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High Altitude Revegetation Workshop No. 12

Edited by
Warren R. Keammerer

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NO. 12

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Edited by

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PREFACE

The 12th Biannual High Altitude Revegetation Conference was held at the University Park Holiday Inn, Fort Collins, Colorado on February 21-23, 1996. 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 215 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 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 members of the HAR Committee.

In 1996, in addition to the papers presented on February 21-22, a field trip to the Denver Botanic Garden was conducted on February 23,1996.

The most important contributors to the conference were the speakers. These Proceedings are their product, and we express our gratitude to them. The Proceedings include the Keynote Address, 19 papers grouped into six conference sessions, remarks presented by four participants in a panel discussion and ten poster papers.

Warren R. Keammerer
Editor

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ECOLOGICAL PRINCIPLES AND HIGH ALTITUDE REVEGETATION

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Introduction

Since 1958, I have been observing high altitude revegetation processes in two places on Trail Ridge in Rocky Mountain National Park. In 1956, the National Park Service launched research on the question of "What has happened to the ecosystems of five very popular parks because of visitor activities." Yosemite, Sequoia/King's Canyon, Mt. Rainier, Grand Teton and Rocky Mountain were chosen for observation. Ecologists were retained to observe what was happening in these five national parks. I was selected to work in Rocky Mountain National Park. Emphasis was to be placed on Trail Ridge, especially along the road, which was built in 1932, paralleling a trail that was a route traveled by Native Americans for nearly 12,000 years.

Trail Ridge Studies

The vegetation of Trail Ridge above tree limit is classic alpine tundra, which is dominated by very small, low-growing perennial plants. The growth habit of these plants makes them highly susceptible to damage from trampling--especially by the large surface areas of human feet shod with heavy leather or rubber.

Adjacent to the three major parking areas that had been used during the 26 years since the Road's construction, varying degrees of impacts from visitor's shod feet on the vegetation were discernible. Everything from mashing down of leaves and flowers to extermination of plants accompanied by compaction and erosion of soils--some into the gravelly B horizon--were observed.

At the fourth site--Forest Canyon Overlook--a new parking area had been constructed the fall previous to initiation of my studies--making a perfect opportunity to observe processes and rates of human impact on alpine plants. By the middle of June--two weeks after the Road opened--clear paths led in two directions from the parking area. Once this was brought to the attention of Park Service personnel, a single route was designated with a thin, wide trail of gravel. That first summer, cushion plants were abraded in the center and retained 0.5 to 1.0 cm of leaves around their perimeters.

At the beginning of the second season, a 10-foot square exclosure was placed around an area of damage, in order to observe its response over time. Observations of natural revegetation within this exclosure were made for 20 summers. The last summer, gophers invaded the area, leaving their characteristic mounds throughout the area, burying and killing plants, thus terminating observations. However, during those 19 summers, a seven-inch moss campion *(Silene acaulis)* cushion that had been abraded, leaving a rim of live leaves up to 1.0 cm wide around its perimeter, had been able to grow back towards its center until only a patch nearly 1.0 cm across remained to re-grow. Had the gophers not invaded, I am quite certain the moss campion would have made a full recovery from one season's trampling within 20-21 seasons of re-growth.

At Rock Cut, one of the original parking areas, the story is not as rapid or simple. People had been clambering all over this long, rocky slope above the parking area for 26 seasons. My detailed observations of this slope indicated two things: 1) the vegetation on this sizable area of soil among the large rocks was turf dominated by a fine-leaved sedge, *Kobresia myosuroides*, a turf type considered the most highly developed of alpine tundra communities in the Front Range; and 2) visitors walking on this slope for 26 seasons had produced many degrees of alteration to this ecosystem, from a few effects to denudation and erosion of top soil. Detailed studies I have made there for 38 summers force me to project that it may be centuries, if not longer, before these eroded sites recover to what they were in 1932 when the road opened. Several species not there at the outset have become established, including some species of lichens and mosses. Some surviving plants have expanded, but the area is far from healed.

I take time to give you this information primarily to share with you a baseline of natural revegetation above 11,700 feet with only fencing against added trampling by man, i.e., nature doing revegetation on her own. This might be a helpful baseline for impatient clients to know. It can also strengthen resolve by employees of public agencies to locate or relocate trails, campgrounds, etc. to places where native species are either more resilient or rapid in regrowth.

Ecological Principles

As I contemplated the current environmental attitudes in our Nation in preparation for this talk, one thing was very clear: Policy-makers both in business/industry and much of government are relaxing their former attitudes and efforts to make sure their actions affect "our environment" (Earth's environment) as little as possible. For some, this may <u>seem</u> to be a positive sign, because it means (among other things) that less time, effort and money have to be spent by their department or corporation.

This may seem true from the law enforcement/permitting side of things. But information emanating from the United Nations Environment Programme Rio de Janiero Conference a few years ago points in a very different direction. Yes, effects of man's activities on Earth's living things and the ecosystems in which they live have decreased somewhat. But, still major problems exist, some of which have only recently been identified, let alone solved.

Knowing too that members of this organization generally have bent over backward to help ecosystems survive at the highest level of existence possible -- in spite of their facing total destruction, then reconstructing, I asked myself, "what can I share that will help us all?" The answer was emphatic: Review the <u>Principles</u> of Ecology with them. Why my choice? Because, even today, more than 20 years after the first Earth Day, very few people 1) know the difference between environment and ecology; 2) know that there are natural principles that are the fundamentals of the science of ecology and form a sound basis for decisions about protecting our habitats and other living things on the Planet; 3) realize that "environment" per se is a component of all ecosystems; and 4) realize that the term environment has been expanded greatly in its implications since Earth Day 1970.

Another reason for sharing the Principles of Ecology with you is that they provide a hard core basis for thinking and decision-making about the broad array of matters that now are lumped as "environmental." My experience indicates to me that when people focus on the fact that there are natural laws comparable to gravity that govern the functioning of Earth's ecosystems--not a group of human opinions--people awaken to the need to look more carefully at how Earth's ecosystems do function. Then, knowing this, they can determine how humans can tailor their actions to function in harmony with Earth's ecosystems.

A parallel benefit from your standpoint is that the public's perception of what you are proposing to do in any given situation will grow in respect and desire to conform with your suggestions, as they see and understand that your proposals and statements are based on the findings of a science that has been studied and practiced for more than 130 years. A science, not just an agglomeration of various people's opinions, science, like math and chemistry, that has principles that govern it. So what are these Principles of Ecology?

First and foremost principle: "everything affects everything else, directly or indirectly." At first glance, this seems to be too absolute--that there must be exceptions. But during the many years of ecological observations and investigation, to date no findings have yet been made that contradict this principle. Furthermore, expanding ecological investigations confirm this principle.

Second principle: all areas of Earth contain one or more recognizable, discrete segments, most of which are visible to the eye. The recognizable segments are called Ecosystems.

Third principle: ecosystems are composed of three major groups of components: 1) environment factors--water, land, air, energy, etc., which are not living; 2) organisms - bacteria, trees, lions, etc., which are living; and 3) interactions--operating among components of these first two groups.

Fourth principle: there are one or more factors that limit the functioning of any given ecosystem. In the American West, water quality, quantity and distribution are major limiting factors. Quantity and availability of oxygen are other major limiting factors, especially for animals. Carbon dioxide is a key limiting factor for green plants.

Fifth principle: all ecosystems have a limited capacity to carry on their functions. Once the Carrying Capacity for any given factor, such as oxygen, or for any given function, such as photosynthesis, is exceeded, the ecosystem cannot continue as an entity. Some facet of it will be harmed or destroyed. One of the most obvious examples of Carrying Capacity is consumption of available water by plants and animals living in an ecosystem. A point comes where all organisms are short-changed in the water they need to function. If the shortage lasts and increases, the living organisms are threatened with migration or death.

Sixth principle: is POPULATION DYNAMICS, which addresses questions like: On what do various species in a given ecosystem feed? How much food do they need? How do the food species reproduce? What do they feed on? Population ecologists are equipped to make studies of the populations living in a given kind of ecosystem and to estimate whether or not those populations are in, or close to, a balance. If they are not, they can predict what changes are needed to approach a balanced, on-going steady state.

These comments are just the "tip of the iceberg" of a dynamic, fascinating and essential science that I am glad to share, primarily because there still seem to be so few people who know about the science of ecology and what it has to offer.

Russian Knapweed Biology & Management
Through Integrated Methods

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Russian knapweed (*Acroptilon repens*) is a creeping, herbaceous perennial member of the sunflower family. It is characterized by vertical and horizontal roots that have a brown to black scaly appearance around the crown that may extend down onto the horizontal components of the root system. Roots may grow 20 feet deep, but more commonly grow at least 10 feet deep. The deep root system allows Russian knapweed to grow in xeric environments because it can extract available soil moisture from deeper depths than most rangeland grasses. The deep root system also allows Russian knapweed to recover from control endeavors because new shoots may develop at any point along the root system.

Research at Colorado State University characterized the root bud development over time. Russian knapweed was sampled at weekly intervals throughout the year from two Front Range locations. Twenty samples were collected each week and segmented into 10 cm sections. Buds were counted along each section and their lengths measured. In late August to early September, root buds begin to develop and reach a maximum number within 2 to 3 weeks. Bud numbers fluctuate with soil temperature; for example, when soil temperatures fall below 0 C, buds are lost, but replaced immediately with new buds. This was determined by measuring bud lengths at each collection. When bud numbers decreased because of frozen soil, bud numbers decreased but rapidly increased to the average level and they were shorter than measurements taken the previous week. Buds began to elongate in mid-March and shoots emerge in early April at which time bud numbers began to decrease to zero by May. No buds were found along the roots or crowns from May until late August.

Typically, shoots emerge in April and grow as a rosette for approximately 1 month then shoot elongation begins. The first flower buds usually develop in late May to early July and the plant flowers throughout the summer. Seeds that develop in flower heads are not dispersed from the plant by wind but may be dispersed by small rodents that eat the seeds. Where rodents or other animals do not disperse the seeds, Russian knapweed seedheads from the previous 1 to 3 years can be found on the soil surface. Russian knapweed seedlings (those derived from seeds) have not been found in any of the field plots conducted by Colorado State University. It is probable that seeds simply serve to begin new Russian knapweed infestations some distance from the parent infestation and the encroachment of an existing infestation is primarily or exclusively from vegetative propagation from the root system.

