. Their root and shoot biomass was measured, following cleaning and drying. In 1997, height and biomass measurements were only taken on seedlings that germinated and established in 1996.

Transplant areal extent and seedling locations were digitized to allow spatial analysis. Treatment effects were analyzed using standard statistical techniques, primarily t-tests and analyses of variance.

## RESULTS

In September 1995, a total of 206 plugs were transplanted onto 36 of the 78 plots. These plugs contained 354 individual transplants (either separate species, separate individuals, or separate vertical stems that might be separate individuals). By September 1996, 96% of these plugs and 92% of the individual transplants were still at least partially alive. By September 1997, 96% of the original plugs were still living and the number of live individual transplants (382) exceeded the number apparent at the time of planting. The canopy cover of surviving transplants (areal extent) decreased 2% between September 1995 and September 1996. By September 1997, however, canopy cover was 21% greater than at the time of transplanting. Mean transplant height declined 4% during the first year following transplanting. After two years, mean transplant height was 34% greater than at the time of transplanting. In 1997, 12% of the transplants flowered.

During the summer of 1996, almost 20,000 seedlings germinated and established on the 76 1 m<sup>2</sup> plots. Most of these seedlings (>70%) germinated from the seed we had broadcast. However, volunteers germinated from seed that reached the site through natural dispersal processes or perhaps, from the soil seed bank. In 1996, most of the volunteers were perennial species; in 1997, most volunteers were annual species. Germination and establishment continued throughout the two-month assessment period (early July to early September). However, about two-thirds of the seedlings established (cotyledons were well-developed) in the early August period--about one month after snow had left most plots. Germinants were probably emerging from the soil about two weeks prior to the point at which we considered them established.

In 1997, the 1996 seedling cohort generally emerged early, by mid to late July. The 1997 seedling cohort established throughout the season, but primarily in early August. The 1997 cohort of seeded species was about one-third as abundant as the 1996 cohort (fig. 1). The 1997 cohort of volunteer perennials was about one-half as abundant as the 1996 cohort. However, annuals were about 4 times more abundant in 1997 as in 1996. In 1997, the total number of seedlings that either reemerged (the 1996 cohort) or became established (the 1997 cohort) on the 78 1 m<sup>2</sup> plots exceeded 25,000. Seedling

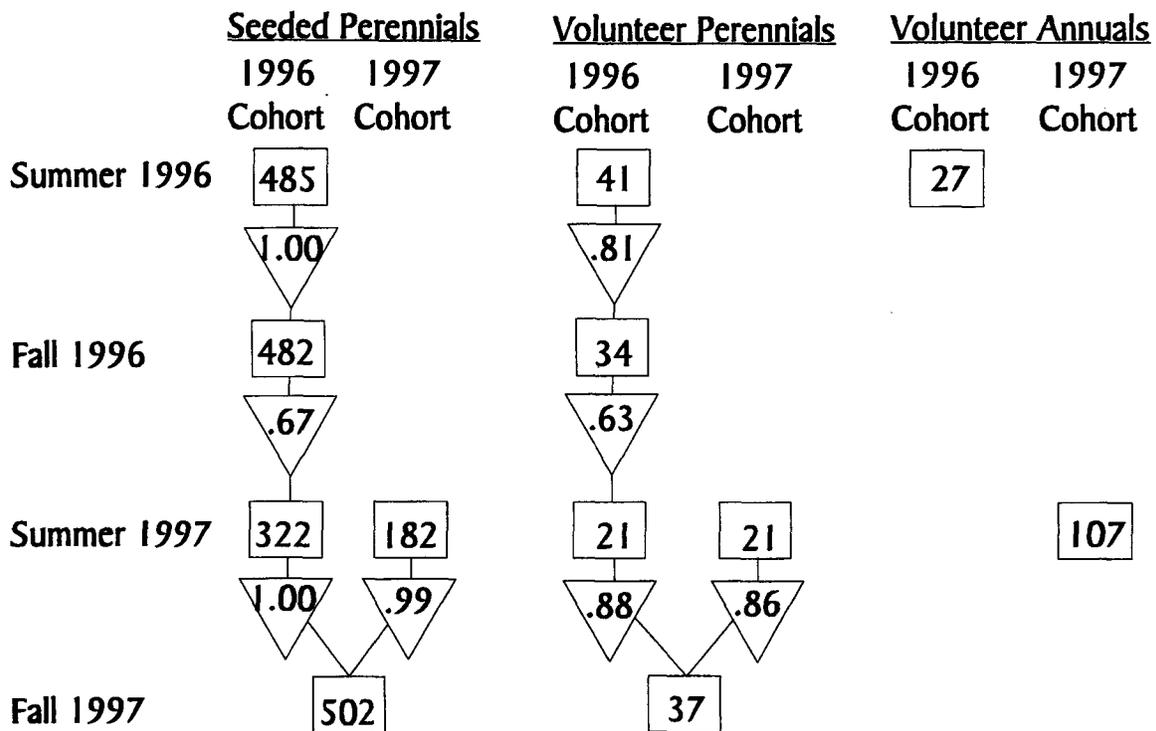


Fig. 1. Seedling density (#/m<sup>2</sup> - in rectangles) and rate of survival (in triangles) of seeded species and volunteers during the first two years of treatment.

density did vary greatly between the six campsites.

Seedling survival varied between seeded species and volunteers (fig. 1). Survival varied little between 1996 and 1997 or between the 1996 and 1997 cohorts. We could not assess mortality prior to seedling establishment (the emergence of well-developed cotyledons). However, once established, there was virtually no mortality (< 1%) during the summer for seeded species, either in 1996 or 1997. For volunteer perennial species, mortality rates were 19% in the summer of 1996 and about 13% in 1997. For both seeded and volunteer species, mortality during the winter was about 35%. Overall about 65% of the seedlings that established in 1996 were still alive in fall of 1997. Mortality within the 1996 cohort was more than offset by germination and establishment of additional seedlings in 1997. About 17,000 perennial seedlings were alive on the 78 1 m<sup>2</sup> plots in September 1996; about 18,000 perennial seedlings were alive in September 1997.

The 1996 cohort of seedlings was neither regularly nor randomly distributed. They were aggregated to a significant degree. Seeded species were more aggregated than volunteers. This suggests that aggregation resulted from both the seeding process and the availability of "safe sites". Seedling density was greater outside transplant plugs than within, but seedlings were attracted to the transplants (i.e. they were located closer to transplants than expected). Seeded and volunteer species did not differ in the extent to

which they were less abundant under transplants or more abundant close to transplants. This suggests that conditions close to transplants favor seedling establishment, while conditions underneath transplants discourages establishment. It is unclear whether these spatial patterns result from transplant effects on seed dispersal-entrapment patterns, soil conditions, microclimatic conditions, or competitive interactions.

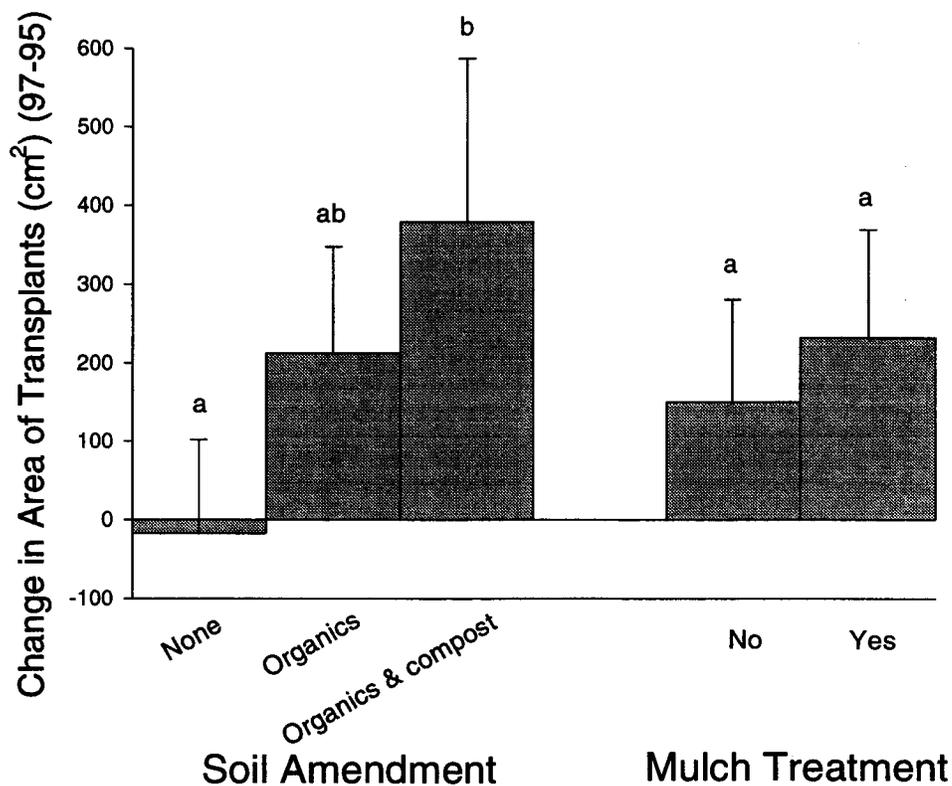


Fig. 2. Effect of soil organic amendments and mulch on growth of transplants (change in canopy cover), 1995 to 1997.

#### Treatment Effects

Survival of transplants was high (about 96%) regardless of treatment. Increase in canopy cover (areal extent) of transplants, between 1995 and 1997, was significantly

greater on plots with the organic and compost soil amendments than on scarified plots that received no soil amendments (fig. 2). Increase in height was also greater on organic and compost plots, although differences were not statistically significant. Compared to plots without a surface application of mulch, mulched plots experienced a greater increase in canopy cover but less of an increase in height. Neither of these differences was statistically significant, however.

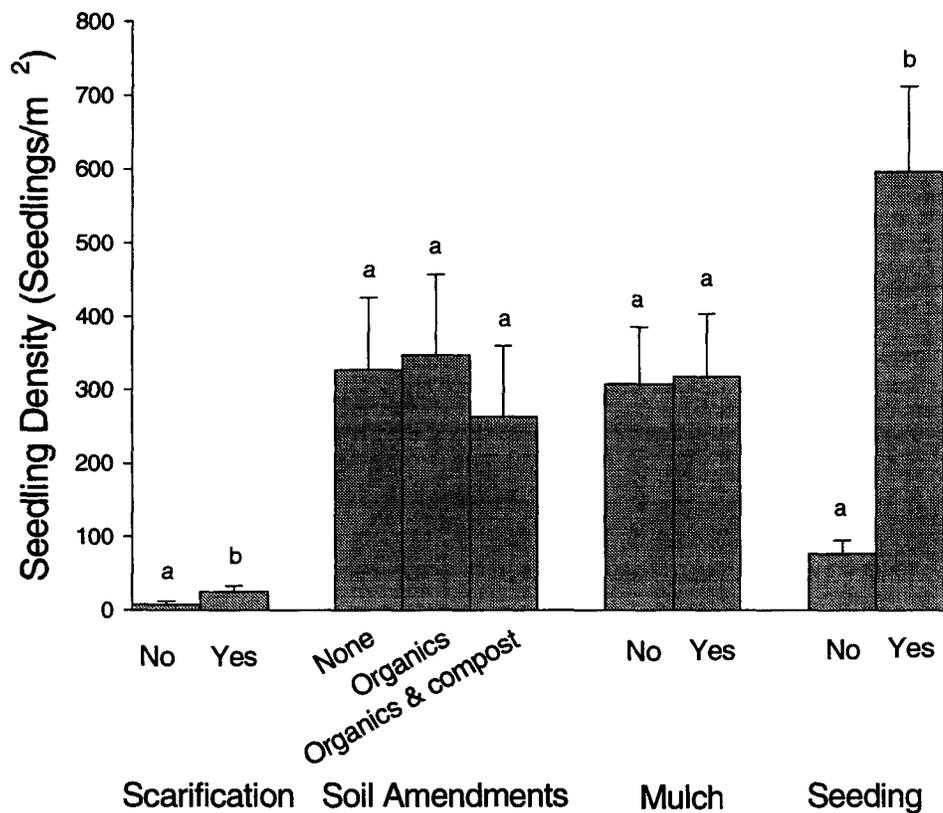


Fig. 3. Effect of scarification, soil organic amendments, mulch, and seeding on seedling density, fall 1997. The scarified plots were not seeded or mulched and received no soil amendments.

The effect of scarification on seedling density was assessed by comparing the non-scarified control plot with plots that were scarified but received no other treatment. On these two sets of plots, all established seedlings are volunteers. Scarified plots had a significantly greater seedling density (mean of 25 seedlings/m<sup>2</sup>) than control plots (7 seedlings/m<sup>2</sup>). Seeding had a tremendous influence on seedling density, with seeded plots having almost 8 times as many seedlings as unseeded plots, two years after seeding (fig. 3). Volunteers were equally abundant on seeded and non-seeded plots. However, neither soil amendments nor the surface mulch had a significant effect on total seedling density, the density of seeded species, or the density of volunteers.

Seedling growth, in contrast, was influenced by both soil amendments and mulching. In September 1996, mean seedling height was 1.7 cm. Seedling height was significantly greater on plots that received either the organics amendment (mean of 1.8 cm) or the organics and compost amendment (1.9 cm) than on plots without amendments (1.5 cm). Seedling height was also significantly greater on mulched plots (2.0 cm) than on plots without mulch (1.5 cm). By September 1997, the mean height of seedlings established in 1996 had increased to 3.5 cm. By this time, seedling height on the plots with the organics and compost amendment was significantly greater (mean of 5.3 cm) than on plots receiving organics (3.1 cm) or no soil amendments at all (2.2 cm). By 1997, it was possible to confidently guess a plots soil treatment simply by observing seedling robustness. Seedling height was also greater on the mulched plots (4.0 cm) than those without mulch (3.0 cm), although differences were not statistically significant. For seeded species, the mean biomass of seedlings that established in 1996 increased from 12 mg in 1996 to 190 mg in 1997. Their root:shoot ratio increased from 0.34 in 1996 to 0.52 in 1997. In both 1996 and 1997, seedlings on plots amended with organics and compost had significantly more biomass than seedlings on other plots (fig. 4). Root:shoot ratios did not differ significantly with soil treatment, although they were higher on the organics (0.65) and organics and compost plots (0.55) than on plots without soil amendments (0.37). Mulching had no effect on biomass in either year.