The variation in Russian knapweed growth and seed production was evaluated at eight Colorado locations. Site conditions were rangeland or roadsides; elevation varied from 4900 to 7600 feet; and precipitation among sites varied from 7 to 18 inches annually. Russian knapweed average shoot height varied from 45 to 70 cm, average shoot weight from 3.6 to 12.6 g/shoot, average canopy diameter from 12.6 to 29 cm, and average shoot density from 3 to 12 shoots/ft^2. Average number of seedheads/shoot varied from 8 to 36, average total seed/shoot from 9 to 340 and average total viable seed from 6 to 137/shoot. This study is ongoing and is matched with a nursery study where each of the eight accessions were transplanted and the same data are being collected, however, 1995 was the first year of the nursery study and data are not yet available. The nursery study will help to determine if the variation observed in the field is due to genotype, environmental conditions, or a combination of both. It is apparent that Russian knapweed growth potential varies with location in the state and from a management standpoint, more vigorously growing Russian knapweed may be more difficult to control and/or better equipped to recover from management stresses.

The allelopathic potential of Russian knapweed makes it more difficult to manage than some other noxious weeds. It tends to form monocultures in some locations and may be present in a mixed stand in other locations. The mechanism of this is poorly understood but may be related to allelopathy. A simple experiment was conducted at Colorado State University where a single accession of Russian knapweed was grown in root boxes filled with three different soils; a clay soil, an organic soil, and a sandy soil. Visual observations indicate a difference in root growth among the three soils where Russian knapweed roots branched to form secondary and tertiary roots at much shallower depths in the clay soil compared to the others. Research conducted by USDA-ARS at Albany, CA found that Russian knapweed exudes polyacetylenes from its roots and these are known to inhibit the root growth of certain bioassay species by 50% at a concentration of 12 ppm. The concentration of polyacetylenes under field conditions was found to vary from 4 to 5 ppm over the growing season and at this concentration, it was calculated that root growth of sensitive plant species would be inhibited by 30%. We hypothesize that the more branched root system observed when Russian knapweed was grown in a clay soil may allow a greater soil volume influenced by polyacetylenes and this may explain our observations that monocultures tend to be found in locations where clay content is higher than where mixed stands occur. However, this still is speculative and research is in progress to test this hypothesis. Regardless, from a management perspective we know through preliminary research conducted by the University of Wyoming that to successfully establish perennial grasses during revegetation of a Russian knapweed infested site, the soil must be tilled to destroy the allelopathic influence. Exactly what is occurring biochemically is unknown.

A cooperative project between Colorado State University and the University of Wyoming was initiated in 1993 to test the combined effects of various suppression treatments combined with reseeding of perennial grasses on Russian knapweed control and site revegetation. The experiment was conducted at two rangeland sites; Mead, CO and Boysen Reservoir, WY. Our hypothesis was that the combination of suppression treatments and seeding with perennial grasses would control Russian knapweed more thoroughly and more successfully revegetate the site than suppression treatments or reseeding alone.

MATERIALS AND METHODS

Suppression treatments included Curtail (3 qt/A), Escort (1 oz/A), sequential treatments of Roundup (1 qt + 1 qt/A), and two mowings. Curtail, Escort, and the first Roundup treatment were applied in spring when Russian knapweed was in the bud growth stage. The first mowing treatment was done at the bud growth stage and repeated 8 weeks later at which time the second Roundup treatment was applied; Russian knapweed was in a vegetative growth stage at the second mowing and Roundup treatments. A no suppression treatment control was included. Both sites were rototilled in September, 1993 and the Boysen Reservoir site was planted in October and the Mead site in November, 1993. Perennial grasses at both sites included 'Hyvar' crested wheatgrass, 'Bozoisky' Russian wildrye, streambank wheatgrass, thickspike wheatgrass, and a non-seeded control.

Percent cover data were taken in each plot in May and June in 1993 at Mead and Boysen Reservoir, respectively, to establish baseline plant populations and again at the same time in 1994 and 1995 to determine the effects of treatments. Plant biomass was harvested from each plot in August, 1994 and 1995 at which time percent control was estimated visually in each plot.

RESULTS

Mead, Colorado:

In 1995, Russian knapweed cover was lowest from the Curtail suppression treatments and 33% less than from other suppression treatments and 30% less than the control (Table 1). Similarly, the least Russian knapweed biomass was harvested from the Curtail treatments (51, 62, 55, and 43% less than in the control, Escort, Roundup, and mowing treatments, respectively). An average of 61% of Russian knapweed was controlled by Curtail while all other suppression treatments controlled less than 10% of Russian knapweed. Russian wildrye and crested wheatgrass established better than the other grass species at Mead. Approximately 2.4 and 5 times more crested wheatgrass was harvested compared to streambank wheatgrass and thickspike wheatgrass, respectively, and 3.6 and 1.8 times more Russian wildrye than streambank or thickspike wheatgrasses (Table 2). However, only Russian wildrye produced greater cover than other seeded grasses at Mead. A significant replication effect was observed at Mead for Russian knapweed cover, biomass, and control, and seeded grass cover and biomass. For example, there was approximately 10 to 11 times more seeded grass biomass harvested in reps 1 and 2 compared to 3 and 4 (Table 3). Seeded grasses emerged early in reps 3 and 4 in 1994 (approximately early February) and a hard freeze killed emerged grasses in these reps. Seeded grasses had not emerged in reps 1 and 2 before the freeze occurred. Consequently, seeded grasses established better and Russian knapweed was controlled better in reps 1 and 2 than in reps 3 and 4. Russian knapweed cover was 61 and 55% in reps 3 and 4, but 31 and 24% in reps 1 and 2 (data not shown). No treatment by seeded grass interaction was observed at Mead.

Table 1. Russian knapweed cover, biomass, and control in 1995 as influenced by suppression treatment at Colorado[a].

Treatment	Rate (oz/A)	Cover %	Weight g	Control %
Control	0	47 ab	119 b	8 bc
Curtail	96	17 c	58 c	61 a
Roundup	32 + 32	48 ab	128 ab	7 bc
Escort	1	51 a	152 a	10 bc
2 mowings	0	52 a	123 ab	7 c

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Means followed by the same letter are not different, LSD (0.05).

Table 2. Cover and biomass of seeded grasses in 1995 as influenced by seeded grass species at Colorado[a].

Grass species	Cover %	Weight g
Crested wheatgrass	15 bc	24 a
Streambank wheatgrass	15 b	10 b
Thickspike wheatgrass	10 c	5 b
Russian wildrye	20 a	18 a
No grass	1 c	0.2 d

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Means followed by the same letter are not different, LSD (0.05).

Table 3. Cover and biomass of seeded grasses in 1995 as influenced by rep at Colorado[a].

Replication	Cover %	Weight g
1	27 a	22 a
2	13 b	20 a
3	4 c	2 b
4	5 c	2 b

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Means followed by the same letter are not different, LSD (0.05).

Boysen Reservoir, Wyoming:

In 1995, Russian knapweed cover was influenced by suppression treatment where percent Russian knapweed cover was similar among the Roundup, mowing, and control treatments and averaged 52% (Table 4). Russian knapweed cover was 32 and 48% less from the Escort and Curtail suppression treatments, respectively. In general, more Russian knapweed was harvested from the Roundup and mowing suppression treatments than all other treatments and the control (2.6 times more Russian knapweed than from the Escort treatment and 5.2 times more than from the Curtail treatment; Table 4). The least Russian knapweed was harvested from the Curtail treatment. Russian knapweed was controlled best by Curtail (89%) and Escort controlled more Russian knapweed (59%) than Roundup (25%) and Roundup more than the control (6%) and the mowing treatment (4%), which were similar. Cover and biomass of seeded grasses varied with suppression treatment where the average cover of all seeded grasses within the Curtail, Escort, and Roundup treatment were similar and approximately 13% greater than in the mowing or control treatments (Table 5). Average seeded grass biomass in the Curtail, Escort, and Roundup treatments were approximately 20 and 11 times greater than in the mowing and control treatments, respectively. Seeded grass biomass also varied with seeded grass species where harvested crested wheatgrass biomass was 5 times greater than harvested streambank wheatgrass and thickspike wheatgrass and 40 times greater than Russian wildrye (Table 6). Bareground cover also varied with suppression treatment (Table 5) and seeded grass species (Table 6). Greatest bareground was observed with the Escort treatment which was 22% greater than the Curtail treatment, 25% greater than Roundup, and 27% greater than the mowing or control treatments. The least bareground occurred where crested wheatgrass was sown and bareground within the crested wheatgrass plots was 6, 8, and 9% less than in the streambank wheatgrass, thickspike wheatgrass, and Russian wildrye plots, respectively.

Most importantly in 1995, a suppression treatment by seeded grass interaction was observed for Russian knapweed biomass and percent control, and seeded grass cover and biomass and these are the most appropriate effects to discuss; although, the previous discussion about treatment or seeded grass effects is an aid to better understand the interactions. There were no differences for Russian knapweed biomass among seeded grass species within any suppression treatment or the control (Table 7). Approximately 10 times more Russian knapweed was harvested within the Roundup plus Russian wildrye combination compared to the Curtail plus Russian wildrye management system. About 94% less Russian knapweed was harvested from the Curtail plus streambank wheatgrass management system compared to other streambank wheatgrass plus suppression treatment combinations. More Russian knapweed was controlled when Curtail was combined with any seeded grass species compared to any other suppression treatment combined with any grass species except that Russian knapweed control from Curtail combined with thickspike wheatgrass was similar to Escort plus thickspike wheatgrass (Table 8). For example, when Curtail was combined with Russian wildrye seeding, 34-84% more Russian knapweed was controlled compared to other suppression treatments combined with Russian wildrye; Curtail plus crested wheatgrass controlled 32-92% more Russian knapweed than other suppression treatments plus crested wheatgrass; 42-92% better

Table 4. Russian knapweed cover, biomass, and control in 1995 as influenced by suppression treatment at Wyoming.