## CONCLUSIONS

Overall, the restoration techniques we employed were highly effective. Virtually all of the transplants survived the procedure and, after two years, most were growing vigorously and many were flowering. Soil amendments (organic matter, soil inoculum, and composted sewage sludge) contributed greatly to the vigor of transplant growth. The surface mulch had no clear effect, either positive or negative.

Although seedling density varied greatly between campsites, the mean seedling density of perennial species on seeded plots was over 500 seedlings/m<sup>2</sup> two years after seeding. Seedling mortality was low, particularly during the growing season, and seedlings were growing vigorously. Mean seedling biomass increased more than 10 fold during the second growing season. Scarification and seeding were the treatments that significantly increased the density of seedling establishment. The organics and compost

treatment was most effective in enhancing seedling growth. This effect of soil amendments only became apparent in the second growing season. The surface mulch had a less clearcut positive effect on seedling growth, an effect that was most consistent on plots that also received the organics and compost soil amendment.

The high level of seedling establishment and survival on all seeded plots and the relative ineffectiveness of the mulch treatment were two surprising results. Both results

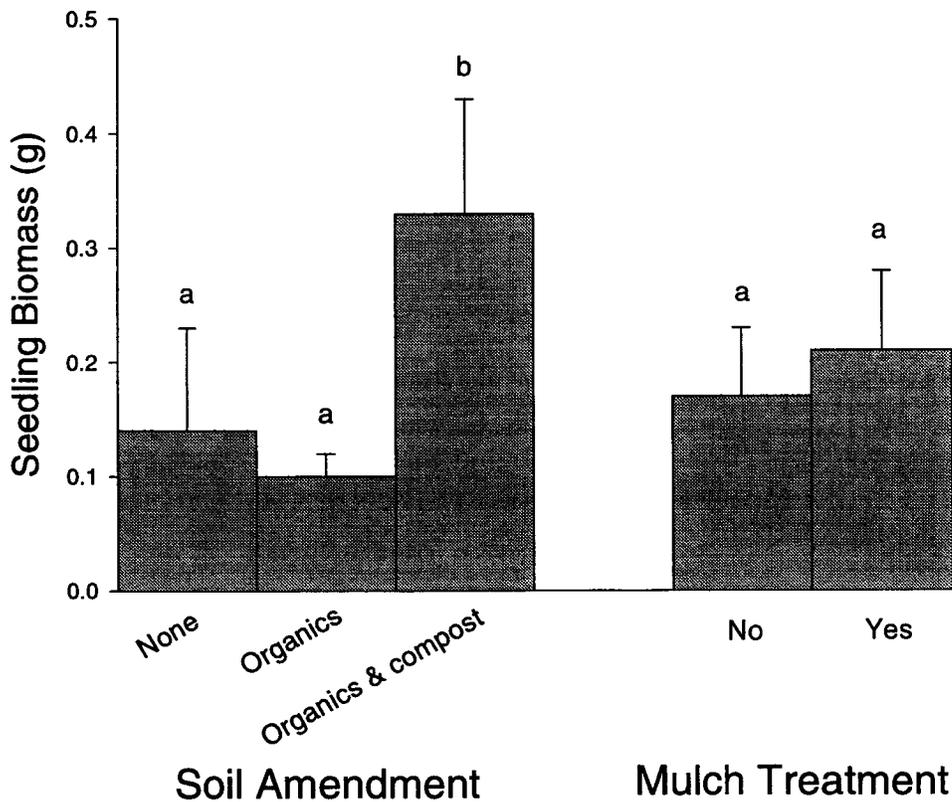


Fig. 4. Effect of soil organic amendments and mulch on biomass of 2-year-old seedlings.

might be explained by the unusual climatic conditions that persisted over the three summers of field work. In all three years, late snow combined with frequent summer rainfall meant that soil moisture levels were probably relatively high. With abundant soil moisture, seedling germination, establishment and survival might have been unusually

high, even without some of the microclimatic amelioration that a surface mulch can provide. If so, supplemental watering may be critical to effective restoration during years with less snowpack and drier summer weather.

#### ACKNOWLEDGEMENTS

We appreciate the logistical help and field assistance of many personnel from the Wallowa-Whitman National Forest, particularly Tom Carlson. The use of trade names in this paper is for reader information and does not imply endorsement by the U.S. Department of Agriculture.

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# GLACIER POINT REHABILITATION PROJECT

Julie Etra, Ann and Jeff Chandler

Owner, Western Botanical Services Inc., Reno, NV 89511; Co-owners Cornflower Farms,  
Elk Grove, CA 95759

## ABSTRACT

The Glacier Point Rehabilitation Project, funded and designed by both the public and private sector, involved the replacement, upgrading, and installation of new facilities at Glacier Point, Yosemite National Park. These included the construction of a new concession building, replacement of septic facilities, construction of a new amphitheater, development of a trail system and interpretive signing, and restoration of the landscape. The landscape restoration work was completed during the summer and fall of 1997.

Landscape restoration presents a challenge at this site due to a variety of factors. Site constraints included limited access, sterile soils, a short growing season, heavy snow load, wildlife use, and heavy foot traffic. The plant palette also presented some challenges, and all materials for use in propagation had to be collected within the vicinity of the project. The targeted restoration species included *Arctostaphylos patula* (greenleaf manzanita) and *Quercus vaccinifolia* (huckleberry oak), two species that are particularly difficult to propagate and establish. This project has far-reaching implications regarding our ability to restore native plant communities in disturbed soils throughout the Sierra Nevada.

## INTRODUCTION

Yosemite National Park has been a top attraction for many generations since the first tourist parties arrived in 1885. Glacier Point drew may thrill seekers and inspired bizarre theatrics, including driving cars to the edge of the point, performing acrobats, and pushing burned embers off the edge to the valley below, the famous 'fire falls'. At 7,200 feet above sea level, Glacier Point stands 3,200 feet above Yosemite Valley. The Park's most spectacular vistas can be seen from Glacier Point. One-half million visitors a year are drawn to Glacier Point during its five month season.

The areas adjacent to the actual Point, which include the former site of two hotels, had become degraded and barren. Poorly designed and sighted restrooms (on a septic system) and 26 year old 'temporary' concession facilities contributed to the degraded condition of the area and detracted from the beauty of the site. The objective of the project was to redesign the site and facilities to handle the large number of visitors and to restore vegetation. This had to be accomplished with the constraints of both the site and Park Service policy.

The landscape architecture firm of Royston, Hanamoto, Alley, and Abey of Mill Valley, California, was selected to lead a multi-disciplinary design team. Western Botanical Services Inc. (WBS) was selected to design the plant layout, track the plant propagation program, and to inspect installation. Cornflower Farms was selected by WBS to provide top-quality native plants. The \$2.7 million project was funded by the Park's new concession contract (Yosemite Concession Services) and a large contribution from The Yosemite Fund, a truly unique public and private partnership.

## DESIGN

### Facilities

The design objective of the project was to provide functional facilities in keeping with the spectacular location, in a way that would be both harmonious and timeless. The design included a new view terrace and amphitheater constructed of large blocks of Sierra granite, providing informal seating and a place for star gazing and interpretive programs. New restrooms and concession building were set back in the forest and out of primary view areas. A well defined asphalt path system was designed to provide access to all site facilities and included split rail fencing and rock barriers to protect restoration plantings. Interpretive and wayfinding signs as well as a new wastewater treatment system were designed. Design elements incorporated existing contours to minimize site disturbance. This is exemplified by the amphitheater, which sits in a natural bowl with views of Halfdome and the Sierra Nevada as a backdrop. Native granite was used extensively throughout the project as design elements, barriers, and in the buildings.

### Landscape Restoration

Landscape restoration presented a particular challenge at this site. Site constraints included sterile soils, a short growing season, heavy snow load, wildlife use, and heavy foot traffic. In addition, the National Park Service requires that all plants be propagated from source material collected close to the site and within the same watershed.

Adjacent, undisturbed montane chaparral was the community targeted for restoration, which is dominated by *Arctostaphylos patula* (greenleaf manzanita) and *Quercus vaccinifolia* (huckleberry oak), two species that are particularly difficult to propagate and establish. Other native shrubs, forbs, and trees were selected for aesthetic qualities (color, texture). These included *Anaphalis margaritacea* (pearly everlasting) *Keckiella breviflora*, *Penstemon newberryi* (Mtn. pride penstemon) *Symphoricarpos mollis* (creeping snowberry) and *Pinus jeffreyi* (Jeffrey pine). Thorny species, including *Ribes roezlii*, (Sierra gooseberry), *Ceanothus cordulatus* (whitethorn) and *Rubus leucodermis* (blackcap raspberry) were selected to help direct foot traffic and protect the slower-growing plants.

The restoration project also included seeding non-planted areas with native species of forbs and grasses. A total of four collections were made between 1995 and 1997 with volunteer employees of the Capital Group, Park Service personnel, WBS, and a representative of the Yosemite Fund.

## PLANT PROPAGATION

On-site collection and propagation of container grown plant materials began during the summer of 1995, two years prior to outplanting. A total of six trips to the site were completed during this period to collect seeds, cuttings, and native soil (used for inocula and laboratory analyses). A winter collection was accomplished by traveling over ten miles on snowmobiles. A total of sixteen species were propagated, six more than were required under the contract. Five species were propagated from cuttings, five from seed, and six from both cuttings and seed. The long lead time prior to out-planting, combined with multiple collection trips and good propagation methodologies, resulted in the high success rate. The number of plants produced exceeded the number specified in the propagation contract.

The majority of the growing phase took place during the 1996 season. With the exception of *Arctostaphylos patula*, all species were grown in deepots (2 1/2" diameter X 10" long, 40 Cubic inches on volume, with root trainers). *A. patula* was grown in a tree pot (4" square X 14" long, 180 cubic inches in volume, open bottom, with root trainers) because of superior performance achieved in previous projects.

Native soil, used an inocula for mycorrhizae and other beneficial soil microorganisms, was obtained from plants that appeared healthy near the planting site. Laboratory analysis confirmed that these soils contained the desired organisms. These soils were either directly incorporated into the container soil mix or made into a thick slurry and used as a drench.

Comparative soils analyses from and near the site indicated that the site was deficient in nitrogen (and possibly sulfur) by an amount equivalent to 50 lbs. of total N per acre. Ten gram, tea bag type, slow release fertilizer (18-6-6-5.7 S) was placed into every planting hole. It is believed that such a low level of supplemental fertilization will not impair microbial colonization of roots while stimulating plant growth.

## INSTALLATION

Landscape restoration was conducted in the fall of 1997, following completion of all structures and facilities. The work began with the installation of an irrigation system. This automated system will insure that adequate moisture is provided to the plants during the establishment period. It is expected to operate for two to three years, although this buried, permanent system can be re-activated if needed.

All plants were enclosed with hardware cloth and anchored in a four inch deep trench. The enclosure will protect the plants from browsing and foraging animals and from human foot traffic. They will be removed after two to three years.

All bare, non-planted areas were treated with the native seed/mulch mix.

## MONITORING AND CONTINGENCY

The Contractor is responsible for insuring 100% survival one year following planting. The Contractor will be supplied with up to 25% of the original plant numbers (500 plants) for this contingency re-plant, if necessary. WBS will inspect the site during 1998 to evaluate species performance and need for remedial work. The Park Service will be responsible for all site improvements and maintenance following the fall of 1998.

## CONCLUSION

Initially, this propagation, design, and installation project has exceeded the project's objectives. Follow-up monitoring over the next few years will assess the long term success of this challenging project.

# **SLOPE RESTORATION AND REVEGETATION ON COLORADO STATE HIGHWAY 82 FROM WELLER LAKE TO INDEPENDENCE PASS, PITKIN COUNTY, COLORADO. A CONTINUING STUDY.**

Jonathan L. White  
Project Geologist  
Colorado Geological Survey  
1313 Sherman Street, Room 715  
Denver, CO 80203  
Ph. (303) 894-2167  
jonathan.white@state.co.us

Mark Fuller  
Executive Director  
Independence Pass Foundation  
P.O. Box 1700  
Aspen, CO 81612  
Ph. (970) 963-4959

## **ABSTRACT**

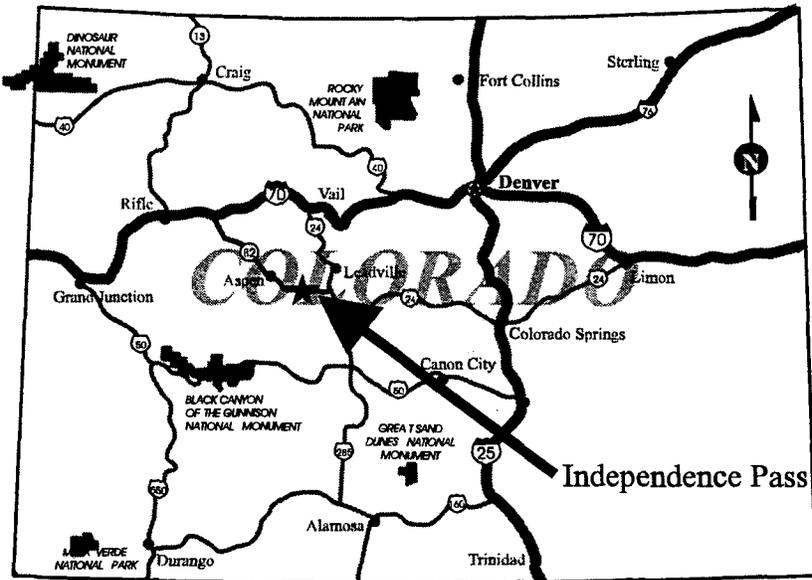
State Highway 82 from Aspen to Independence Pass is a corridor of cut slopes and steep eroding ground from elevations of 8,000 to 12,093 feet within the White River National Forest. The road alignment lies within the core of the Sawatch Range in Precambrian rock terranes and glacial geomorphology. Steep surface conditions, poor early road cut design, and climate set the stage for existing stability problems. Current erosion and earlier detrimental maintenance procedures have created degraded environmental conditions and rock slide hazards. Individuals concerned with the environmental degradation along the highway corridor formed the Independence Pass Foundation. This non-profit environmental organization, based in Aspen, has formed the Independence Pass Restoration Team Partnership. This partnership includes private individuals, various state and federal agencies, Pitkin County, and Aspen. Earlier successful work at the road cut at Weller Lake Campground (elev. 9,300 feet) has led to more aggressive slope restoration work at elevations from 11,500 to 12,000 feet where the worst environmental damage and rockfall threat exists. Prototype projects have been completed at this 'Top Cut' area that included slope reconstruction, slope stabilization, and revegetation. The primary factors in design concepts were costs, simplicity, and natural appearances.

## **INTRODUCTION**

State Highway 82 crosses Independence Pass at an elevation of 12,093 feet at the Continental Divide. Historically this route was taken by miners and early homesteaders from Leadville to found the towns of Aspen and Independence. The early stagecoach route was used exclusively until the narrow gauge rail was advanced up the Roaring Fork Valley to the silver mines of Aspen. The over Independence Pass route was improved for vehicles in 1927 and further modernized in the 1950's. It was this excavation for the modern two lane corridor that created the high eroded cut slopes and denuded native slopes seen today. In the early design and construction of Highway 82, as in many highways of Colorado, it was not policy to address potential geotechnical and environmental impacts in the long-term erosion of cut slopes in varying rock and soil types. Once the topsoil has been stripped away and the toe of a natural slope is removed, instability results with further erosion of the weathered rock mass. Rock and soil debris falls away from the cut slope and collects at the base of the slope, many times into the roadway itself. Continued maintenance is then required to dispose

of the material. The severe winter seasons and danger of avalanches forces Colorado Department of Transportation (CDOT) to close this highway from October until the Memorial Day Holiday weekend every year.

Because of its seasonal status and non-use by commuters, Highway 82 rates a lower priority for CDOT in the region. It was felt by many locals that the roadway corridor was being neglected. The Independence Pass Foundation



**Figure 1.** Project site location.

(IPF) was formed in 1989 by the Environmental Research Group, an Aspen area non-profit citizen's group dedicated to mitigating human impacts on high mountain ecosystems. The IPF was created to focus on major restoration work along the Independence Pass corridor, and to coordinate restoration activities between the many government entities involved in Independence Pass management. The Foundation consists of a 14-member Board of Directors, a paid Executive Director, and a paid fund-raising consultant. In 1990 the IPF formed the Independence Pass Restoration Team, consisting of the IPF, Pitkin County, the City of Aspen, CDOT, USFS, the Colorado Geological Survey, and several other agencies. Since 1990 the IPF and the restoration team have planned and supervised the expenditure of approximately \$1.5 million dollars toward Pass revegetation, stabilization, and safety improvements. The IPF has also supervised the work of hundreds of volunteers who have provided countless hours of labor and planted thousands of trees and shrubs along the sixteen mile corridor between Aspen and the summit of the Pass. This corridor crosses five different ecosystems ranging from the montane zone near Aspen through the spruce-fir forest, sub-alpine meadows, the Krumholz zone at timberline, and the alpine tundra. Road Cuts and other human activities threaten all of these ecosystems, which support a wide variety of flora and fauna, as well as the headwaters of the Roaring Fork River.

Two locations will be discussed to illustrate revegetation and slope reconstruction efforts on Highway 82 from Aspen to Independence Pass, the completed Weller Cut Project and the continuing project at the Top Cut on Independence Pass.

**WELLER CUT PROJECT**

One of IPF's major projects has been the slope reconstruction and revegetation of the Weller Cut, seven miles east of Aspen at an elevation of approximately 9,300 feet. The area consists of typical subalpine evergreen forest characterized by dense stands of subalpine fir and Englemann spruce with occasional stands of aspen and native shrubbery in open locations. This road cut area

is approximately 200 meter long and varies from 15 to 80 vertical feet high from the highway surface. At its previous 1:1 slope it was a dangerous and unstable rockfall area that was deteriorating at a rapid rate. In 1990, the Restoration Team approved re-working of this slope at their first major project. During the summer of 1990 the slope was laid back and re-contoured at a grade of 2:1. In 1994, IPF and CDOT further improved on the Weller area by realigning Highway 82 to provide a new parking area and trailhead, significantly improving safety and access. Since then, the reconfigured slope has been the site of a concentrated and consistent revegetation effort. In 1991 the area was sprayed with Bio-Sol and concentrated hydromulch and seed mixture, including native wildflower and grass seeds. Hydromulching and seeding were repeated in 1995. Grass and wildflower species included in these mixes are shown in Table 1. From 1991 - 1995 a total of 1000 native shrubs and 630 trees were planted at Weller and 30 pounds of seed mix were broadcast to augment the hydroseeding. In 1996 and 1997 further plantings were installed as shown in Table 2 and 3. The successful revegetation of this area can be attributed both to the intensity of the effort and the irrigation system that has been developed for this location. The initial irrigation facility consisted of a hand-dug reservoir which captured the output of a natural drainageway and directed it by gravity to several sprinklers. In 1996 a system was installed which includes two pumps, approximately 1,500 feet of PVC pipe, and forty sprinkler heads distributed across five coverage zones. This system pumps water directly from the Roaring Fork River and is run intermittently throughout the summer season. This irrigation will cease in the future so the flora can reach equilibrium with the climate of the region.

Common Name	Specie Name	Quantity
Sheep fescue	<i>Festuca ovina</i>	30%
Mountain Brome	<i>Bromus marginatus</i>	22%
Slender Wheatgrass	<i>Elymus trachycaulus</i>	22%
Canby Bluegrass	<i>Poa canbyi</i>	8%
Canada Buegrass	<i>Poa comprssa</i>	8%
Rocky Mountain Penstemon	<i>Penstemon strictus</i>	5%
Blue Flax	<i>Linum lewisii</i>	5%
Showy Goldeneye	<i>Viguiera multiflora</i>	<1%
Western yarrow	<i>Achillea miiefolium</i>	<1%
Tufted hairgrass	<i>Deschampsia caespitosa</i>	<1%

Table 1. Seed mix used at Weller Lake (Elev. 9,300 Ft) road cut.

Common Name	Specie Name	Quantity (ea)
<b>Shrubs and Forbs</b>		
Native Yarrow	<i>Achellea lanulosa</i>	5
Alpine Avens	<i>Acomastylis rossii</i>	4
Pearly Everlasting	<i>Anaphalis margaritacea</i>	15
*Pussytoes	<i>Antennaria alpina</i>	30
Wild Blue Columbine	<i>Aquilegia caerulea</i>	20
Mountain Aster	<i>Aster ascendens</i>	20
*Alpine Mound Erigeron	<i>Erigeron compositus</i>	2
*Goldern Aster	<i>Heterotheca pumila</i>	47
*Alpine Sunflower	<i>Hymenoxis grandiflora</i>	30
Alpine sorrel	<i>Oxyria digyna</i>	35
*Hall's Penstemon	<i>Penstemon hallii</i>	48
Purple Fringe	<i>Phacelia sericea</i>	42
Golden Ragwort	<i>Senecio atratus</i>	90
*Fremont Senecio	<i>Senecio fremontii</i>	9
Mountain Goldenrod	<i>Solidago multiradiata</i>	37
*Parry's Clover	<i>Trifolium parryi</i>	14
Bog Birch	<i>Betula glandulosa</i>	10
Native Willow	<i>Salix brachycarpa</i>	40
*Grown from seed collected by G. Ludwig, Pleasant Avenue Nursery		

Table 2. 1996 Plantings at Weller and Top Cut area.

## TOP CUT PROJECT

The Independence Pass 'Top Cut' is 1.5 miles of excavated rock and soil cuts at Highway 82 from milepost 59.3 to 60.8. It is located within the core of the Sawatch Mountain Range at treeline, from elevations of 11,500 to 12,000 feet above sea level. The alignment of the roadway leaves the bottom of the Upper Roaring Fork Valley, curves up onto the eastern flank of the valley, and begins to level off as it approaches the Continental Divide. The glacial valley has the classic U-shape cross-sectional configuration. This morphology has resulted in the substantial cut required for the roadway through the middle elevations of the valley,

where natural slopes are at their steepest. These cuts erode and fill the ditch below. Until recently the method of disposal was to simply cast this material over the side onto the fill slope below the road. This activity, in conjunction with snow removal also disposed over the side, has created accelerated erosion zones below the roadway. These accelerated erosion or stripped vegetation zones below the roadway are the most visually obtrusive aspect of the 'top cut' as seen from across the valley. The Independence Pass 'Top Cut' has been recognized for some years as an active rockfall hazard zone. Five slopes have been delineated that have been rated in CDOT's Colorado Statewide Rockfall Project. Two slopes rated sufficiently in severity to be included within the top 10 rockfall hazard slopes in CDOT Engineering Region 3/Maintenance Section 2, one of which rated No. 11 overall, statewide.

To understand the complexity of the geology, soils, hydrology, and climate of the 'Top Cut' area engineering geology, avalanche, and later hydrologic studies of the area were conducted. In addition, research was conducted on available anchored revegetation systems on the market and existing research projects on highways in Colorado where aggressive revegetation systems in difficult terrains was being tested. The biggest problems was the continual erosion of (1) the existing cut slopes and (2) the damaged slopes below the road that had been stripped of vegetation, either through erosion or burial. Rates of erosion varied, dependant on the quality of the rock mass. The table below shows the mapped rock units from the engineering geology study, their areal extent, and sediment yields from the hydrologic study.

Common Name	Specie Name	Quantity (ea)
<b>Shrubs and Forbs</b>		
Wolf's currant	<i>Ribes wolfii</i>	60
Rock Spirea	<i>Holodiscus dumosus</i>	90
Whitestem Gooseberry	<i>Ribes inerme</i>	90
Squaw current	<i>Ribes cereum</i>	90
Woods Rose	<i>Rosa woodsii</i>	90
Wild raspberry	<i>Rubus ideaus</i>	60
Serviceberry	<i>Amelanchier alnifolia</i>	30
Bog Birch	<i>Betula glandulosa</i>	25
Native Willow	<i>Salix brachycarpa</i>	50
<b>Trees</b>		
Quaking Aspen	<i>Populus tremuloides</i>	395
Engleman Spruce	<i>Picea englemanni</i>	185
Subalpine Fir	<i>Abies lasiocarpa</i>	185
Lodgepole Pine	<i>Pinus contorta latifolia</i>	288
An estimated 2,000 additional seedlings of a mixture of the above tree species were planted in various locations from 1991 to 1996.		

Table 3. 1997 Plantings at Weller and Top Cut area.

<b>Cut slope Rock Units</b>	<b>Acres</b>	<b>Sediment Yield (Tons/acre/year)</b>	<b>Estimated Sediment Load (tons/acre/year)</b>
Hard Rock	0.89	0	0
Slightly Weathered Rock	1.03	2.84	2.9
Weathered Fragmented Rock	1.93	5.68	11.0
Decomposed Rock and Soil	2.26	32.65	73.8
Natural vegetated slope	0.18	1.66	0.30
		<b>Total</b>	<b>88.0</b>

Note: Sediment yield and load figures do not include the larger rocks or boulders eroding from the slopes nor road sand mixtures introduced by CDOT .

<b>Slopes below Highway</b>			
Stripped Vegetation Zones	20.05	71.4	1,432
Exposed Bedrock	5.78	0	0
Vegetated Zones	145.17	3.3	479
		<b>Total</b>	<b>1,911</b>

It was on the basis of this work that prototype projects were designed for slope reconstruction, stabilization, and revegetation. The priorities being those slopes dangerous to the public (rockfall) and those slopes with the highest sediment yields and erosion potential. During the fall of 1996 and 1997 the Independence Pass Foundation and the Colorado Department of Transportation implemented and shared costs in a rockfall mitigation project, and a prototype slope reconstruction, restoration, and revegetation project known as the Twin Gullies project at the Top Cut. Two small gullies mark the formational contact of gneiss and granite. Gullying has occurred in zones of bedrock weakness at these near vertical rock contacts that has advanced up the steep hill side. The right ravine has advanced over 130 feet up into the natural slope. Total expenditure for the combined project was around \$220,000.

In the Fall of 1996 and Summer of 1997 this project completed the following:

1. Highway rock cuts were scaled of loose rock through the entire project site, almost a mile of heavily eroded cut slopes in rock, weathered rock, and soil. CDOT maintenance crews moved boulders and rocky fill during scaling and ditch clean-out operations. This fill was instrumental in IPF's Twin Gullies slope reconstruction project.
2. 6,324 square feet of wire mesh was anchored to a dangerous rock slope that had continuously rained rocks onto the road and filled the ditch width. This mitigation prevents further erosion, stabilized the tundra brow, and prevents rockfall from the roadway. The wire mesh was PVC coated a dark brown color. The dark wire mesh blends with the irregular rock face and is almost invisible. This was specialized work requiring a crane and manned drilling basket.
3. Rock reinforcement, with rockbolts, was completed at one of the more dangerous rock features identified at this rated slope.
4. Reconstruction of slopes using geotextile reinforced rock buttresses at the Twin Gullies

Prototype site. A schematic is shown in Figure 2. Fill material and boulders were provided from the scaling operation and collections from ditch clean outs in other areas of Highway 82 between Aspen and the Pass. The fill for the slope reconstruction above the rock walls had to be placed by crane bucket and smoothed and compacted by the inmates from the Buena Vista Correctional Facility. The final slope was smoothed and prepared with top soil donated and hauled from the Village of Snowmass. Enkamat "S" 7010 was chosen for the revegetation matting because of its long life, durability, strength, and three-dimensionality. Installation and anchorage followed specifications provided by the manufacturer. The IPF and the Colorado Geological Survey were concerned not only with the probable years it may take to revegetate these high elevation slopes but also passive and dynamic snow loading every winter. Matting anchorage was further strengthened by the use of 18 inch, #4 rebar J-hooks. A one to two inch layer of screened (<3 inch) fines were then placed atop the Enkamat and worked into the three dimensional matrix of the matting. A seed mix, designed for this elevation (See Table 4) was broadcast over the restored slope and Willow and Bog Birch plants were installed before the slope was hydromulched.