Treatment	Rate (oz/A)	Cover %	Weight g	Control %
Control	0	52 a	61 b	6 e
Curtail	96	4 c	20 d	89 a
Roundup	32 + 32	50 a	110 a	25 c
Escort	1	18 b	39 c	59 b
2 mowings	0	53 a	95 a	4 e

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Means followed by the same letter are not different, LSD (0.05).

Table 5. Seeded grass cover and biomass and bareground cover in 1995 as influenced by suppression treatment at Wyoming.

Treatment	Rate (oz/A)	Grass Cover %	Grass Weight g	Bareground %
Control	0	4 b	1.3 b	6 c
Curtail	96	18 a	13.0 a	11 b
Roundup	32 + 32	15 a	14.0 a	8 bc
Escort	1	16 a	15.0 a	33 a
2 mowings	0	2 b	0.7 b	6 c

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Means followed by the same letter are not different, LSD (0.05).

Table 6. Cover and biomass of seeded grasses and bareground cover in 1995 as influenced by seeded grass species at Wyoming.

Grass species	Grass cover %	Grass weight g	Bareground %
Crested wheatgrass	32 a	25.0 a	6 c
Streambank wheatgrass	8 b	6.0 b	12 b
Thickspike wheatgrass	7 b	5.0 b	14 ab
Russian wildrye	2 c	0.6 c	15 a
No grass	0 d	0.3 c	14 ab

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Means followed by the same letter are not different, LSD (0.05).

Table 7. Russian knapweed biomass in 1995 as influenced by suppression treatment combined with seeded grass species at Wyoming[a].

Treatment	Rate (oz/A)	CWG	STWG	THWG	RWR	No grass
			Seeded	Grass	Species	
		------------	Russian	knapweed	weight g	------------
Control	0	56 A a	62 A a	54 A a	68 A ab	58 A a
Curtail	96	8 A a	4 A b	18 A a	15 A b	54 A a
Roundup	32 + 32	85 A a	109 A a	35 A a	147 A a	175 A a
Escort	1	50 A a	26 A a	36 A a	50 A ab	35 A a
2 mowings	0	107 A a	100 A a	77 A a	106 A ab	85 A a

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Use lower case letters to compare means within a column and upper case letters to compare means within a row. Means followed by the same letter within a column or within a row are not different, LSD (0.05).

Table 8. Percent control of Russian knapweed in 1995 as influenced by suppression treatment combined with seeded grass species at Wyoming[a].

Treatment	Rate (oz/A)	CWG	Seeded STWG	Grass THWG	Species RWR	No grass
		-----------	Russian	knapweed	control %	-----------
Control	0	4 A c	8 A c	9 A c	8 A c	1 A b
Curtail	96	95 A a	96 A a	88 AB a	89 AB a	79 B a
Roundup	32 + 32	26 B c	18 B c	42 A b	21 B c	18 B b
Escort	1	63 A b	54 A b	68 A ab	55 A b	58 A a
2 mowings	0	3 A c	4 A c	6 A c	5 A c	3 A b

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Use lower case letters to compare means within a column and upper case letters to compare means within a row. Means followed by the same letter within a column or within a row are not different, LSD (0.05)

Table 9. Biomass of seeded grasses in 1995 as influenced by suppression treatment combined with seeded grass species in Wyoming[a].

Treatment	Rate (oz/A)	CWG	Seeded STWG	Grass THWG	Species RWR	No grass
		------------	Seeded	grass	weight g	------------
Control	0	4.4 A d	1.3 AB c	0.8 AB c	0 B b	0 B a
Curtail	96	33.5 A c	24.1 AB a	7.9 B ab	0.3 C b	0.9 C a
Roundup	32 + 32	45.3 A b	7 BC b	15.9 B a	2 CD a	0 D a
Escort	1	63.4 A a	3.9 B b	3.6 B b	0.6 C ab	0.8 C a
2 mowings	0	1.8 A d	0.4 A c	0.6 A c	0.6 A ab	0 A c

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Use lower case letters to compare means within a column and upper case letters to compare means within a row. Means followed by the same letter within a column or within a row are not different, LSD (0.05).

control when combined with streambank wheatgrass; and 46-83% better control when Curtail was combined with thickspike wheatgrass compared to other suppression treatments combined with this grass species. More crested wheatgrass biomass was harvested than any other seeded grass species within any herbicide treatment except that harvested seeded grass biomass from Curtail plus crested wheatgrass and Curtail plus streambank wheatgrass were similar (Table 9). There was about 4 times more seeded grass harvested from the Curtail plus crested wheatgrass compared to Curtail plus thickspike wheatgrass and 112 times more than in the Curtail plus Russian wildrye combination. Approximately 7 times more seeded grass was harvested from the Roundup plus crested wheatgrass combination than Roundup plus streambank wheatgrass, 3 times more than Roundup plus thickspike wheatgrass, and 23 times more than Roundup plus Russian wildrye. Sixteen times more seeded grass was harvested from the Escort plus crested wheatgrass combination than Escort plus streambank wheatgrass, 18 time more than Escort plus thickspike wheatgrass, and 105 times more than the Escort plus Russian wildrye combination. Additionally, 2-35 times more crested wheatgrass was harvested from the Escort plus crested wheatgrass combination than any other suppression treatment combined with crested wheatgrass seeding. All grasses established poorly within the mowing suppression treatment and the no suppression treatment control, although, crested wheatgrass within the control treatment established better than Russian wildrye (as evidenced by harvested biomass of seeded grasses). The effect of the treatment by seeded grass interaction on seeded grass cover was similar to seeded grass biomass (Table 10). Any suppression treatment combined with crested wheatgrass seeding produced greater seeded grass cover than any suppression treatment combined with any other seeded grass species. Also, any herbicide treatment combined with crested wheatgrass seeding produced greater crested wheatgrass cover than mowing plus crested wheatgrass which produced greater crested wheatgrass cover than the non-treated control plus crested wheatgrass seeding. For example, any herbicide plus crested wheatgrass produced on the average 45% (8 times) more crested wheatgrass cover than the mowing plus crested wheatgrass and 37% (3.5 times) more than the non-treated control plus crested wheatgrass. Upon comparing seeded grass cover within any suppression treatment or the control, it is apparent that crested wheatgrass established the best. When crested wheatgrass seeding was preceded by the Curtail application, crested wheatgrass cover was 37, 40, and 50% greater than when this herbicide was combined with thickspike wheatgrass, streambank wheatgrass, or Russian wildrye, respectively. Roundup plus crested wheatgrass produced 28% greater seeded grass cover than Roundup plus streambank wheatgrass, 35% more than Roundup plus thickspike wheatgrass, and 43% more cover than Roundup plus Russian wildrye. Crested wheatgrass cover from the Escort plus crested wheatgrass combination was 46% greater than Escort plus streambank wheatgrass, 47% greater than Escort plus thickspike wheatgrass, and 52% greater than Escort plus Russian wildrye. Crested wheatgrass also established best within the mowing plus crested wheatgrass or the non-treated control plus crested wheatgrass combinations where mowing plus crested wheatgrass produced 6, 5, and 7% greater seeded grass cover than mowing plus streambank wheatgrass, thickspike wheatgrass, or Russian wildrye, respectively; or where the control plus crested wheatgrass produced 13% more seeded

Table 10. Percent cover of seeded grasses in 1995 as influenced by suppression treatment combined with seeded grass species in Wyoming[a].

Treatment	Rate (oz/A)	CWG	Seeded STWG	Grass THWG	Species RWR	No grass
		------------	Seeded	grass	cover %	------------
Control	0	14.8 A b	1.6 B b	1.4 B c	0.8 BC bcd	0 C a
Curtail	96	54.5 A a	14.6 C a	17.6 B a	4.5 D ab	0 E a
Roundup	32 + 32	45.8 A a	18.3 B a	10.6 B b	2.6 C abc	0 D a
Escort	1	56.6 A a	11.0 B a	9.5 BC b	4.9 C a	0 D a
2 mowings	0	6.6 A b	0.4 B c	1.3 B c	0 B d	0 B a

[a]Data were analyzed as arc sine square root transformations but are presented as their original values. Use lower case letters to compare means within a column and upper case letters to compare means within a row. Means followed by the same letter within a column or within a row are not different, LSD (0.05).

grass cover than the control plus streambank wheatgrass or thickspike wheatgrass and 14% more cover than the control plus Russian wildrye.

Results from the Colorado and Wyoming sites indicate that Russian knapweed was controlled best by Curtail. However, the treatment by seeded grass interactions that were detected at the Wyoming site were most revealing. Few differences were apparent within the treatment by seeded grass interaction effect on Russian knapweed biomass; but, upon examining the interaction effect on Russian knapweed control, the Curtail combined with any seeded grass species generally controlled more Russian knapweed than other suppression treatments combined with grass seeding (with one notable exception mentioned above). Relative to grass establishment and recovery of the infested site, crested wheatgrass established the best but successful establishment occurred only when crested wheatgrass seeding was preceded by a herbicide application, as evidenced by the treatment by seeded grass interaction effect on seeded grass biomass and especially seeded grass cover. Our data suggest that to achieve acceptable Russian knapweed control and revegetate the site to desirable grasses, Curtail combined with crested wheatgrass seeding may provide the best opportunity to be successful. However, ultimately the goal of site recovery is to revegetate the area with desirable grasses and produce harvestable forage for domestic livestock and wildlife and the Escort plus crested wheatgrass seeding management system represents the best opportunity for success as evidenced by the interaction effect on seeded grass biomass; but, this management system will have to augmented with additional herbicide treatments after grass establishment to reduce the Russian knapweed population to acceptable levels. Regardless of the choice of suppression treatment, our data strongly indicate that Russian knapweed is controlled better when suppression treatments are combined with perennial grass seeding compared to suppression treatments alone and site recovery is much more effective with the management systems compared to suppression treatments alone.

ENHANCEMENT OF SHRUB GROWTH ON AN OIL SHALE TRACT IN THE PICEANCE BASIN OF COLORADO

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ABSTRACT

In the early 1980s, impacts associated with oil shale mining and processing were major issues in western Colorado. Federal lease Tract C-a was being developed by US oil companies to test, in part, open pit mining and waste rock disposal techniques. Mitigation of environmental impacts was required on this Tract located in the Piceance Basin - winter range of the largest migrating mule deer herd. Methods were tested to orient and shape waste rock dumps to provide valuable deer habitat. A simulated bench was created in overburden material on a south-east facing slope to "harvest" water from normal precipitation. The intent was to enhance shrub and other vegetative growth on a south-facing slope which would be more available to deer during extended periods of snow cover.