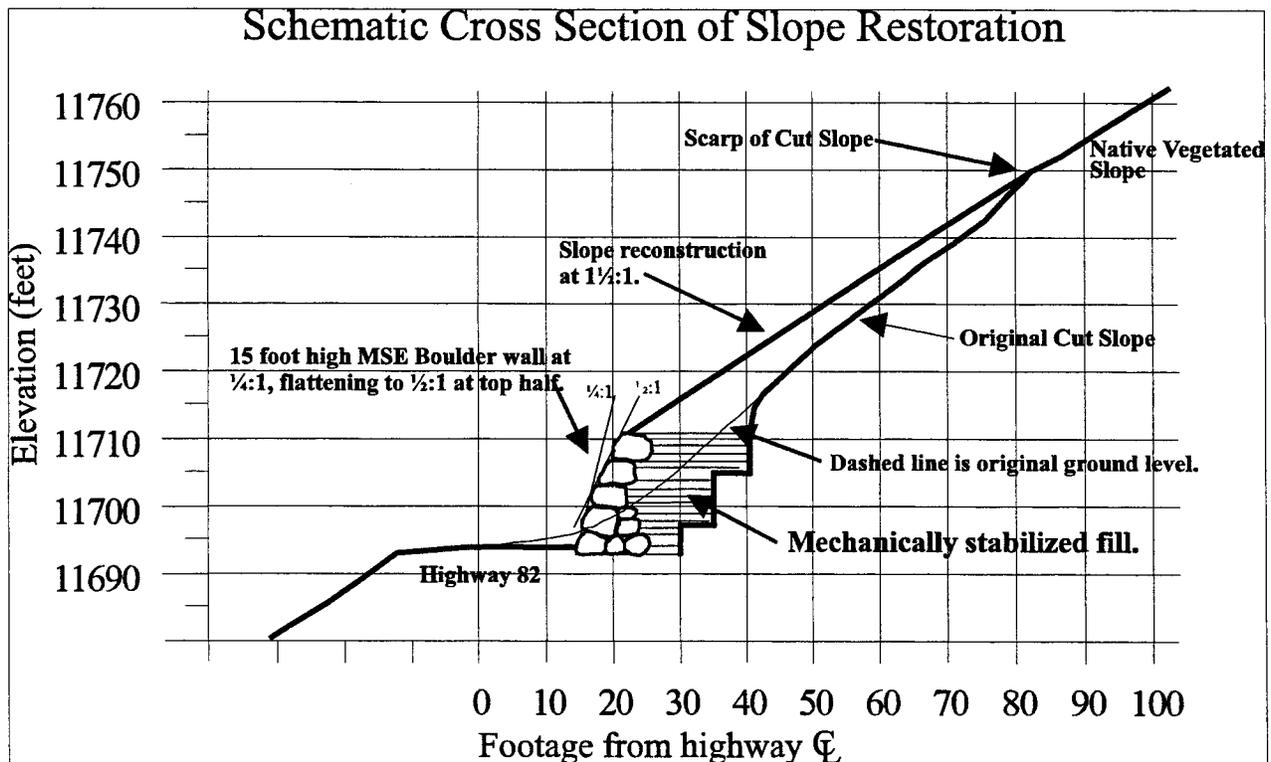


Figure 2. Schematic of slope reconstruction used at Top Cut.

5. At the head of the ravine of the right twin gully 6" thick gabion mattresses were installed and anchored to steel pins drilled and grouted into the underlying rock. Three to six inch diameter rock was screened from the fill stockpiled by CDOT and transported by crane basket to the gabion mattresses. The mattresses will prevent further headward erosion of the ravine.

6. Inmates from the Buena Vista Correctional Facility and assorted volunteers planted tree seedlings and other plants shown in Tables 2 and 3 at both the Top Cut and Weller Cut.

Common Name	Specie Name	Quantity
Alpine Bluegrass	<i>Poa alpinum</i>	25%
Alpine Fescue	<i>Festuca brachyphylla</i>	25%
Tufted hairgrass	<i>Deschampsia caespitosa</i>	25%
Alpine Timothy	<i>Phleum alpinum</i>	12%
Popcorn Sedge	<i>Carex microptera</i>	5%
Black Sedge	<i>Carex chalciolepis</i>	5%
Western Yarrow	<i>Achillea lanulosa</i>	1%
Wipples Penstemon	<i>Penstemon whippleanus</i>	1%
Sulpher Paintbrush	<i>Castilleja sulphurea</i>	1%

Table 4. Seed mix used at Top Cut area (Elev. 11,700 Ft).

7. A rock-faced, geotextile reinforced, slope was reconstructed in a small erosional amphitheatre in very weak decomposed rock, similar to the schematic shown on Figure 2. As with the Twin Gullies reconstruction, Enkamat "S" revegetation matting was also installed. This work was high on the slope and required a crane for access.

8. Based on the slope classification map, a GIS map of slope grades produced from a digital elevation model, test plots were selected within the stripped vegetation zone below the roadway and installed with revegetation matting donated to the IPF. Test planting terraces were also constructed into the stripped vegetation zone (with the highest sediment yeild) to control further erosion.

## CONCLUSIONS AND KEYS TO SUCCESS

Costs were kept down by the use of rock buttresses, reinforced by geotextiles, for slope reconstructions and restorations. A very flexible design with a natural appearance. To further defray costs CDOT Maintenance provided haul trucks, heavy equipment, and personnel while contractors and vendors provided portions of their services or materials as tax deductible donations to the Foundation. The primary labor force was free, provided by inmates from the Buena Vista Correctional Facility. The apparent success of this project has led to the planning of larger, more ambitious, projects for the future. The test plots and prototype restorations will be continously monitored and evaluated. The keys to success are many.

### Plant Survival

Plant viability and survival rates have been encouraging. For the shrubs shown in Table 2, planted in 1996, the survival rate was 90% as of initial green-up in June of 1997 at both locations. A follow-up survey is anticipated for June of 1998. This high success rate is largely attributed to the cool and moist spring conditions at the Top Cut area, transplanting within undisturbed soils, and to the irrigation system at the Weller cut. The high survival rates are also attributed to careful transplanting techniques that include the application of peatmoss, compost, water-retaining crystals, and fertilizer with each installed plant. Success is also clearly improved when container plants grown from native seed are tranplanted, as opposed to hydroseeding or hand-broadcasting of seed.

Prior efforts to revegetate, which have included hand-broadcasting of seed, seeding over organic reveg. matting and transplanting without any of the above-noted enhancements, has generally met with a less than 10% success rate. An gravity irrigation system will be constructed at the top cut for those reconstructed areas to enhance survival rates.

### **Volunteerism**

Volunteers to IPF projects have consisted mostly of local schoolchildren, who have participated in planting projects in every year of IPF's existence. Five local schools, the Aspen Community School, the Aspen Middle School, the Aspen High School, the Aspen County Day School, and the Colorado Rocky Mountain School have all spent a half day, with an average of 20 children, planting on the Pass. American Adventures, a private camping outfitter for teenagers, has also volunteered a community service day for four groups of 15 members each summer for the last four years. Other volunteer groups have included the Aspen Skiing Company, The Aspen Women's Group, and the Aspen and Snowmass Chapters of the Rotary Club. In addition, a number of special volunteer events held on a sporadic basis, including Good Roads Day, Make a Difference Day, and Youth Volunteer Day have drawn strong responses from a variety of interested local residents. Volunteer hours from 1991-1997 have averaged approximately 750 hours per year.

### **Free Labor Pool**

The IPF has also been able to take advantage of inmate labor from the State Correctional Facility in Buena Vista, Colorado from 1994 to 1997. That labor has generally consisted of a crew of 8 individuals for 2 to 6 weeks each summer. IPF anticipates future use of the inmates for an average of 4 weeks every summer season.

### **The Restoration Team Approach**

During the construction season of 1996 and 1997 several entities contributed time, effort, or materials. Pitkin County and CDOT Maintenance made equipment and personnel available. Vendors entered into this partnership by either donating or provided material at cost. The White River National Forest provided equipment at subsidized costs and borrow areas for rock and fill. We cannot forget the expertise of those individuals that attended the restoration meetings providing invaluable insight and recommendations. While most of these contributions are modest individually, the total is substantial and notable

## **FUTURE ACTIONS**

In 1997, IPF secured funding in the amount of \$100,000 to support erosion-control activities in the Independence Pass area. This funding came from the federal budget for the Intermodal Surface Transportation Efficiency Act (ISTEA) through CDOT and Pitkin County. CDOT sponsored the funding request at the federal level and Pitkin County is acting as the Local Agency (a local government entity must administer the funding). IPF will do the project planning and contracting associated with expenditure of these funds. IPF will also provide the 20% match

(\$25,000) required in order to secure the \$100,000 grant. This funding will be spent on stabilization and rehabilitation work below the highway in connection with the old stagecoach road in this location. Also each year additional plantings are planned for volunteers and inmates from the Buena Vista Correctional Facility. Those plants are shown in Table 5.

Common Name	Specie Name	Quantity (ea)
Pussytoes	<i>Antennaria alpina</i>	45
Alpine Mound Erigeron	<i>Erigeron compositus</i>	45
Goldern Aster	<i>Heterotheca pumila</i>	45
Alpine Sunflower	<i>Hymenoxis grandiflora</i>	45
Alpine sorrel	<i>Oxyria digyna</i>	45
Hall's Penstemon	<i>Penstemon hallii</i>	45
Purple Fringe	<i>Phacelia sericea</i>	45
Golden Ragwort	<i>Senecio atratus</i>	45
Fremont Senecio	<i>Senecio fremontii</i>	45
Tufted Hairgrass	<i>Deschampsia caespitosa</i>	90
Canada Reedgrass	<i>Calamagrostis purpurensis</i>	90
Native Willow	<i>Salix brachycarpa</i>	90

Work will also continue with the cut slopes above the highway at the Top Cut. The next

**Table 5.** Plantings for Summer 1998 at Top Cut area (Elev. 11,700 Ft).

project at the Top Cut is a \$400,000 project to restore slopes at what is called the 'Big Cut'. The first phase of this project will begin in October, 1998.

The Big Cut is the longest and highest of the eroding cut slopes along the Highway 82 'Top Cut' area. The cut length is 600 feet long and the highest part 100 vertical feet high. The bedrock was mapped as Decomposed Rock and Soil. The description is: "Highly fractured and very weathered with most rock structure lost. Small areas of relic rock structure remain mostly jumbled and indistinct. Cut slopes continuously erode back to an angle of repose that approximates colluvial rocky soils. Vegetation at brow of cut slope is continuously undermined. Continual talus and grus fan deposition at the base of the slope require periodic removal to retain road ditch width and recover plugged culverts." Much of the surface slope material is grus, which is the loose fragments of the disintegrated granite. Scattered though are zones of intact weathered rock and 'core stones'; large unweathered boulders that occur within the weathered rock mass. These larger rocks create serious rockfall hazards. This slope has been rated in CDOT's Statewide Rockfall Hazard Rating Project. Rocks continually roll out onto the road. Slope grades at the site range from the angle of repose (34°), to overhanging at the brow (scarp) and are completely barren.

To keep the restoration consistent with the Twin Gullies site the IPF proposes additional rock wall construction using geotextile reinforcement of the backfill. Refer to slope reconstruction schematic in Figure 2. The height of the cut slope will not permit slope reconstruction from the top of the rock wall, to meet the brow of the cut slope at an angle that would permit long-term revegetation - 1½(H):1(V). To prevent further erosion at the oversteepened tundra brow above, anchored and draped wire mesh, colored dark brown, is warranted. Soil nail-anchored wire mesh, underlined by Akzo Nobel Enkamat revegetation matting, would contain further loss of the tundra brow and eliminate the serious rockfall hazard at this site. To stabilize further slope material loss and foster partial revegetation, wire mesh will be draped on the slope below the anchorage to where the reconstructed slope begins. This slope reconstruction design can be done in staged or phased construction as funding and/or material becomes available.

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## PLANT CENTER - MESA VERDE COOPERATIVE AGREEMENT

Dr. Gary L. Noller

Upper Colorado Environmental Plant Center  
P O Box 448  
Meeker CO 81641

### ABSTRACT

The Upper Colorado Environmental Plant Center entered into an agreement with Mesa Verde National Park on September 26, 1990. This agreement was amended in 1995 and now involves 19 species, with 1342 pounds of seed production and 5172 live plants.

### POSTER

The Upper Colorado Environmental Plant Center entered into an agreement with Mesa Verde National Park on September 26, 1990. This agreement was amended in 1995 and now involves 19 species, with 1342 pounds of seed production and 5172 live plants. Targeted species are; western wheatgrass (Agropyron smithii), slender wheatgrass (A. trachycaulus), salina wildrye (Elymus salinus), muttongrass (Poa fendleriana), yarrow (Achillea millefolium), blueleaf aster (Aster glaucodes), hairy golden aster (Chrysopsis villosa), Louisiana sage (Artemisia ludoviciana), low penstemon (Penstemon linarioides), spur lupine (Lupinus caudata), evening primrose (Oenothera caespitosa), Utah serviceberry (Amelanchier utahensis), mountain mahogany (Cercocarpus montanus), snowberry (Symphoricarpos oreophilus), gambel oak (Quercus gambelii), fourwing saltbush (Atriplex canescens), antelope bitterbrush (Purshia tridentata), pinyon pine (Pinus edulis) and Utah juniper (Juniperus osteosperma).

Seed has been collected at the park from 1990 through 1997, by plant center and park personnel. This involves finding sites with the species wanted, determining the correct time for collection, estimating the quantity needed, collecting only the species designated and not collecting a seed mix. Some of the Mesa Verde species were relative easy to collect and were collected during one season. Other species were more difficult and required up to 7 years to obtain the quantity needed.

Seed collection is a high dollar item on the park contracts. Therefore, seed viability should be protected so recollections are not necessary.

The seed material collected is conditioned and cleaned, then tested for purity, germination, other seed materials and weeds. The cleaned and tested seed can be used for seeding seed production fields (grasses and forbs), or provided back to the park (shrubs) to revegetate disturbed sites.

Clean tested seeds are planted at the plant center in clean seed fields that are isolated from other species capable of crossing. Seed fields are cultivated, watered, weeded, fertilized and inspected for weed free production. Seed is harvested at maturity by appropriate methods. The seed is then conditioned, cleaned and tested as before. This seed that is native to the park is then available to the park for seeding disturbed sites.

In 1996, some of these seed materials were provided to Mesa Verde for fire rehabilitation for a fire that occurred that year. This made it possible for the park to use native park materials for part of their fire rehabilitation work.

A 0.75 acre seed field of hairy golden aster was established in 1991. During the first winter after planting, the plants remained green under our snow cover and Elk dug each row out from under the snow and grazed them. This use did not damage the stand. Hairy golden aster seed has been difficult to producer and through 1997 only a little more than 18.0 PLS pounds (plus 8.8 pounds of clean seed for 1997 harvest) has been produced.

A 0.18 acre seed field of yarrow was established by 1992. Since yarrow is a forb like hairy golden aster, they present special weed control problems and require a lot of hand labor. They each represent special harvesting methods (Flail-o-vac for hairy golden aster and a combine collector attachment - A.K.A. - A Diaper). So far 31.0 PLS pounds of yarrow (plus 18.0 pounds of clean seed in 1997) have been produced.

Seed of Salina wildrye was collected from the park over a period of two years (1991 and 1992). In 1991 (a year with a dry spring) 140.0 grams of clean seed was collected, enough to plant 3 rows 450 feet long. In 1992 (a year with a wetter spring) 1.23 pounds of clean seed was collected from almost the same area and was enough to plant a 0.5 acre seed field. Seed production has been low with only 4 PLS pounds of seed through 1996, plus 21 pounds of clean seed in 1997.

Seed of western wheatgrass was collected from the park over a two year period and amounted to 2.26 pounds of clean seed. A 0.9 acre seed field was established in 1993. A total of 108.0 PLS pounds of seed , plus 10.0 pounds of clean seed in 1997, has been produced. This particular western wheatgrass has very aggressive rhizomes and becomes root bound quickly.

Several of these native park materials (western wheatgrass, slender wheatgrass and salina wildrye) have been provided to the park and have been initially successfully seeded on a disturbed site.

## **PARTICIPANT LIST**

We were pleased to have a total of 236 participants at the Thirteenth High Altitude Revegetation Conference. Representatives from three foreign countries, as well as from 18 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 South Africa were present.

For all of you that came, thank you for your participation. Make plans for attending in 2000. The High Altitude Revegetation Conference will be held in February or March, 2000 in Ft. Collins, Colorado. Pass the word to your colleagues, so that the 2000 conference will be a great success.

For current information on upcoming High Altitude Committee events, visit our website at [www.highaltitudereveg.com](http://www.highaltitudereveg.com).

Warren R. Keammerer

Table 1. Geographical distribution of participants at the Thirteenth High Altitude Revegetation Conference (March 4-6, 1998).

<b>Geographic Entity</b>	<b>Number of Participants</b>	<b>Percent of Total Participants</b>
<b>CANADA</b>		
Saskatchewan	3	1.27
<b>SOUTH AFRICA</b>	2	0.84
<b>SWITZERLAND</b>	1	0.42
<b>UNITED STATES</b>		
Alaska	1	0.42
Arizona	2	0.84
California	4	1.69
Colorado	176	74.57
Idaho	2	0.84
Kansas	2	0.84
Minnesota	1	0.42
Montana	9	3.81
Nevada	3	1.27
New Mexico	3	1.27
Oregon	5	2.12
South Dakota	4	1.69
Tennessee	2	0.84
Texas	1	0.42
Utah	4	1.69
Washington	1	0.42
Washington, D.C.	1	0.42
Wisconsin	1	0.42
Wyoming	8	2.39
Total	236	100.00

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### Participant List

#### Thirteenth High Altitude Revegetation Workshop

Colorado State University-Fort Collins, CO

Dates Held: 3/4/98 to 3/6/98

---

1. Melvina M. Adoff  
1389 Wolverine Lane  
Bozeman, MT 59718  
Telephone: 406-587-2087  
Fax:  
Melvina@mailexcite.com
2. William Agnew  
REVEG Environmental Consulting  
719 Rocky Mountain Way  
Fort Collins, CO 80526  
Telephone: 970-226-5729  
Fax: 970-225-2224  
REVEGInc@aol.com
3. Jack Alexander  
4095 East Lake Blvd  
Carson City, NV 89704  
Telephone: 702-849-9614  
Fax: 702-849-3876
4. Rick Allen  
Bio Flora International  
9220 Cody Lane  
Westminster, CO 80021  
Telephone: 303-456-9475  
Fax: 303-456-9479
5. Jon Alstad  
ENSR  
1601 Prospect Parkway  
Fort Collins, CO 80525  
Telephone: 970-493-8878  
Fax: 970-493-0213  
jalstad@ENSR.com
6. Karma Anderson  
Colorado State University  
3704 West City Road 10  
Berthoud, CO 80513  
Telephone: 970-491-6928  
Fax:  
kander@lamar.colostate.edu
7. Julie Annear  
State of Colorado--DMG  
1313 Sherman Street  
Room 215  
Denver, CO 80203  
Telephone: 303-866-3567  
Fax: 303-832-8106
8. Ann Armstrong  
Boulder Mountain Parks  
P.O. Box 791  
Boulder, CO 80306  
Telephone: 303-413-7275  
Fax: 303-413-7201  
armstronga@cl.boulder.co.us
9. Jeff Arredondo  
Colorado Mountain College  
418 East 2nd Street, #1  
Leadville, CO 80461  
Telephone: 719-486-1438  
Fax:  
jarredon@cmel.coloradomtn.edu
10. Denise Arthur  
Colorado State University  
667 Hurricane Hill Drive  
Nederland, CO 80466  
Telephone: 303-258-3303  
Fax:

11. Loren E. Avis  
COGCC  
1120 Lincoln, Ste 801  
Denver, CO 80203  
Telephone: 303-894-2100  
Fax: 303-894-2109  
loren.avis@state.co.us
12. Laura Backus  
Dames and Moore  
633 17th Street  
Suite 2500  
Denver, CO 80202-3625  
Telephone: 303-299-7932  
Fax: 303-299-7901  
denllb@dames.com
13. Carol Baker  
Colorado Springs Utilities  
102 South Weber Street  
Colorado Springs, CO 80903  
Telephone: 719-448-8699  
Fax: 719-448-8666  
cbaker@csv.org
14. Ed Baker  
White River Nahcolite  
P.O. Drawer 72  
Rifle, CO 81650  
Telephone: 970-878-3674  
Fax: 970-878-5866
15. Mike Banovich  
CO Dept. of Transportation  
4201 E. Arkansas  
Room 415  
Denver, CO 80222  
Telephone: 303-757-9542  
Fax: 303-757-9868
16. Phil Barnes  
Homestake Mining Co.  
630 East Summit  
Lead, SD 57754  
Telephone: 605-584-4790  
Fax:  
pbarnes@homestake.com
17. W.R. Rocky Beavers  
National Park Service - DSC  
P.O. Box 25287  
Denver, CO 80225-0287  
Telephone: 303-969-2734  
Fax:
18. Ed Beddow  
Bureau of Reclamation  
Mail Code D-8210  
P.O. Box 25007  
Denver, CO 80225  
Telephone: 303-445-2234  
Fax:
19. Stuart A. Bengson  
ASARCO Incorporated  
P.O. Box 5747  
Tucson, AZ 85703  
Telephone: 520-798-7733  
Fax: 520-798-7783
20. David Bergey  
Thompson Creek Mine  
P.O. Box 62  
Clayton, ID 83226  
Telephone: 208-838-2200  
Fax: 208-838-2299
21. Virgil Best  
Box 8202  
Breckenridge, CO 80424  
Telephone: 970-453-9469  
Fax:  
klphoto@snowcap.net
22. Dick Bettale  
Arkansas Valley Seed Co.  
P.O. Box 16025  
Denver, CO 80216  
Telephone: 303-320-7500  
Fax: 303-320-7516

23. Carol Bieschke  
10405 SW Denney Road #40  
Beaverton, OR 97008  
Telephone: 503-644-8369  
Fax:  
duke503@gte.net
24. David Blauch  
Aquatic and Wetland Company  
1655 Walnut, Suite 205  
Boulder, CO 80302  
Telephone: 303-442-5770  
Fax:
25. Nicole Bogardus  
Colorado State University  
10555 West Jewell Avenue  
Apt. 15-307  
Lakewood, CO 80232  
Telephone: 303-716-0749  
Fax:
26. Corrine Boyd  
Environmental Tech  
324 West 9th Street  
Leadville, CO 80461  
Telephone: 719-486-2819  
Fax:
27. Dwayne Breyer  
Truax Company, Inc.  
4821 Xerxes Avenue  
Building "B"  
Minneapolis, MN 55430  
Telephone: 612-537-6639  
Fax:
28. Larry F. Brown  
L.F. Brown & Associates, Inc.  
P.O. Box 698  
Idaho Springs, CO 80452  
Telephone: 303-674-9813  
Fax: 303-567-9306  
larbrown@aol.com
29. Andrew Bruttig  
CMC Leadville, CO  
Environmental Tech Program  
901 South Hwy 24  
Campus Box 109  
Leadville, CO 80461  
Telephone: 719-486-4313  
Fax:
30. David Buckner  
ESCO Associates Incorporated  
P.O. Box 18775  
Boulder, CO 80308  
Telephone: 303-447-2999  
Fax: 303-499-4276
31. Gregg Campbell  
Colorado School of Mines  
Graduate Student  
76 Bethaven Place  
Boulder, CO 80303  
Telephone: 303-543-0922  
Fax: 303-938-0103
32. Erika Campos  
National Park Service  
P.O. Box 8  
Mesa Verde, CO 81330  
Telephone: 970-529-4465  
Fax: 970-529-4498  
enka-campos@nps.gov
33. William J. Carter  
State of Colorado--DMG  
1313 Sherman Street  
Room 215  
Denver, CO 80203  
Telephone: 303-866-4940  
Fax:
34. David Chenoweth  
Western States Reclamation  
11730 Wadsworth Blvd  
Broomfield, CO 80020  
Telephone: 303-469-1986  
Fax: 303-465-2478
-

35. Dana Christensen  
Colorado State University  
Horticulture & Landscape Arch.  
Fort Collins, CO 80521  
Telephone: 970-482-8563  
Fax:
36. Vic Claassen  
University of California-Davis  
Land, Air, Water Res. & Soils  
One Shields Avenue  
Davis, CA 95616-8627  
Telephone: 916-752-6514  
Fax:
37. Joe Cogan  
24899 South Hwy. 285  
Nathrop, CO 81236  
Telephone: 719-395-2339  
Fax:
38. Tom Colbert  
R & R International, Inc.  
3333 Quebec Street  
Suite 7800  
Denver, CO 80207  
Telephone: 303-322-1511  
Fax: 303-322-1544
39. David Cole  
Rocky Mountain Research  
Forestry Sciences Laboratory  
P.O. Box 8089  
Missoula, MT 59807  
Telephone: 406-542-4150  
Fax: 406-543-2663
40. David Conlin  
Colorado College  
Dept. of Biology  
14 East Cache la Poudre  
Colorado Springs, CO 80903  
Telephone: 719-389-6401  
Fax: 719-389-6940  
d-conlin@cc.colorado.edu
41. Jeff Connor  
Rocky Mountain Nat'l Park  
Estes Park, CO 80517  
Telephone: 970-586-1296  
Fax: 970-586-1392
42. Marvin Courtnege  
Buckley Powder Co.  
42 Inverness Drive E.  
Englewood, CO 80112  
Telephone: 303-790-7008 ext.177  
Fax: 303-790-7033
43. Susan Cousins  
Aquatic & Wetland Company  
1655 Walnut Street, Suite 205  
Boulder, CO 80302  
Telephone: 303-442-5770  
Fax:
44. Gerald L. Cox  
Alliance of Growing Tech.  
119 North Parker  
Suite 143  
Olathe, KS 66061  
Telephone: 913-393-0100  
Fax: 913-829-3571  
glgrotc@aol.com
45. Scott Davis  
Bureau of Land Management  
Colorado State Office  
2850 Youngfield Street  
Lakewood, CO 80227  
Telephone: 303-239-3721  
Fax: 303-239-3808  
s2davis@co.blm.gov
46. Claire DeLeo  
Boulder Ct. Parks & Open Space  
P.O. Box 471  
Boulder, CO 80306  
Telephone: 303-441-1643  
Fax: 303-441-1644  
cldpa@boco.co.gov
-

47. Athena Demetry  
Sequoia National Park  
P.O. Box 4  
Sequoia Nat'l Park, CA 93262  
Telephone: 209-565-3949  
Fax:  
ademetry@thegrid.net

49. James Dillie  
State of Colorado--DMG  
1313 Sherman Street  
Room 215  
Denver, CO 80203  
Telephone: 303-866-3567  
Fax: 303-832-8106

51. Todd Duex  
LAC Minerals Inc.  
P.O. Box 892  
Lead, SD 57754  
Telephone:  
Fax:

53. Lois Dworshak  
Upper CO. Enviro. Plant Center  
P.O. Box 448  
Meeker, CO 81641  
Telephone: 970-878-5003  
Fax: 970-878-5004  
plant@cmn.net