INTRODUCTION

The Federal Prototype Oil Shale Leasing Program was developed with an objective to provide a new source of energy to the Nation by stimulating the development of commercial oil shale technology by private industry. The program was designed with the concept that each lease tract would be developed with significantly different mining and processing technologies. The Rio Blanco Oil Shale Company (RBOSC), a Partnership of Gulf Oil Corporation and Amoco Corporation, was successful in acquiring the Colorado lease Tract C-a. This tract was initially identified as the only prototype tract believed to be amenable to surface mine development.

Development of Tract C-a would have required disposal of processed shale and overburden in a pile, or dump, encompassing approximately 4,000 acres near the Tract. The dump would range in height from 400 to 1,100 feet and would contain approximately 3.6 billion cubic yards of material. Sufficient topsoil and soil-like material would be stripped before dump construction. The stripped material would be placed in stockpiles and revegetated for later use. The dump was to be built in 50-foot lifts with the intermediate slopes being graded to a 3.5 (horizontal) to 1 (vertical) (3.5:1) slope. Benches were to be constructed at intervals of 50 vertical feet, were to be approximately 25 feet in width, and were to be of reverse (in-sloping) grade. The benches were to provide a collection area for potential surface erosion and runoff, and would direct excess runoff to appropriate drop structures, as required.

The processed shale was to be capped with an overburden layer 8 to 10 feet thick and covered with 18 inches of previously stripped and stockpiled topsoil and soil-like material.

In addition to promoting maximum cost effective resource recovery, the Prototype Leasing Program intended to ensure the environmental integrity of the affected area by developing a full range of environmental safeguards and restoration techniques for incorporation into the planning of a mature oil shale industry. Techniques to reclaim disturbed lands and to provide wildlife habitat were among those being developed by RBOSC.

OBJECTIVES AND RATIONALE

Reclamation of areas disturbed by Tract C-a activities were to be accomplished according to a state and Federal approved reclamation plan. Reclamation techniques implemented by RBOSC were expected to result in adequate habitat for livestock and wildlife, as was compatible with the existing land use. Developing cost-effective steps which may reduce the amount of time necessary to establish such habitat was desirable. Shrub growth enhancement through water harvesting was thought to represent one such technique. The objective of this study was to evaluate water harvesting techniques as a means of habitat establishment and enhancement.

Revegetation testing by RBOSC and others was providing information relative to reclamation techniques which would result in production of adequate forage for livestock and wildlife in a relatively short time. One component of wildlife habitat, cover, would take longer to establish.

In the semi-arid environment of the Piceance Basin, increased shrub growth, and hence wildlife cover, may be achieved by augmenting soil moisture via water harvesting techniques. Water harvesting is a technique designed to conserve and more efficiently use normal runoff by concentrating runoff from a large area into a smaller area where it is available to plants. In addition, water can be harvested by accumulating snowfall.

In the Piceance Basin, south-facing slopes support significantly less vegetation than north-facing slopes due to desiccation by the sun and prevailing winds. However, south-facing slopes may be the only areas available to deer during periods of deep snow cover. Consequently, an experiment was conducted to enhance shrub growth by water harvesting on an available south-east slope.

METHODS

The design of the simulated waste rock dump bench is presented in Figures 1 and 2. Water from accumulated snowpack and runoff from snowmelt and rainfall should concentrate along the two rows of shrubs on the 6:1 (horizontal:vertical) bench slope (Rows B and C). Increased moisture also should be available to the shrubs in the water bar below the bench (Rows D and E). The rows of shrubs (Rows A and E) on the 3:1 slope between the bench and the water bars serve as controls where shrub growth without increased moisture was monitored.

In order to establish wildlife cover rapidly, five shrub species were planted in the study area because they are not normally used as food by deer. These five shrub species were New Mexico foresteria (Foresteria neomexicana), Apache plume (Fallugia paradoxa), New Mexico black locust (Robinea neomexicana), oldman wormwood (Artemisia abrotanum), and skunkbrush sumac (Rhus trilobata). In addition, two other shrub species, serviceberry (Amelanchier alnifolia) and four-wing saltbush (Atriplex canescens), are choice deer food and were included to test the effect of deer browsing pressure on shrub growth.

One-half of the study area was fenced to exclude deer and cattle; the other half was fenced to exclude cattle but allow deer entry. All shrub species were planted as tubelings in June of 1982. Shrubs were watered at the time of planting and irrigated as necessary during the first summer to enhance establishment. All areas between shrub rows were planted with a RBOSC seed mixture as might be required in final reclamation.

Two individuals of the shrub species serviceberry, oldman wormwood, Apache plume, and skunkbrush sumac were initially planted at each designated location in Rows B and C to ensure adequate survival for testing purposes. The weaker individual was removed at the beginning of the 1984 growing season. (It should be noted that these species were of greenhouse stock, eight months old; individuals of the four-wing saltbush were of uneven age, from eight to eighteen months; and, the New Mexico black locust and the New Mexico foresteria were 18 months old at planting.)

The main goal of harvesting water to enhance shrub growth on the simulated bench was to provide vegetation cover for deer within four years of planting. In the Piceance Basin, this cover is necessary for thermal protection and predator avoidance. This cover is normally provided by pinyon-juniper forests, tall sagebrush in valley bottoms, and other areas of tall, dense vegetation. A criterion of four feet (about 120 centimeters) was arbitrarily set as the lower limit of adequate cover for mule deer. A diameter of similar dimension also was considered important for each shrub. Because the seven species of shrubs used in the study have different growth rates and physiognomy, it was necessary to compare shrub growth performance by a

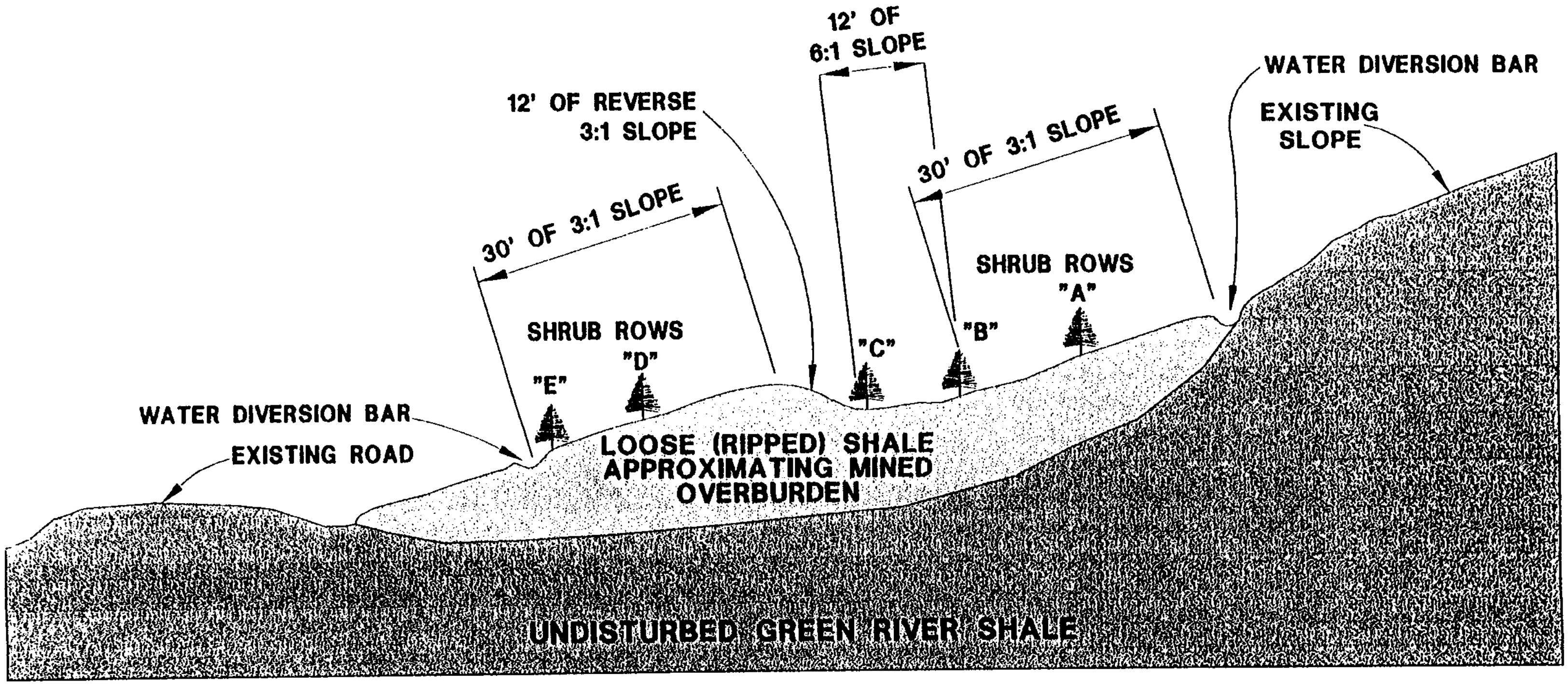

FIGURE 1

CROSS SECTION OF SIMULATED WASTE ROCK DUMP BENCH FOR TESTING OF SHRUB GROWTH THROUGH WATER HARVESTING

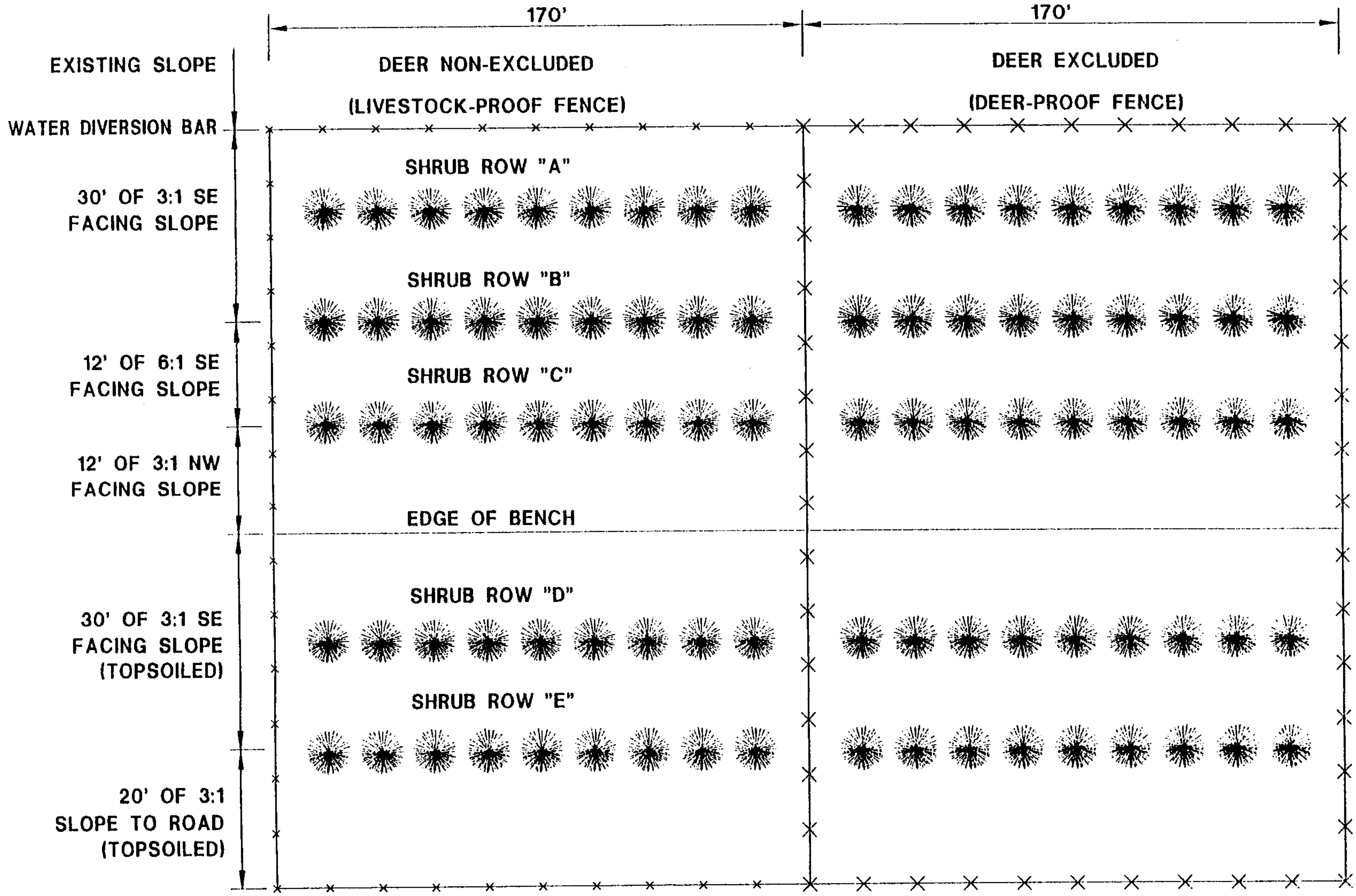

FIGURE 2

PLAN VIEW OF SIMULATED WASTE ROCK DUMP BENCH FOR TESTING OF SHRUB GROWTH THROUGH WATER HARVESTING common index. A plant height - plant diameter (PH-PD) index was developed and derived by the following formula:

$$\text{PH-PD} = \frac{\dfrac{\underline{\text{Shrub Height (cm)}}}{120 \text{ cm}} + \dfrac{\underline{\text{Shrub Diameter (cm)}}}{120 \text{ cm}}}{2}$$

This index provided information on how well shrubs in the various treatments achieved the lower limit of adequate cover (120cm). The shrub size criterion for the experiment would be reached when the PH-PD index equaled one.

Data collection began one year after planting, or in 1983. Shrub measurements (plant height and diameter) of each individual were made on a monthly basis from 1983 through 1985, and then only in September at the end of the growing season in 1986 and 1987.

In order to test the effectiveness of the water harvesting technique, moisture content was measured monthly during the growing season (May through September) at 25, 75, and 150 cm depths within the soil profiles on all portions of the simulated bench. Permanently placed soil access tubes allowed for repeated soil moisture determinations at the same locations using a Troxler Neutron Moisture Gauge.

RESULTS AND DISCUSSION

Although measurements were made monthly throughout the growing season for several years, the emphasis of this report is the end of the 1987 growing season - the last year measurements were taken.

A. Shrub Survival

Percent survival of all shrub species by treatment for the 1982 through 1987 study period are presented in Table 1. Overall averages for 1987 were 75 and 57 percent for deer excluded and deer not-excluded portions of the study site, respectively.

The lowest overall survival for the study period was exhibited by serviceberry, although all mortalities of this species occurred before the 1986 sampling period. The highest overall survival percentage after six growing seasons was exhibited by New Mexico black locust with a 92 percent survival rate and Apache plume with an 86 percent survival rate. These high survival percentages may have occurred, in part, because these species were planted only in Rows B and C, which have the highest survival percentages (among

TABLE 1

PERCENT SURVIVAL OF ALL SHRUB SPECIES BY TREATMENT ON THE SIMULATED WASTE ROCK DUMP BENCH THROUGH SEPTEMBER 1987 (AFTER SIX GROWING SEASONS)

	Deer Excluded						Deer Not Excluded					
	A	B	C	D	E	Avg	A	B	C	D	E	Avg
Serviceberry	33	50	67	17	33	40	0	57	67	0	0	25
Oldman Wormwood	100	80	100	33	0	63	100	100	100	0	0	60
Fourwing Saltbush	nd	57	100	100	50	77	nd	0	17	71	0	22
Apache Plume	nd	100	100	nd	nd	100	nd	60	83	nd	nd	72
New Mexico Foresteria	nd	100	100	50	83	83	nd	83	100	83	17	71
Skunkbrush Sumac	83	100	100	50	17	70	67	83	100	33	0	57
New Mexico Black Locust	nd	100	83	nd	nd	92	nd	83	100	nd	nd	92
Average	72	84	93	50	37	75	56	67	81	37	3	57

nd - Indicates no data because shrubs of a particular species were not planted in that treatment.

Rows) of all species studied.

Row C had the highest overall survival among the treatments. However, this row did not receive the highest overall water availability based on the neutron probe measurements. Therefore, it would seem that moisture was not the only factor contributing to increased shrub survival. Snowpack was deepest along this row, and snow generally covered all shrubs completely during the first winter. This protection from desiccation and/or freezing may have contributed to increased overall shrub survival.

Skunkbrush sumac and New Mexico foresteria both suffered mortality on the portion of the bench where deer were allowed access. These species are generally considered non palatable to deer and consequently, mortality could have been related to other conditions.

Most species show a higher survival rate on the deer excluded portion of the study site; New Mexico black locust exhibited the same survival for both portions. This general pattern of survival was observed regardless of whether the species in question was palatable to deer or not. However, in the case of serviceberry and four-wing saltbush, which are both considered palatable to deer, survival percentages were markedly lower than for non-browse species on the portion of the study where deer were not excluded. Consequently, there seems to be some benefit to planting non-browse shrub species when the objective is to develop wildlife cover.

The lowest shrub survival was found in Row E, the waterbar/topsoil treatment. The majority of plant mortality occurred in this row by 1984, within the first three growing seasons. This early mortality was attributed to topsoil settling and to frost-heaving. Since early in the study period, deposition of shale/soil occurred in the waterbar from the long 3:1 slope above it which effectively buried some of the smaller shrubs.

B. Shrub Growth

Means for the PH-PD index for each species by row and fence treatment as measured in 1987 are presented in Table 2. Greater overall plant growth is represented by larger numbers in this table. The average PH-PD index for the deer excluded and the deer not-excluded portions of the study bench were 0.58 and 0.48, respectively.

All species, except Apache plume, exhibited higher average PH-PD indices on the deer excluded portion than where deer were allowed to browse. Limited browsing (i.e. "testing" for palatability) by deer may have an effect on shrub growth when shrubs are small. Some non-palatable shrubs may not have the ability to grow as rapidly after such test browsing.

During the study period, four-wing saltbush on the deer excluded portion was the only species to have attained the arbitrary minimum PH-PD criterion (1.0) for cover, and this index was reached after four growing seasons. Four-

TABLE 2

MEANS OF THE PLANT HEIGHT - PLANT DIAMETER (PH-PD) INDEX FOR EACH SHRUB SPECIES BY TREATMENT ON THE SIMULATED WASTE ROCK DUMP BENCH TEST IN SEPTEMBER 1987 (AFTER SIX GROWING SEASONS)

	Deer Excluded						Deer Not Excluded					
	A	B	C	D	E	Avg	A	B	C	D	E	Avg
Serviceberry	.21	.32	.36	.05	.23	.23*	0	.17	.22	0	0	.20*
Oldman Wormwood	.36	.45	.51	.23	0	.39*	.28	.21	.42	0	0	.30*
Fourwing Saltbush	nd	1.03	1.28	1.27	1.12	1.18	nd	0	.90	1.32	0	1.11
Apache Plume	nd	.74	.53	nd	nd	.64	nd	.56	.73	nd	nd	.65
New Mexico Foresteria	nd	.53	.65	.32	.34	.46	nd	.57	.46	.23	.15	.35
Skunkbrush Sumac	.50	.37	.42	.25	.66	.44*	.41	.28	.27	.13	0	.27*
New Mexico Black Locust	nd	.71	.78	nd	nd	.75*	nd	.45	0	nd	nd	.45*
Average						.58						.48

* - Significant differences seen between fencing treatments at $\alpha = 0.05$.

nd - Indicates no data because shrubs of a particular species were not planted in that treatment.

wing saltbush on the deer not-excluded portion also reached the 1.0 index goal after six growing seasons, and was the only species to do so in this fence treatment area.

Serviceberry exhibited the lowest PH-PD indices for both fencing treatments, supporting the conclusion that this species is not suited to south-east facing slopes at about 6,800 feet elevation in northwest Colorado.

New Mexico black locust was set back several years due to frost damage, but still attained substantial growth.

C. Soil Moisture

Soil moisture levels were typically highest at all depths within the soil profiles during the May sampling period. Moisture levels at all depths generally decreased through September except during months of abundant rain.