55. Kevin Edinger  
University of Wyoming  
8300 Hildreth Road  
Cheyenne, WY 82009  
Telephone: 307-638-4996  
Fax:  
skidoo@uwyo.edu

57. Gerard Eldridge  
905 South Pennsylvania Street  
Denver, CO 80209  
Telephone: 303-733-4557  
Fax:

48. Roseann Densmore  
US Geological Survey  
Biological Resources Division  
1011 East Tudor Road  
Anchorage, AK 99503  
Telephone:  
Fax:  
roseann\_densmore@usgs.gov

50. Myron Dortch  
Western States Reclamation  
11730 Wadsworth Blvd  
Broomfield, CO 80020  
Telephone: 303-469-1986  
Fax: 303-465-2478

52. Nancy Dunkle  
National Park Service  
P.O. Box 25287  
Denver, CO 80225-0287  
Telephone: 303-969-2568  
Fax: 303-969-2236  
Nancy\_Dunkle@nps.gov

54. Jim Ebersole  
Colorado College  
Dept. of Biology  
14 East Cache la Poudre  
Colorado Springs, CO 80903  
Telephone: 719-389-6401  
Fax: 719-389-6940  
jebersole@cc.colorado.edu

56. Michael Edwards  
National Geographic Magazine  
17th & M Streets  
Washington, DC 20036  
Telephone:  
Fax:

58. Michael Ellis  
Ellis Env. Engineering., Inc.  
4342 Ulysses Way  
Golden, CO 80403  
Telephone: 303-279-8532  
Fax: 303-279-1609

59. Wally Erickson  
CO Div. of Minerals & Geology  
484 Turner Drive  
Building F, Suite 101  
Durango, CO 81301  
Telephone: 970-247-5469  
Fax: 970-247-5104
60. Julie Etra  
Western Botanical Services  
5859 Mt. Rose Hwy.  
Reno, NV 89511  
Telephone: 702-849-3223  
Fax: 702-849-3303
61. Mark Faller  
Independence Pass Foundation  
0238 Faun Drive  
Carbondale, CO 81623  
Telephone: 970-963-4959  
Fax:  
fulcon@rof.net
62. Camille Farrell  
CO Dept. of Public Health  
P.O. Box 2927  
Telluride, CO 81435  
Telephone: 970-728-5487  
Fax: 970-728-3415
63. Kevin Fisher  
Colorado State University  
P.O. Box 2469  
Fort Collins, CO 80522  
Telephone: 970-484-8448  
Fax:  
fish@lamar.colostate.edu
64. Suzanne Folke  
Western Native Seed  
P.O. Box 1463  
Salida, CO 81201  
Telephone: 719-539-1071  
Fax: 719-539-6755
65. Chance Foreman  
Vance Bros, Inc  
P.O. Box 369  
3313 Moline Street  
Aurora, CO 80040  
Telephone: 303-341-2604  
Fax: 303-341-2036
66. Justin French  
Antelope Coal Company  
Caller Box 3008  
Gillette, WY 82717  
Telephone: 307-464-1133  
Fax: 307-464-2588  
frenchj@kennecott.com
67. Harvey Fryberger  
Sharp Bros Seed Co.  
101 East 4th Street Road  
Greeley, CO 80631  
Telephone:  
Fax:
68. Amanda B. Fuller  
1734 Pine Street  
Boulder, CO 80302  
Telephone: 303-544-1039  
Fax:  
fulleramanda@yahoo.com
69. Richard G. Gatewood  
Nat. Park Service, CSU Student  
Box 1, Su 52  
Los Alamos, NM 87599  
Telephone: 505-672-3861, x559  
Fax: richard\_gatewood@nps.gov
70. Richard Goehring  
Twenty First Century Seeders  
203 Racquette Drive  
Ft. Collins, CO 80524  
Telephone: 970-490-6142  
Fax:

71. Wes Goff  
Colorado Dept of Trans.  
P.O. Box 399  
Dumont, CO 80439  
Telephone: 303-569-3291  
Fax: 303-623-0542
72. Paul Goodman  
John Galt Systems  
3144 7th Street  
Boulder, CO 80304  
Telephone: 303-546-6238  
Fax:
73. Donna Graham  
White River Nat'l Forest  
P.O. Box 948  
Glenwood Springs, CO 81602  
Telephone: 970-945-2521  
Fax: 970-945-3288  
whiteriver@fs.fed.us
74. Dimitri Grobovsky  
American Mountain Foundation  
1520 Alamo Avenue  
Colorado Springs, CO 80907  
Telephone: 719-471-7736  
Fax: 719-577-4552  
amfbox@aol.com
75. Grant Gurnee  
Aquatic and Wetland Company  
1655 Walnut, Suite 205  
Boulder, CO 80302  
Telephone: 303-442-5770  
Fax:  
wetland123@aol
76. Kara Gwin  
Bowman Construction Supply  
2310 South Syracuse Way  
Denver, CO 80231  
Telephone: 303-696-8960  
Fax: 303-696-0620
77. Blair Hall  
Town of Breckenridge  
P.O. Box 168  
Breckenridge, CO 80424  
Telephone: 970-453-2251, x390  
Fax: 970-453-1513
78. Kathy Halm  
CO Dept. of Transportation  
4201 E. Arkansas  
Room 415  
Denver, CO 80222  
Telephone: 303-757-9174  
Fax: 303-757-9868
79. David Hamilton  
CO Fourteeners Initiative  
600 South Marion Parkway  
Denver, CO 80209  
Telephone: 303-715-1010 x13  
Fax: 303-715-1212
80. Karen Haner  
Denver Water  
1600 West 12th Avenue  
Denver, CO 80254  
Telephone: 303-628-6383  
Fax: 303-628-6853
81. John T. Harrington  
New Mexico State University  
P.O. Box 359  
Mora, NM 87732  
Telephone: 505-387-2319  
Fax: 505-387-9012  
joharrin@nmsu.edu
82. Jan Harrison  
Frontier Env. Technologies  
P.O. Box 542  
Fort Collins, CO 80522  
Telephone: 970-498-8705  
Fax: 970-498-8720  
erosion-solutions@msn.com

83. Jim Hartman  
Western Area Power Admin.  
P.O. Box 3700  
5555 East Crossroads Blvd.  
Loveland, CO 80539  
Telephone: 970-490-7450  
Fax: 970-490-7579  
hartman@wapa.gov
84. Wendell G. Hassell  
7866 Marshall Street  
Arvada, CO 80003  
Telephone: 303-422-2440  
Fax:  
wghassell@aol.com.
85. Bruce Hastings  
USFWS  
Rocky Mountain Arsenal  
National Wildlife Refuge  
Building 613  
Commerce City, CO 80022  
Telephone: 303-289-0232 ext.113  
Fax: 303-289-0579
86. Celeste Havener  
University of Wyoming  
94 Fox Creek Road  
Laramie, WY 82070  
Telephone: 307-742-9204  
Fax:  
celesteh@uwyo.edu
87. William H. Hawkins  
West Ridge Corporation  
583 Cerro Ct.  
Evergreen, CO 80439  
Telephone: 303-674-1874  
Fax:
88. Walt Henes  
Southwest Seed Inc.  
13260 CR 29  
Dolores, CO 81323  
Telephone: 970-565-8722  
Fax: 970-565-2576
89. Walter Henes  
Southwest Seed Inc.  
13260 CR 29  
Dolores, CO 81323  
Telephone: 970-565-8722  
Fax: 970-565-2576
90. Loren Hettinger  
Dames & Moore  
#2500 - 633 17th Street  
Denver, CO 80202  
Telephone: 303-299-7836  
Fax: 303-299-7901  
denlrh@dames.com
91. Don Hijar  
Southwest Seed Inc.  
P.O. Box 1604  
Greeley, CO 80632  
Telephone: 970-356-7002  
Fax: 970-356-7263
92. Diane Hillgrove  
Colorado Mountain College  
901 South Hwy 24 Box 212  
Leadville, CO 80461  
Telephone: 714-486-4362  
Fax:  
h0424@cmcl.coloradomtn.edu
93. Janey Hines  
H.B. Milagard Landscapes  
3758 County Road 301  
Parachute, CO 81635  
Telephone: 970-285-1133  
Fax:  
hinesjf@aol.com
94. Matthew L. Hogen  
Colorado Mountain College  
417 West 7th #4  
Leadville, CO 80461  
Telephone: 719-486-3197  
Fax:  
MCHOGEN@Hot mail.com

95. Jeffrey Hovermale  
U.S. Forest Service  
Pikes Peak Ranger District  
601 South Weber Street  
Colorado Springs, CO 80903  
Telephone: 719-636-1602  
Fax: 719-477-8273  
jeff4trees@aol.com
96. Dave Hull  
Idaho Div. of Environ. Quality  
224 South Arthur  
Pocatello, ID 83204  
Telephone: 208-236-6160  
Fax: 208-236-6168
97. Harold B. Humphries  
CO Div. of Minerals & Geology  
Room 215  
1313 Sherman Street  
Denver, CO 80203  
Telephone: 303-866-3567  
Fax: 303-832-8106
98. Charles Jackson  
PO Box 207  
Idaho Springs, CO 80452  
Telephone: 303-567-2708  
Fax:  
kjackson@mstg.net
99. Justin James  
James Ranches Landscaping  
33800 Hwy 550  
Durango, CO 81301  
Telephone: 970-259-0301  
Fax: 970-259-0307  
jdjames@frontier.net
100. William F. Jennings  
P.O. Box 952  
Louisville, CO 80027  
Telephone: 303-666-8348  
Fax: 303-666-8348
101. Darryl Joewik  
American Colloid Co.  
P.O. Box 3386  
Gillette, WY 82717  
Telephone: 605-892-6371  
Fax:
102. Clyde B. Johnson  
Bureau of Land Management  
701 Camino del Rio  
Durango, CO 81301  
Telephone: 970-385-1352  
Fax: 970-385-1375
103. Louise Johnson  
Yosemite National Park  
Flood Recovery Branch  
P.O. Box 700-w  
El Portal, CA 95318  
Telephone: 209-379-1027  
Fax: 209-379-1149  
louise\_Johnson@nps.gov
104. Rodney Jones  
Western Area Power Admin.  
P.O. Box 3700  
Loveland, CO 80539  
Telephone: 970-490-7371  
Fax: 970-490-7213  
rjones@wapa.gov
105. Christina Kamnikar  
State of Colorado--DMG  
1313 Sherman Street  
Room 215  
Denver, CO 80203  
Telephone: 303-866-3567  
Fax:
106. Dushen Kasenov  
Kumtor Operating Comp.  
#4-130 Robin Crescent  
Saskatoon, SK  
Canada S7L 6M7  
Telephone: 306-242-4442  
Fax: 306-242-7237
-

107. Deb Keammerer  
The Restoration Group, Inc.  
5858 Woodbourne Hollow Road  
Boulder, CO 80301  
Telephone: 303-530-1783  
Fax: 303-581-9219
108. Warren R. Keammerer  
Keammerer Ecological Consult.  
5858 Woodbourne Hollow Road  
Boulder, CO 80301  
Telephone: 303-530-1783  
Fax:  
warren\_keammerer@msn.com
109. Terry Keane  
Colorado Dept of Trans.  
202 Centennial  
Glenwood Springs, CO 81601  
Telephone: 970-945-8187  
Fax: 970-945-3860
110. Ken Kinnard  
Bowman Construction Supply  
2300 S. Syracuse Way  
Denver, CO 80231  
Telephone: 303-696-8960  
Fax: 303-696-0620
111. Kathy Kircher  
Denver Botanic Gardens  
8500 Deer Creek Canyon Road  
Littleton, CO 80123  
Telephone: 303-973-3705  
Fax: 303-973-1979
112. Kenneth S. Klco  
Azurite, Inc.  
P.O. Box 338  
Cotopaxi, CO 81223  
Telephone: 719-942-4178  
Fax: 719-942-4178
113. Elizabeth Klein  
KIOWA Engineering Corp  
2814 International Circle  
Colorado Springs, CO 80910  
Telephone: 719-630-7342  
Fax: 719-630-0406
114. Ed Kleiner  
Comstock Seed Co.  
8520 West 4th Street  
Reno, NV 89523  
Telephone: 702-746-3681  
Fax:
115. Sandra Klepadlo  
National Park Service  
P.O. Box 7  
Crater Lake, OR 97604  
Telephone: 541-594-2211 X620  
Fax: 541-594-2261
116. Steve Kloetzel  
Bitterroot Restoration, Inc.  
445 Quast Lane  
Corvallis, MT 59828-9406  
Telephone: 406-961-4991  
Fax: 406-961-4626  
sales@revegetation.com
117. Burke Korol  
T.A.E.M. Ltd.  
#4-130 Robin Crescent  
Saskatoon, SK  
Canada S7L 6M7  
Telephone: 306-242-4442  
Fax: 306-242-7237
118. Paul Krabacher  
CO Div. of Minerals & Geology  
2946 B1/2 Road  
Grand Junction, CO 81503  
Telephone: 970-248-7253  
Fax: 970-248-7253