In general, soil moisture content was higher in near-surface (25 cm deep) soils along Rows B, C, and E than along Rows A and D. At the 75 and 150 cm depths, no significant differences were found except for Row D which exhibited less soil moisture.

CONCLUSIONS

1) It appears that shrub growth can be enhanced through water harvesting

2) Deer browsing can effect shrub survival and growth

3) Successful reclamation can be accomplished on Green River Shale overburden material on a south-east facing slope

VEGETATION RECOLONIZATION ON SALT-DAMAGED SOIL IN ARCTIC ALASKA

Jay D. McKendrick[1]

Abstract

Twenty centimeters of topsoil, fertilizer, and seed of *Poa glauca*, *Arctagrostis latifolia*, and *Festuca rubra* were applied to revegetate a barren tundra soil. Seeded grasses developed the first year. The seeding was subsequently destroyed when the site was reconstructed. A second application of seed and fertilizer followed. Saline soil conditions caused the second seeding to fail. The site remained mostly barren for three more growing seasons. Late in the fifth growing season, the U.S. Army Corps of Engineers and BP Exploration (Alaska), Inc. initiated tests to remedy the situation. Treatments to remove salts failed to reduce soil salinity. Indigenous salt-tolerant plant species, primarily *Puccinellia langeana*, *Dupontia fisheri*, and *Arctophila fulva* currently dominate the plant community. Between the fifth and seventh growing seasons, canopy cover increased from 5% to 37%. Even though the chemical failed to reduce soil salinity, mean canopy cover of established vegetation increased to nearly 64% where the chemical was applied. Also palatability of seedlings and mature plants was elevated by the chemical treatment. Moss as well as higher plants appeared to have benefitted from the chemical. Numbers of vascular plant species increased from zero the first year to more than 16 in the seventh growing season. Continued increases in plant canopy cover and numbers of indigenous plant species at the site indicate natural recolonization is a feasible option to revegetate salt-damaged mineral soils in this region. It is suggested that multiple indicators of vegetation trend be used to evaluate revegetation success in the Alaska Arctic, rather than exclusively relying on canopy cover criterion.

Introduction

A flare pit for the Pad X in the Western Operating Area of the Prudhoe Bay Oil Field was closed in 1989. The 0.86 ha rectangular pit had been constructed with 1.5 to 2.0 meter thick gravel berms, placed on the surface of a wet sedge meadow tundra. Following the enlargement of X Pad, the pit became unusable, requiring its removal (May 1989). Water impounded within the pit killed the original tundra plant communities. BP Exploration (Alaska), Inc. was granted a permit from the U.S. Army Corps of Engineers to remove the gravel berm and spread a thin layer of topsoil (ca. 20 cm) over this wetland site, to revegetate the barren area within the flare pit. Excavation of the ice from inside the pit, removal of the gravel berms, and placement of the topsoil was completed during late winter, while the soil remained frozen. Topsoil came from overburden removed at a gravel pit along the Kuparuk River (BP Exploration, 1994).

In May 1989 the area was seeded with a mixture (each of equal weight) of three recommended grass species: *Arctagrostis latifolia* (Alyeska polargrass), *Festuca rubra* (Arctared red fescue), and *Poa glauca* (Tundra glaucous bluegrass) for a total application of 42 kg/ha. This provided 7,400, 3,000, and 6,800 seeds/m^2, respectively, for each of the three species, or a total of 17,200 live seeds/m^2. A commercial fertilizer 20-20-10 was applied at 360 kg/ha. Seed and fertilizer were broadcast and raked into the soil surface (McKendrick and Smith, 1993). During the first growing season (1989), the seeded grasses germinated and established a stand having an estimated 60% canopy cover. Geese and caribou were attracted to the seeding and grazed it heavily, a usual occurrence on grass seedings in this region.

The U.S. Army Corps of Engineers inspected the site in the summer of 1989 (a summer with above-normal temperatures) and concluded that gravel removal from the perimeter berm was insufficient and required correction. In the winter of 1990, the topsoil was scraped from the perimeter to the center of the

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pit area, and more of the underlying gravel was removed. Topsoil was redistributed across the site. In the spring of 1990, the seeding and fertilizing treatments were repeated.

In the summer of 1990 (a summer with average temperatures) the seeding developed less successfully than in the previous year, although some seed germinated and young plants established. Grazing pressures from geese and caribou continued. Seedling establishment faltered during the summer of 1991 (an unusually cool summer). Poor seedling development was initially attributed to weather. During the summer of 1991, all vegetation growth in the Prudhoe Bay area was severely limited. During the summer of 1992, a summer with normal temperatures, the stand deteriorated farther. Testing of soil samples and measurements of surface water electrical conductivity during 1992 indicated that soil and water salinities were elevated in the area of the flare pit (McKendrick and Smith, 1993). The source of this salinity was not confirmed; however, circumstantial evidences strongly indicated that salts affecting this site had probably seeped from the drilling pad gravel.

Late in the summer of 1993, the U.S. Army Corps of Engineers and BP Exploration (Alaska), Inc. decided to conduct tests at the site to remove the sodium from the soil using a commercial product, LCA-II, and to test the effects of that product on grass seedlings and established vegetation at the site (BP Exploration, 1994). The soil and vegetation monitoring results from that project for the years 1994 and 1995 are presented in this paper.

Methods

LCA-II treatments

The standard procedure for removing excess sodium from soils is to apply large quantities of Ca^{++}, usually as calcium sulfate (gypsum), and replace Na^{+} with Ca^{++} on soil colloids through mass action. Na^{+} can be subsequently flushed from the soil with water (U.S. Soil Salinity Laboratory Staff, 1954). For several years, the manufacturer of LCA-II had been soliciting potential users of this product to remedy sodium-damaged soils, in Alaska's oil fields. The chemical is a proprietary formulation of calcium nitrate.

To test effects of the LCA-II chemical's effectiveness in reducing soil salinity and possibly affecting grass seedling establishment, three 9 X 12 m blocks of plots were staked. Test plots were situated in a portion of the flare pit in which vegetation recovery was especially poor and soil remained nearly barren. LCA-II was applied as a mixture with warm water using hand-pressure chemical sprayers, during late August 1993. Each block was divided into four plots, with two plots receiving LCA-II and two remaining as untreated controls. The first snow of the upcoming winter had already fallen on the site; this snow had melted, leaving the soil saturated at the time of application. The LCA-II application was approximately 6,800 l/ha or 0.68 l/m^2, as recommended by the supplier based on preliminary soil salinity and pH data from samples collected during the summer of 1992.

To test effects of the chemical on established vegetation, twelve small plots (2 X 2 m) were located within the flare pit where either volunteer or seeded grasses were growing. These plots were selected on the basis of the grass species which were dominant at each location. Three plots dominated by each of the following grass species were treated with LCA-II according to the recommended application: *Arctophila fulva*, *Dupontia fisheri*, *Poa glauca*, and *Puccinellia langeana*.

Soil monitoring

Soil was sampled (0-15 cm) with a soil corer in all control and LCA-II-treated plots in August, prior to chemical application. Sampling was repeated in August 1994 and 1995. Salinity was measured on saturated paste extracts from soil samples with a standard E.C. (electrical conductivity) meter. Soil analyses were performed by the Colorado State University Soil, Water, and Plant Testing Laboratory, Ft. Collins, CO.

Grass seeding tests

On the barren soil, grass seed was broadcast and raked into the soil surface of plots in the three blocks treated with LCA-II. All seed applications, either mixtures or single species, were designed to provide about 1,100 live seed/m^2, substantially less than the two previous revegetation applications, because we had observed elsewhere in the oil field that grass stands developing from intense seeding levels were often over-populated and comprised of poor specimens. Species included in the test plots were the three previously used on the site, *Arctagrostis latifolia*, *Festuca rubra*, and *Poa glauca*. In addition, *Deschampsia beeringensis*, a commercially available grass originating from the western and southwestern coastal regions of Alaska, and *Puccinellia langeana*, an indigenous grass from the Prudhoe Bay vicinity were seeded. *Puccinellia langeana* seed for these plots was hand-stripped during the last week of August 1992 from a stand near the Putuligayuk River, about 2 km north of the drilling pad. Seed was applied evenly to all plots (LCA-II and control) in each of the three blocks.

One block was seeded only to the three grasses used in the two original flare pit revegetation attempts. One block was seeded to those same three species plus *Puccinellia langeana*. In the third block, plots were subdivided to provide the four following seeding treatments: 1) one pure seeding of *Puccinellia langeana*, 2) one pure seeding of *Deschampsia beeringensis*, 3) one seeding mixture (50/50 to apply equal numbers of live seeds per unit area) of *Deschampsia beeringensis* and *Puccinellia langeana*, and 4) one mixture (to apply equal numbers of seed per unit area) for each of the three species, *Arctagrostis latifolia*, *Festuca rubra*, and *Poa glauca*.

Vegetation monitoring

Vegetation was measured using a walking point (Owensby, 1973) to obtain canopy cover, basal cover, and species composition within treated plots and on the flare pit area outside the test plots. For the portion of the flare pit outside test plots, five east-to-west transects were spaced at equal intervals (north to south) across the flare pit area. One hundred points were read on each transect near the end of the 1994 and 1995 growing seasons. Within each seeded test plot, thirty points were read on diagonal transects across each LCA-II and control plot. Twenty-five points were read in each test plot on established vegetation. In the seeded blocks, LCA-II and control plot vegetation was sampled only in 1995, because the seedlings were too small to measure in 1994. Photographs from marked camera points were also taken in August each year (1993-95) to document aspect changes among years, as described by McKendrick (1976) and Sharp et al. (1992).

Results

Soil monitoring

LCA-II treatment was ineffective in lowering salt levels in the three seeded blocks, according to soil E.C. data (Figure 1). Overall soil salinity in these plots averaged 11.03 mmhos/cm in 1993, and 7.54 and 12.68 in 1994 and 1995, respectively.