119. Dennis Krochak  
T.A.E.M. Ltd.  
#4-130 Robin Crescent  
Saskatoon, SK  
Canada S7L 6M7  
Telephone: 306-242-4442  
Fax: 306-242-7237
120. A. J. Kruchten  
Colorado Mountain College  
148 Rafferty Drive  
Leadville, CO 80401  
Telephone: 719-486-9328  
Fax:
121. Janet Kudell-Ekstrum  
U.S. Forest Service  
P.O. Box 720  
Eagle, CO 81631  
Telephone: 970-328-6388  
Fax: 970-328-6448
122. Lynn Kunzler  
UT Div. of Oil, Gas & Mining  
1594 West North Temple  
Box 145801  
Salt Lake City, UT 84114  
Telephone: 801-538-5310  
Fax: 801-359-3940  
LKunzler@state.ut.us
123. Amy Laartz  
Colorado State University  
2230 Tanglewood Drive  
Fort Collins, CO 80525  
Telephone: 970-493-4174  
Fax:  
amyl@neota.cnr.colostate.edu
124. Ken Lair  
NRCS-USDA  
655 Parfet Street  
Room E200C  
Lakewood, CO 80215  
Telephone: 303-236-2886 x210  
Fax: 303-236-2896
125. Jim Lance  
Colorado Dept. of Trans.  
222 S. 6th Street  
Room 317  
Grand Junction, CO 81501  
Telephone: 970-248-7255  
Fax: 970-248-7254
126. Thomas D. Landis  
U.S. Forest Service  
P.O. Box 3623  
333 SW First Avenue  
Portland, OR 97208  
Telephone: 503-808-2344  
Fax: 503-808-2339  
nurseries@aol.com
127. Eric M. Lane  
State Weed Coordinator  
CO Dept. of Agriculture  
700 Kipling Street #4000  
Lakewood, CO 80215  
Telephone: 303-239-4182  
Fax: 303-239-4177  
elane6276@aol.com
128. Joyce Lapp  
Glacier National Park  
West Glacier, MT 59936  
Telephone: 406-888-7817  
Fax: 406-888-7808  
joyce\_lapp@nps.gov
129. Steve Leach  
Pittsburgh and Midway Coal  
7412 E. Long Circle  
Englewood, CO 80112  
Telephone: 303-930-4014  
Fax:  
slse@chevron.com
130. David Lentz  
Larimer County  
Dept. of Natural Resources  
P.O. Box 1190  
Fort Collins, CO 80522  
Telephone: 970-498-5765  
Fax:
-

131. David Levy  
Shepard Miller, Inc.  
3801 Automation Way  
Suite 100  
Fort Collins, CO 80525  
Telephone: 970-206-4292  
Fax: 970-223-1777
132. Jeffrey Lormand  
Deleuw, Cather & Company  
1700 Broadway, #600  
Denver, CO 80290  
Telephone: 303-863-7900  
Fax: 303-863-7110
133. Mark S. Loye  
Independent Consultant  
13593 West 24th Place  
Golden, CO 80401  
Telephone: 303-271-5062  
Fax: 303-271-5064  
mloye@co.jefferson.co.us
134. Gary A. Ludwig  
Pleasant Avenue Nursery, Inc.  
P.O. Box 257  
Buena Vista, CO 81211-0257  
Telephone: 719-395-6955  
Fax: 719-395-5718
135. Carl Mackey  
Morrison Knudsen  
P.O. Box 1717  
Commerce City, CO 80037  
Telephone: 303-286-4825  
Fax: 303-853-3946  
carl\_mackey@mk.com
136. Penny Mackey  
Colorado Mountain College  
P.O. Box 1928  
Leadville, CO 81620  
Telephone: 719-486-0558  
Fax:
137. Chad Malear  
Colorado Mountain College  
Environmental Tech  
148 Rafferty Drive  
Leadville, CO 80461  
Telephone: 719-486-9328  
Fax:  
cmalear@hotmail.com
138. H. Ward Marotti  
ESCO Associates Incorporated  
P.O. Box 18775  
Boulder, CO 80308  
Telephone: 303-666-7432  
Fax:
139. Dave McAdoo  
Bitterroot Restoration, Inc.  
445 Quast Lane  
Corvallis, MT 59828-9406  
Telephone: 406-961-4991  
Fax: 406-961-4626  
sales@revegetation.com
140. David McDowall  
Homestake Mining Co.  
630 East Summit  
Lead, SD 57754  
Telephone: 605-584-4790  
Fax:
141. Thomas R. McGee  
Streamside Excavation & Reclam  
P.O. Box 3273  
Glenwood Springs, CO 81602  
Telephone: 970-945-7357  
Fax:
142. Pat McGuire  
REI  
4738 N. 40th Street  
Sheboygan, WI 53082  
Telephone: 920-458-8871, x2572  
Fax: 920-458-0550  
pat\_mcguire@rustei.com
-

143. Terry McLendon  
University of Texas-El Paso  
Dept. of Biological Sciences  
El Paso, TX 79968  
Telephone:  
Fax:
144. Floyd A. McMullen, Jr.  
Office of Surface Mining  
1999 Broadway  
Suite 3320  
Denver, CO 80202  
Telephone: 303-844-1493  
Fax: 303-844-1538
145. Peter McRae  
Quattro Environmental, Inc.  
649 "I" Avenue  
Coronado, CA 92118  
Telephone: 619-522-0044  
Fax: 619-522-0055
146. Jim Meining  
Western States Reclamation  
11730 Wadsworth Blvd  
Broomfield, CO 80020  
Telephone: 303-469-1986  
Fax: 303-465-2478
147. Daryl E. Mergen  
Colorado State University  
116 Vandy Lane  
Fort Collins, CO 80524  
Telephone: 970-484-8989  
Fax:
148. Sharon Meyer  
CO Dept. of Transportation  
4201 E. Arkansas  
Room 415  
Denver, CO 80222  
Telephone: 303-757-9174  
Fax: 303-757-9868
149. Victor Meyer  
Colorado State University  
Student  
1801 Brookwood Drive  
Fort Collins, CO 80525  
Telephone: 970-416-6467  
Fax:
150. Jim Miller  
City of Fort Collins  
P.O. Box 580  
Fort Collins, CO 80522  
Telephone: 970-416-2133  
Fax: 970-224-6177  
jmiller@ci.fort-collins.co.us
151. Randy D. Moench  
Colorado State Forest Service  
Colorado State University  
01 Nursery  
Fort Collins, CO 80523  
Telephone: 970-491-8429  
Fax:  
rmoench@lamar.colostate.edu
152. Peter G. Moller  
Colorado Mountain College  
Timberline Campus  
Environmental Technology Prog.  
Leadville, CO 80461  
Telephone: 719-486-4222  
Fax: 719-486-3212  
moller@cmc1.coloradomtn.edu
153. Orlando Montero  
Colorado Mountain College  
Environmental Tech. Student  
901 South Hwy 24  
Leadville, CO 80461  
Telephone: 719-486-4350  
Fax:  
yerba@hotmail.com
154. Chris Monz  
NOLS  
808 Redwood Court  
Bellvue, CO 80512  
Telephone: 970-484-2288  
Fax:  
cmonz@frii.com
-

155. Bruce Moorman  
Green Acres Nursery  
4990 McIntyre  
Golden, CO 80403  
Telephone: 303-279-8204  
Fax: 303-278-1832  
gacres@rmi.net
156. Robert Hugh Morrison  
Kirtec Resources USA LTD  
380 East Fort Lowell Road  
Suite 235  
Tucson, AZ 85705  
Telephone: 520-882-0729  
Fax: 520-295-0301  
kirtecens@aol.com
157. Marcia B. Murdock  
PTI Env. Services  
25358 Red Cloud Drive  
Conifer, CO 80433  
Telephone: 303-966-3560  
Fax: 303-966-3578  
marcia.murdock@rfets.gov
158. Patrick H. Murphy  
Ecotone Corporation  
1554 North Street  
Boulder, CO 80304  
Telephone: 303-444-4358  
Fax:
159. Mark Mustoe  
Grassland West  
908 Port Drive  
Clarkston, WA 99403  
Telephone: 509-456-7712  
Fax: 509-758-6601
160. Gregory J. Newman  
Colorado State University  
2201 West Orchard Place #K63  
Fort Collins, CO 80521  
Telephone: 970-407-9829  
Fax:  
gnewman@holly.colostate.edu
161. Stuart Nielson  
Colorado Analytical Laboratory  
P.O. Box 507  
Brighton, CO 80601  
Telephone: 303-659-2313  
Fax: 303-659-2315  
sgni@aol.com
162. Gary Noller  
Upper CO. Enviro. Plant Center  
P.O. Box 448  
Meeker, CO 81641  
Telephone: 970-878-5003  
Fax: 970-878-5004  
plant@cmn.net
163. Ben Northcutt  
Int'l Erosion Control Assoc.  
P.O. Box 4904  
Steamboat Springs, CO 80477-4904  
Telephone: 1-800-455-4322  
Fax:  
ecinfo@ieca.org
164. Maureen O-Shea-Stone  
Plantar Consulting Services  
170 South 33rd Street  
Boulder, CO 80303  
Telephone: 303-543-8715  
Fax: 303-543-9832  
mostone@pcisys.net
165. Hans Oberlohr  
Rocky Mtn. Bio Products, Inc.  
P.O. Box 608  
Edwards, CO 81632  
Telephone: 970-926-1025  
Fax:
166. Larry Oehler  
State of Colorado--DMG  
1313 Sherman Street  
Room 215  
Denver, CO 80203  
Telephone: 303-866-3567  
Fax: 303-832-8106

167. Steve Parr  
Upper CO. Enviro. Plant Center  
P.O. Box 448  
Meeker, CO 81641  
Telephone: 970-878-5003  
Fax: 970-878-5004  
plant@cmn.net
168. Jeff Pecka  
Systems Planning Group  
2973 East Irwin Place  
Englewood, CO 80112  
Telephone: 303-770-0747  
Fax:
169. Andy Pelster  
City of Boulder  
66 South Cherryvale Road  
Boulder, CO 80303  
Telephone: 303-441-4142  
Fax: 303-499-6191  
pelstera@ci.boulder.co.us
170. Jim Perry  
Bureau of Land Management  
P.O. Box 68  
Kremmling, CO 80459  
Telephone: 970-724-3437  
Fax: 970-724-9590  
jperry@co.blm.gov
171. Mark Phillips  
Phillips Seeding  
11843 Billings Avenue  
Lafayette, CO 80026  
Telephone: 303-665-2618  
Fax: 303-828-0229
172. Robin Phillips  
Phillips Seeding  
11843 Billings Avenue  
Lafayette, CO 80026  
Telephone: 303-665-2618  
Fax: 303-828-0229
173. Lee Pierce  
Synthetic Industries  
4019 Industry Drive  
Chattanooga, TN 37416  
Telephone: 423-899-7619  
Fax:
174. Denise Pisani  
Colorado Mountain College  
Environmental Tech. Student  
901 South Hwy 24  
Leadville, CO 80461  
Telephone: 719-486-4350  
Fax:  
malter38@hotmail.com
175. Patrick Plantenberg  
MT Dept of Env. Quality  
P.O. Box 200901  
Helena, MT 59620  
Telephone: 406-444-4960  
Fax: 406-404-1374
176. Mark Plummer  
Plummer Seed Co. Inc.  
P.O. Box 70  
Ephraim, UT 84627  
Telephone: 801-283-4844  
Fax: 801-283-4030
177. Karen Prentice  
CSU - Rangeland Eco. Sci.  
2804 W. Elizabeth  
Fort Collins, CO 80521  
Telephone: 970-472-1746  
Fax:  
kpsc@holly.colostate.edu
178. Mary Rasmussen  
Crater Lake National Park  
P.O. Box 7 Hwy. 62  
Crater Lake, OR 97604  
Telephone:  
Fax:  
mary\_rasmussen@nps.gov

179. Ed Redente  
Colorado State University  
Rangeland Ecosystem Sci Dept  
Fort Collins, CO 80523  
Telephone: 970-491-6542  
Fax: 970-491-2339
180. Steve Renner  
CO Div. of Minerals & Geology  
2148 Broadway #C-5  
Grand Junction, CO 81503  
Telephone: 970-241-0336  
Fax: 970-241-1516
181. Camille Richard  
Colorado State University  
Research Assistant  
P.O. Box 188  
Lake City, CO 81235  
Telephone: 970-944-4117  
Fax:  
crichard@csn.net
182. Robert R. Richardson  
Alliance of Growing Tech.  
119 North Parker  
Suite 143  
Olathe, KS 66061  
Telephone: 913-393-0100  
Fax: 913-829-3571  
growtech@gte.net
183. Timothy C. Richmond  
Wyoming AML (ASSMR)  
Herschler Bldg. 3W  
122 West 25th Street  
Cheyenne, WY 82002  
Telephone: 307-777-6859  
Fax: 307-777-6462  
trichm@misss.state.wy.us
184. John Rohnert  
Colorado Mountain College  
Environmental Tech  
P.O. Box 403  
Leadville, CO 80461  
Telephone: 719-486-2558  
Fax: 719-486-2558  
rohnert@csa.com
185. Bryce Romig  
Climax Molybdenum Co.  
Climax, CO 80421  
Telephone: 719-486-2150  
Fax: 719-486-2251  
bromig@Cyprus.com
186. Ken Sauerberg  
Town of Breckenridge  
P.O. Box 168  
Breckenridge, CO 80424  
Telephone: 970-453-3181  
Fax: 970-453-1513
187. Tom Saunders  
Colorado Mountain College  
417 West 7th Street #4  
Leadville, CO 80461  
Telephone: 719-486-3197  
Fax:  
nerdnose@hotmail.com
188. Herb Schaal  
EDAW  
240 East Mountain Avenue  
Fort Collins, CO 80524  
Telephone: 970-484-6073  
Fax:
189. John Scheetz  
Homestake Mining Co.  
630 East Summit  
Lead, SD 57754  
Telephone: 605-584-4790/605-584-4784  
Fax: 605-584-4948
190. Brenda Schladweiler  
University of Wyoming  
P.O. Box 6021  
Laramie, WY 82073  
Telephone: 307-721-5179  
Fax: 307-721-5179  
bks-en@trib.com
-

191. Tom Schreiner  
State of Colorado--DMG  
1313 Sherman Street  
Room 215  
Denver, CO 80203  
Telephone: 303-866-3567  
Fax:
192. Bob Schroeder  
Ski Monarch  
#1 Powder Place  
Monarch, CO 81227  
Telephone: 719-539-3573  
Fax:
193. Joseph D. Scianna  
USDA NRCS  
Plant Materials Center  
Route 1, Box 1189  
Bridger, MT 59014  
Telephone: 406-662-3578  
Fax: 406-662-3428  
jscianna@mt.nrcs.usda.gov
194. Rebecca M. Siegle  
Office of Surface Mining  
1999 Broadway, Suite 3320  
Denver, CO 80202  
Telephone: 303-844-1498  
Fax: 303-844-1538
195. Catherine "Cat" Skinner  
University of Wyoming  
Soil Science  
Ag 1005  
Laramie, WY 82071-3354  
Telephone: 307-766-3114  
Fax: 307-766-6403  
skinnerc@uwoyo.edu
196. Stephen J. Spaulding  
P.O. Box 96  
Green Mountain Falls, CO 80819  
Telephone: 719-684-2333  
Fax: 719-684-8270  
upct@worldnet.att.net
197. S.J. Steenekamp  
Envirogreen  
P.O. Box 20813  
Potchefstroom, Noordbrug  
South Africa  
Telephone: 0148-297-7455  
Fax: 0148-297-7458  
info@envirogreen.co.za
198. Jay Stevens  
Invisible Structures, Inc.  
20100 East 35th Drive  
Aurora, CO 80011  
Telephone: 303-373-1234  
Fax: 303-373-1223  
jaystevens@earthlink.net
199. Terri Stone  
Colorado Mountain College  
P.O. Box 4032  
Buena Vista, CO 81211  
Telephone: 719-395-2729  
Fax:
200. Pete Strazdas  
MT DEQ  
P.O. Box 200901  
Helena, MT 59620  
Telephone: 406-444-4962  
Fax: 406-444-1374
201. Ernst Strenge  
Colorado State University  
314 Scott Avenue  
Fort Collins, CO 80521  
Telephone: 970-493-4051  
Fax:
202. Crystal Strouse  
City of Fort Collins  
P.O. Box 580  
Fort Collins, CO 80522  
Telephone: 970-416-2133  
Fax: 970-224-6177  
cstrouse@ci.Fort-Collins.co.us
-

203. Suzanne Stutzman  
National Park Service  
P.O. Box 25287  
DFC-LA  
Denver, CO 80225  
Telephone: 303-987-6671  
Fax: 303-969-2236
204. Judd Sundine  
Revex, Inc.  
5325 Garland Street  
Arvada, CO 80002  
Telephone: 303-432-8669  
Fax: 303-423-8469
205. Paul Swartzinski  
Colorado State University  
1525 Crestmore Place  
Fort Collins, CO 80521  
Telephone: 970-495-9901  
Fax:
206. Russell S. Sydner  
Colorado State University  
921 Ponderosa Drive  
Fort Collins, CO 80521  
Telephone: 970-224-2663  
Fax:  
rsydner@lamar.colostate.edu
207. Lisa Tasker  
805 Dewey Avenue  
Boulder, CO 80304  
Telephone: 303-447-9431  
Fax: 303-447-9443  
tasker1@netONE.com
208. Marc S. Theisen  
Synthetic Industries  
4019 Industry Drive  
Chattanooga, TN 37416  
Telephone: 423-899-0444  
Fax:
209. Gary L. Thor  
Colorado State University  
Dept. of Soil & Crop Sciences  
Fort Collins, CO 80523  
Telephone: 970-491-7296  
Fax: 970-491-0564  
garythor@lamar.colostate.edu
210. Jeff Todd  
Schafer & Associates, Inc.  
801 Fourteenth Street  
Golden, CO 80401-1866  
Telephone: 303-216-1600  
Fax: 303-216-1316  
corbin1336@aol.com
211. Alex Tonnesen  
Western Native Seed  
P.O. Box 1463  
Salida, CO 81201  
Telephone: 719-539-1071  
Fax: 719-539-6755
212. Tyler Torrens  
Colorado Mountain College  
212 West Chestnut, Apt 2  
Leadville, CO 80461  
Telephone: 719-486-2136  
Fax:
213. Joan Trindle  
USDA-NRCS Plant Materials Ctr.  
3415 NE Granger Avenue  
Corvallis, OR 97330  
Telephone: 541-757-4812  
Fax: 541-757-4733  
jtrindle@or.nrcs.usda.gov
214. Joe Trlica  
Colorado State University  
Rangeland Ecosystem Sci.  
Fort Collins, CO 80523  
Telephone: 970-491-5655  
Fax:  
joet@picea.cnr.colostate.edu

215. Barry J. Turner  
Wyoming Military Dept.  
1014 East 25th Street, #304  
Cheyenne, WY 82001  
Telephone: 307-772-5285  
Fax:

217. Gayle P. Turner  
Office of Surface Mining  
1999 Broadway, Suite 3320  
Denver, CO 80202  
Telephone: 303-844-1472  
Fax: 303-844-1538

219. Krystyna Urbanska  
Geobotanisches Institute  
Zurichbergstrasse 38  
8044 Zurich, CH  
Switzerland  
Telephone: 632-4308  
Fax:  
urbanska@geobot.umnw.ethz.ch

221. Douglas F. Vance  
Granite Seed Company  
1697 West 2100 North  
Lehi, UT 84043  
Telephone: 801-768-4422  
Fax:

223. C.J. Viljoen  
Envirogreen  
P.O. Box 20813  
Potchefstroom, Noordbrug  
South Africa  
Telephone: 0148-297-7455  
Fax: 0148-297-7458  
cviljoen@envirogreen.co.za

225. Anne Wagner  
Molycorp, Inc.  
P.O. Box 469  
Questa, NM 87556  
Telephone: 505-586-7625  
Fax: 505-586-0811  
awagne@questa.unocal.com

216. Christine Turner  
Revex Incorporated  
P.O. Box 208  
Hygiene, CO 80533  
Telephone: 303-772-4335  
Fax: 303-772-4349  
chris@revex.com

218. Laura Tyler  
Colorado State University  
Graduate Student  
2601 Killdeer Drive  
Fort Collins, CO 80526  
Telephone: 970-226-2734  
Fax:  
tylutki@lamar.colostate.edu

220. Saskia van Woudenberg  
Nilex Corporation  
6810 South Jordan Road  
Englewood, CO 80112  
Telephone: 303-766-2000  
Fax: 303-766-1110  
svw@nilex.com

222. Tim VanWyngarden  
ACZ Laboratories, Inc.  
30400 Downhill Drive  
Steamboat Springs, CO 80487  
Telephone: 970-879-6590  
Fax:

224. Mike Voxakis  
CO Dept. of Transportation  
P.O. Box 399  
Dumont, CO 80436  
Telephone: 303-623-4678  
Fax: 303-623-0542

226. Scott Walker  
Utah Wildlife Resources  
Great Basin Research Center  
540 North Main 32-7  
Ephraim, UT 84627  
Telephone: 435-283-4441  
Fax: 435-283-5616  
NRDWR.Swalker@state.ut.us

227. Jim Walther  
Applewood Seed Company  
5310 Vivian Street  
Arvada, CO 80002  
Telephone: 303-431-7333  
Fax:

229. Gordon Warrington  
WECSA  
8125 Turman Court  
Fort Collins, CO 80525  
Telephone: 970-663-2979  
Fax:

231. Jonathan L. White  
Colorado Geological Society  
1313 Sherman Street  
Room 715  
Denver, CO 80203  
Telephone: 303-894-2167  
Fax: 303-894-2174

233. Rick Williamson  
Pincock, Allen, & Holt  
274 Union Blvd  
Suite 200  
Lakewood, CO 80228  
Telephone: 303-986-6950  
Fax: 303-987-8907  
rlw@hortcrowser.com

235. Ina Zisman  
CO Dept. of Transportation  
P.O. Box 399  
Dumont, CO 80439  
Telephone: 303-569-3291  
Fax: 303-623-0542

228. Scott Wanstedt  
Blue Mountain Energy, Inc.  
3607 County Road 65  
Rangely, CO 81648  
Telephone: 970-675-4322  
Fax: 970-675-5229

230. Mindy Wheeler  
Keammerer Ecological  
4901 Deer Trail Court  
Fort Collins, CO 80526  
Telephone: 970-223-3110  
Fax:  
mwheeler@cnr.colostate.edu

232. Tara Williams  
Glacier National Park  
PO Box 382  
West Glacier, MT 59936  
Telephone: 406-888-7919  
Fax: 406-888-7990  
tara\_williams@nps.gov

234. Robert T. Zakely  
City of Fort Collins  
P.O. Box 580  
Fort Collins, CO 80522  
Telephone: 970-224-6063  
Fax:  
bzakely@ci.fort-collins.co.us

236. Ronald Zuck  
730 Kearney Street  
Denver, CO 80220  
Telephone: 303-320-1691  
Fax:  
ronaldzuck@aol.com

## SUMMARY OF SUMMER TOURS 1974-1998

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 <sub>2</sub> 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

## HIGH ALTITUDE REVEGETATION COMMITTEE MEMBERSHIP LIST

- BILL AGNEW**  
Reveg Env. Consulting  
719 Rocky Mountain Way  
Ft. Collins, CO 80526  
(970) 226-5729
- PHIL BARNES**  
54 Pearson Drive  
Spearfish, SD 57783  
(605) 642-8011
- LARRY F. BROWN**  
L. F. Brown & Associates  
P. O. Box 698  
Idaho Springs, CO 80452  
(303) 567-4447
- RAY W. BROWN**  
USDA Forest Service  
Forestry Sciences Laboratory  
860 North 1200 East  
Logan, UT 84321  
(801) 755-3560
- DAVID L. BUCKNER**  
ESCO Associates  
P. O. Box 18775  
1077 South Cherryvale Road  
Boulder, CO 80308  
(303) 447-2999
- VIC CLAASSEN**  
Soils and Biogeochemistry  
Land, Air, Water Res. Dept.  
University of California  
Davis, CA 95616-8627  
(916) 752-6514
- THOMAS A. COLBERT**  
R&R International, Inc.  
3333 Quebec St., #7800  
Denver, CO 80207  
(303) 322-1511
- JOHN JEFF CONNER**  
Rocky Mountain National Park  
Estes Park, CO 80517  
(970) 586-1392
- ROBIN L. CUANY**  
7351 Manderly Way  
Knoxville, TN 37909
- NANCY DUNKLE**  
National Park SVC-DSC  
Central Team  
12795 W. Alameda Parkway  
Denver, CO 80225-0287  
(303) 969-2568
- MICHAEL D. ELLIS**  
Ellis Environmental  
Engineering  
4342 Ulysses Way  
Golden, CO 80423  
(303) 279-8532
- JULIE ETRA**  
Western Botanical Services  
5859 Mt. Rose Highway  
Reno, NV 89511  
(702) 849-3223
- CAMILLE FARRELL**  
Colorado Department of  
Health and Environment  
P. O. Box 2927  
Telluride, CO 81435  
(970) 728-5487
- WENDELL G. HASSELL**  
7866 Marshall Street  
Arvada, CO 80003  
(303) 422-2440
- DON HJAR**  
Southwest Seed Co.  
P. O. Box 1604  
Greeley, CO 80632  
(970) 356-7002
- BRUCE HUMPHRIES**  
Colorado Division of Minerals  
and Geology  
1313 Sherman St., Room 215  
Denver, CO 80203  
(303) 866-3567
- CHARLES L. JACKSON**  
P. O. Box 207  
Idaho Springs, CO 80452  
(303) 567-2708
- DEBORAH KEAMMERER**  
The Restoration Group  
5858 Woodbourne Hollow Rd.  
Boulder, CO 80301  
(303) 530-1783
- WARREN KEAMMERER**  
Keammerer Ecological  
Consultants, Inc.  
5858 Woodbourne Hollow Rd.  
Boulder, CO 80301  
(303) 530-1783
- JOHN A. LAWSON**  
Meridian Gold  
9670 Gateway Drive  
Reno, NV 89511  
(702) 850-3739
- CARL MACKEY**  
MK-Environmental Services  
Rocky Mtn. Arsenal NWR  
P. O. Box 1717  
Commerce City, CO 80037  
(303) 673-9231
- PETER G. MOLLER**  
Colorado Mountain College  
Timberline Campus  
Leadville, CO 80461  
(719) 486-4222
- BEN NORTHCUTT**  
International Erosion Control  
Association  
P. O. Box 4904  
Steamboat Springs, CO 80477  
(970) 879-3010
- LARRY OEHLER**  
Colorado Division of Minerals  
and Geology  
1313 Sherman St., Room 215  
Denver, CO 80203  
(303) 866-3567
- JEFFREY L. PECKA**  
Systems Planning Group  
5973 E. Irwin Place  
Englewood, CO 80112  
(303) 770-0747
- MARK PHILLIPS**  
Phillips Seeding and  
Reclamation  
11843 Billings  
LaFayette, CO 80026  
(303) 665-2618
- ED REDENTE**  
Rangeland Ecosystem Science  
Department  
Colorado State University  
Ft. Collins, CO 80523  
(970) 491-6542
- BRYCE ROMIG**  
Cyprus Climax Metals Co.  
Climax Mine  
Climax, CO 80429  
(719) 486-2150 x 723
- MARK A. SCHUSTER**  
Grubb & Ellis  
910 Cove Way  
Denver, CO 80209  
(303) 572-7700
- STEPHEN SPAULDING**  
Ute Pass Christmas Trees, Inc.  
P. O. Box 96  
Green Mountain Falls, CO  
80819  
(719) 684-2333
- MARC S. THEISEN**  
Synthetic Industries  
4019 Industry Drive  
Chattanooga, TN 37416
- GARY L. THOR**  
Department of Soil and Crop  
Science  
Colorado State University  
Ft. Collins, CO 80523  
(970) 491-7296
- JEFFREY TODD**  
Schafer & Associates  
801 14<sup>th</sup> Street  
Golden, CO 80401  
(303) 216-1600
- KRISTYNA URBANSKA**  
Swiss Fed. Inst. of Technology  
Zurichbergstrasse 38  
Ch - 8044  
Zurich, Switzerland  
632-4308
- SCOTT WANSTEDT**  
Blue Mountain Energy, Inc.  
3607 County Road 65  
Rangely, CO 81648  
(970) 675-4322
- KEITH ZOEBEL**  
Utah Fuel Co.  
P. O. Box 719  
Helper, UT 84526  
(801) 637-7925
- RON ZUCK**  
730 Kearney Street  
Denver, CO 80220  
(303) 320-1691