LCA-II treatment was also ineffective in permanently reducing soil salinities in plots with established grasses. The mean soil salinity decreased in soils supporting *Puccinellia langeana* and *Arctophila fulva* during the first growing season after applying LCA-II (Figure 2). The first-year decline was significant only for the *Arctophila fulva* soil. In the second year, after LCA-II application, salinity returned to pre-treatment levels in both *Puccinellia langeana* and *Arctophila fulva* soils. Mean salinity in soils supporting *Dupontia fisheri* and *Poa glauca* increased each year after LCA-II application. The increase in soil salinity after two years was significant in the *Poa glauca* soil (Figure 2).

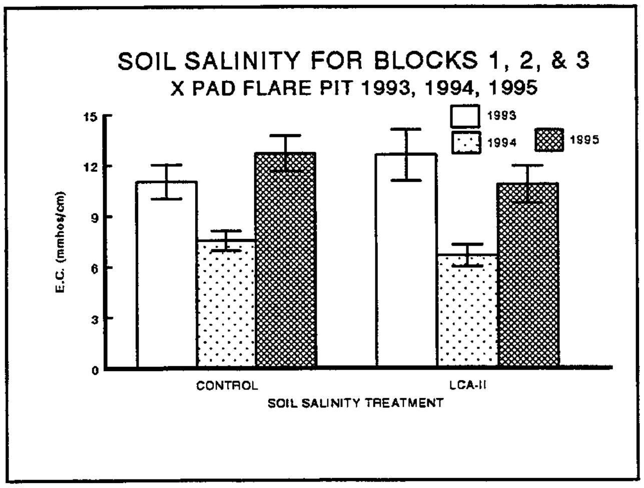

Figure 1. Mean soil salinity for control and LCA-II-treated soils, X Pad Flare pit area 1993, 1994, and 1995.

Vegetation monitoring

Between LCA-II-treated and control plots in the seeded blocks, bare ground, algae, live and total biological cover changed between 1994 and 1995. Bare ground decreased, while algae, live, and total biological cover increased (Figure 3). Total biological cover included all vascular and nonvascular plants, standing dead, litter, and animal feces.

Puccinellia langeana was the only seeded grass to establish in test plots, from both natural recolonization and from seed applications. The natural recolonization accounted for about 20% cover. The combination of both natural and seeded *Puccinellia langeana* produced an average of slightly less than 40% canopy cover (Figure 4).

All established grasses survived the LCA-II treatment (Table 1). The greatest live basal cover, which included moss was about 83% for the *Poa glauca* plots. The greatest canopy cover was 96% for the *Puccinellia langeana* plots. Moss cover was greater in the *Poa glauca* plots than for any other established grass species treated with LCA-II. *Poa glauca* contributed least to the canopy cover and species composition than any of the other grass species evaluated. The native grasses dominated the composition of their respective test plots after two years, with the exception of *Poa glauca*. The *Poa glauca* plots were overtaken by mosses, *Puccinellia langeana* and *Arctophila fulva*.

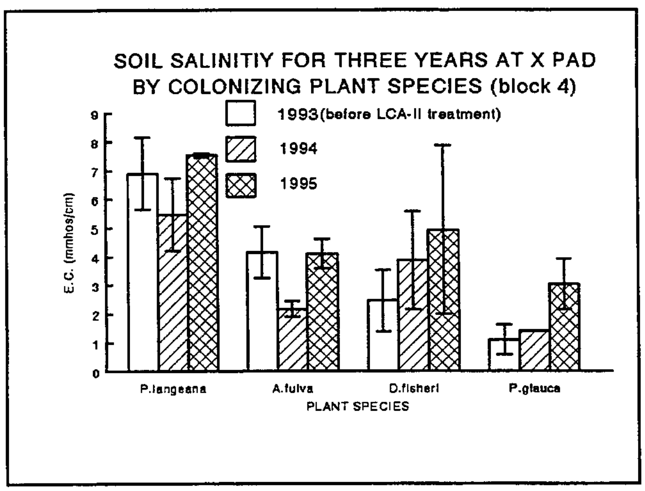

Figure 2. Mean soil salinity for LCA-II-treated plots, X Pad flare pit area, 1993 (pre-treatment), 1994, and 1995.

Indigenous plant species canopy cover on the five transects across the flare pit area outside LCA-II treated plots increased between 1994 and 1995 (Figure 5). Volunteer *Puccinellia langeana* was the dominant vascular plant species outside plots treated with LCA-II, producing approximately 26% canopy cover on this site by the end of the 1995 growing season (Figure 5). *Dupontia fisheri* and *Arctophila fulva* were the next most prominent species. Total vascular plant cover averaged about 37%. In contrast to the native plants, the three grasses, *Arctagrostis latifolia*, *Festuca rubra*, and *Poa glauca* seeded in 1989 and 1990 to revegetate the flare pit, decreased in canopy cover between 1994 and 1995 (Figure 6).

Table 1. Canopy and basal cover and composition percentages on four established grass species treated with LCA-II at the X Pad flare pit site in August 1995, two years after chemical treatment.

Plot Species	Canopy Cover by Plot Species	Total Canopy Cover	Bare Ground (Basal Cover)	Moss Cover	Live Basal Cover	Composition by Plot Species			
						Afu	Dfi	Pgl	Pla
	Percentages								
Arctophila fulva	26.0	42.0	12.0	22.0	40.0	74.0	4.0	6.0	16.0
Dupontia fisheri	28.0	70.7	9.3	65.3	78.7	13.0	40.0	8.0	13.3
Poa glauca	4.0	45.3	8.0	74.7	82.7	26.7	12.0	12.0	42.7
Puccinellia langeana	86.7	96.0	29.3	26.7	62.7	2.7	2.7	0.0	94.7

On the flare pit site, species composition changed between 1994 and 1995 (Table 2). The native *Puccinellia langeana* was the dominant species over the flare pit area, averaging about 72% of the vascular plant population, during both years. The other indigenous plants increased in prominence at the expense of seeded grass species. *Festuca rubra* was the most prominent of the three seeded grasses in 1994, averaging 9.4% of the population in 1994. In 1995, *Festuca rubra* had declined to 2%. *Poa glauca* decreased from 2% in 1994 to 1%. *Arctagrostis latifolia* decreased from 2.6% to 0.2%.

Photo records for 1993 and 1995 illustrate the establishment of *Puccinellia langeana* in seeded plots (Figure 7). There was a visible increase in numbers and sizes of individual plants colonizing within and beyond LCA-II test plots on established vegetation (Figures 8 and 9).

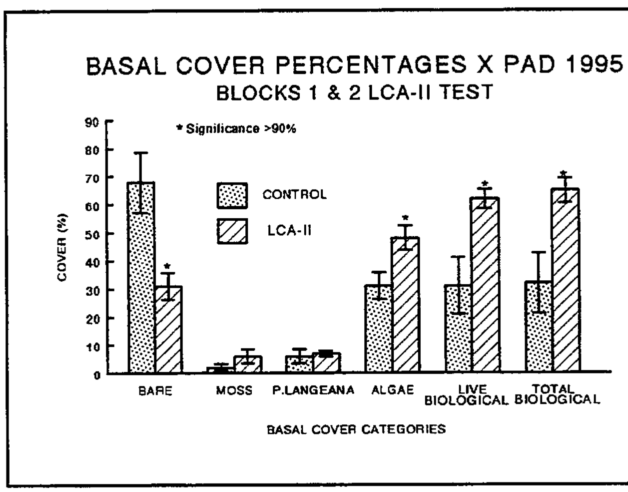

Figure 3. Mean basal cover for LCA-II-treated and control plots in seeded Blocks 1 & 2, X Pad flare pit area, 1995.

Discussion

Soil

LCA-II failed to significantly lower soil salinities in this experiment. Soil salinity varied markedly among years, a fluctuation apparently related to seasonal wetness. The lowest salinity was recorded during the wettest year (1994) and the highest salinity during the driest year (1995). It was anticipated that such variations were likely to occur, and that during the wet years salts would be dissolved, diluted, and flushed from the soil, leading to a gradual decline in soil salinity. Based on these short-term observations, there was no significant difference between treated and control plots. However, there was a very slight trend for less salts in the LCA-II soils in 1995 (Figure 1).

The soil surface in LCA-II-treated plots was a light grey color, suggesting an accumulation of salts on the surface at the end of the 1995 growing season. This was suspected to be a residue from the chemical application, rather than an accumulation of sodium released from the soil colloids by the LCA-II, because it remained on these plots even after spring runoff. However, there was no confirming data to indicate the true nature of this precipitate.

Vegetation

LCA-II treatments were significantly related to increases in moss, algae, live and total biological covers, suggesting there might be some benefits to plants from this chemical, even though it had no measurable effect on soil salinity. These increases in cover may have been a response to the nitrate component in the LCA-II. We observed that plants in some LCA-II-treated plots were darker green than their counterparts in control plots. This dark green color indicated greater succulence in these grasses. A delayed senescence was also observed. Soil fertilization is known to delay senescence in arctic grasses (McKendrick, Ott, and Mitchell, 1978). Geese and caribou selectively grazed LCA-II-treated grasses. These color changes and preferential grazing effects were true not only for seedlings but also for established plants.

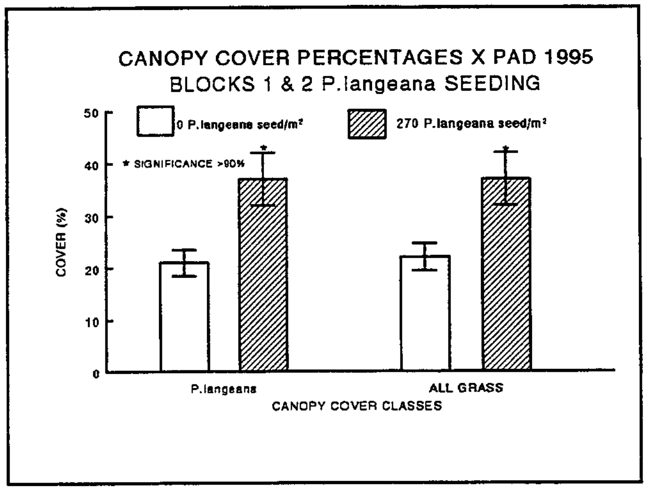

Figure 4. Mean canopy cover for *Puccinellia langeana* and all grass species for seeded and unseeded plots, Blocks 1 & 2 X Pad flare pit area, 1995.

Clearly the three species of grasses seeded to revegetate the site were not suited to the saline soil conditions. They have continued to decline in cover over time, yielding to moss and indigenous vascular plant species. In contrast, indigenous species, primarily *Puccinellia langeana*, *Dupontia fisheri*, and *Arctophila fulva* have increased in prominence on the site through natural recolonization. It is believed that grazing animals are partially responsible for introducing some of the indigenous species of plants to the site. *Puccinellia phryganodes* in particular may have been carried from stands along the seacoast by geese, which typically feed on the grass at those locations. According to Chou et al. (1992), *Puccinellia phryganodes* can regenerate from leaf and stem fragments. Since the grass has not been observed producing inflorescences and seed in this region, it may have been introduced to the flare pit site by vegetative means. Geese are suspected to have been the vector.

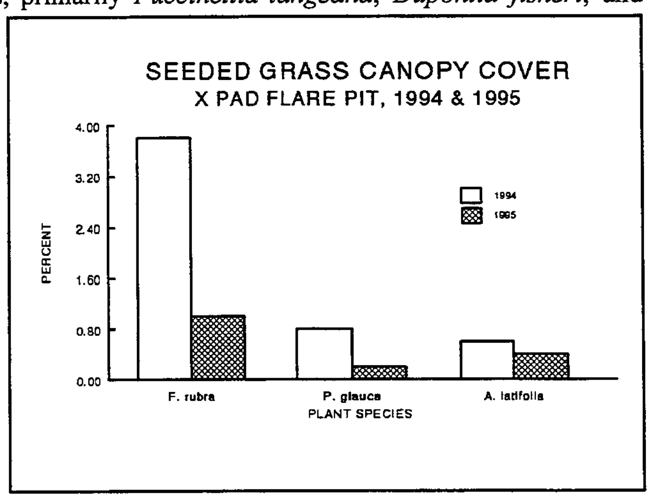

Figure 5. Comparison of canopy cover in 1994 and 1995 for three grasses seeded in 1989 and 1990 to revegetate the X Pad flare pit area.

Phippsia algida, *Carex maritima*, and *Sedum rosea* are three other indigenous species believed to have been carried to the site from coastal communities by geese. Most likely these three species were transported as seeds, adhering to birds as they moved from coastal feeding areas to the flare pit. We have observed that seeds of some native plants readily cling to objects when wet with dew. *Carex maritima* is one example. When mature, the capsules readily disarticulate upon contact. There seems to be a hydrophilic substance on the surface of these capsules which, upon wetting, forms a gelatinous material that enables them to cling to foreign objects. In the Prudhoe Bay Oil Field, *Carex maritima* has been found colonizing several inland disturbed sites, including the X Pad flare pit. The sites where *Carex maritima* was colonizing were known to be frequently grazed by geese, and we believe the birds responsible for introducing the species to those sites. Some seed may also survive after being consumed and passed through the digestive tract of geese. We have germinated seeds contained in goose feces from the Prudhoe Bay region.

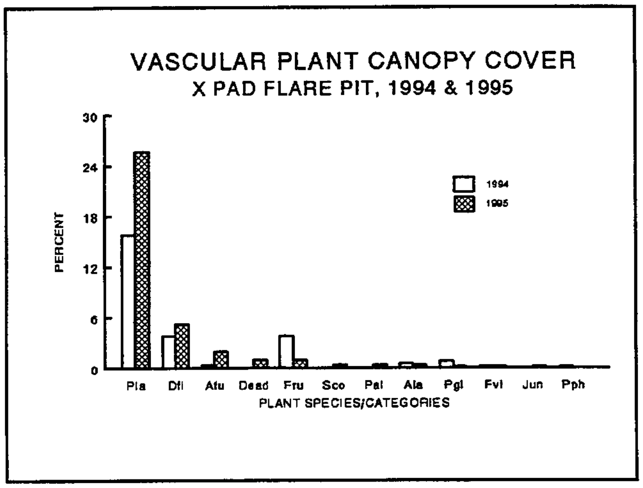

Figure 6. Comparison of canopy cover for all species between 1994 and 1995 at X Pad flare pit, outside plots treated with LCA-II. (See Table 2 for genus and species)

Adjacent to the flare pit the natural tundra has also been killed by salts, with surviving vegetation being confined to the elevated microhabitats of the polygon rims. Even though the barren surfaces have been undisturbed for a longer time than the topsoil-covered flare pit site, there are no vascular plants colonizing on them. Reasons for this difference have not been investigated. It is believed that absence of recolonization may be due to surface conditions. The flare pit surface consists of mineral soil. The undisturbed barren area is peat. We have observed that seedling establishment is more difficult on peat surfaces than on disturbed mineral soils in this region.

Table 2. Plant species composition on X Pad Flare Pit area in years 1994 and 1995.

Plant Species	Origin	1994	1995
Puccinellia langeana		72.0	71.8
Dupontia fisheri		7.6	10.4
Arctophila fulva		3.0	6.6
Phippsia algida/Puccinellia phryganodes		1.0	4.4
Festuca rubra	Seeded	9.4	2.0
Poa glauca	Seeded	2.0	1.0
Senecio congestus		1.4	0.8
Festuca vivipara		0.2	0.8
Carex aquatilis		0.2	0.4
Eriophorum angustifolium			0.4
Arctagrostis latifolia	Seeded	2.6	0.2
Juncus spp.			0.2
Ranunculus gmelini			0.2
Salix ovalifolia			0.2
Alopecurus alpinus		0.4	
Carex maritima		0.2	

The quantity of seed used to successfully establish a population of the indigenous grass, *Puccinellia langeana*, at this site was much less (1/69) than seed quantities of *Arctagrostis latifolia*, *Festuca rubra*, and *Poa glauca*, which were used by the commercial applicator in the previous two revegetation attempts. The modest seed application resulted in more widely spaced individual plants with greater vigor than observed in densely seeded commercial grasses at other locations in the Prudhoe Bay area. About one half of the canopy cover that developed in seeded plots originated from the application of 270 live *Puccinellia langeana* seeds/m^2, and half resulted from natural colonization. Using less seed and encouraging open stands of vegetation more closely imitates the natural recolonization of the arctic tundra than does the practice of intensive

Figure 7. **Photos of plot treated with LCA-II and seeded to *Puccinellia langeana* at time of treatment (7 September 1993, upper) and two growing seasons later (7 August 1995, lower).**

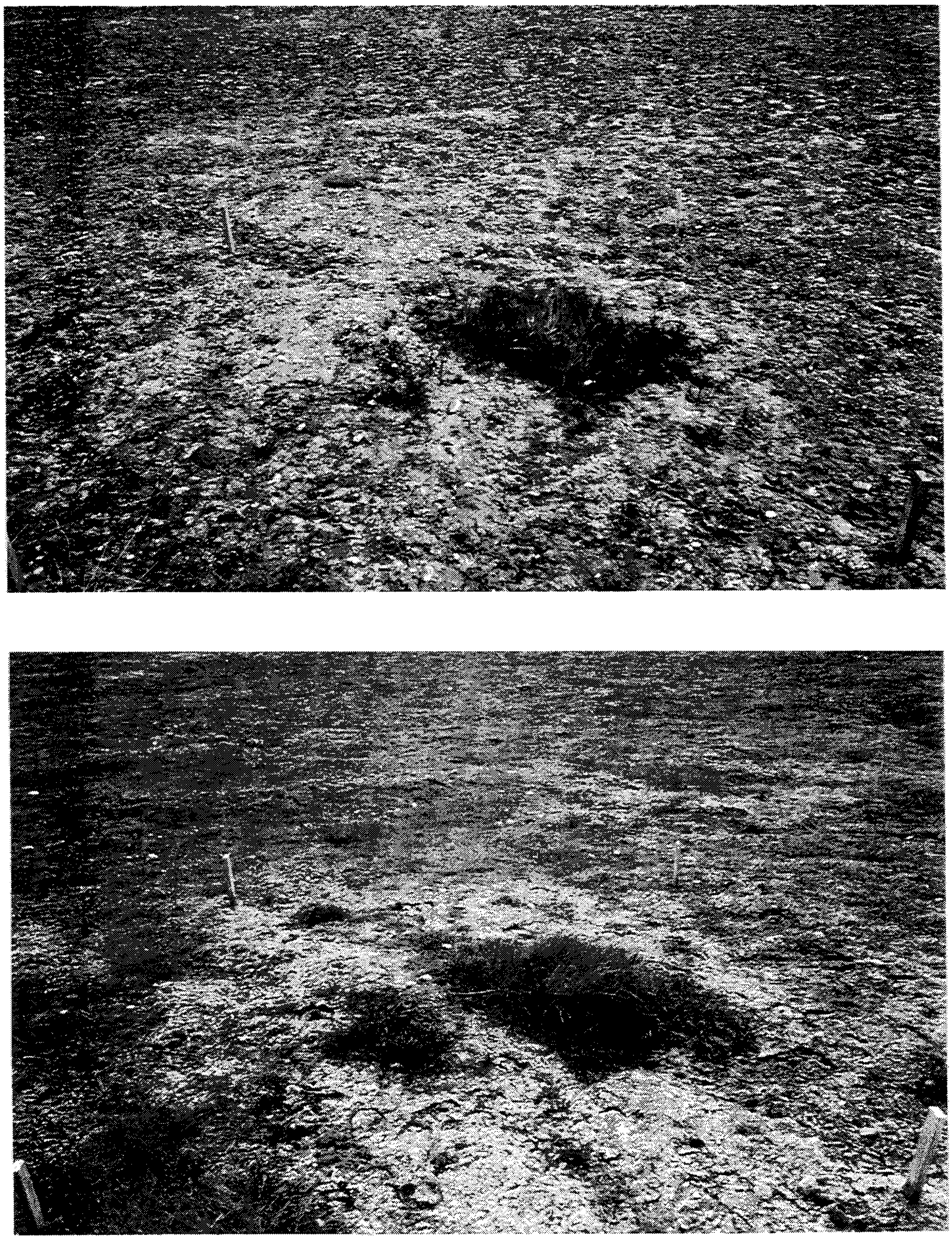

Figure 8. **Photos of *Arctophila fulva* plot treated with LCA-II (at time of treatment, 3 September 1993, upper) and two growing seasons later (7 August 1995, lower).**

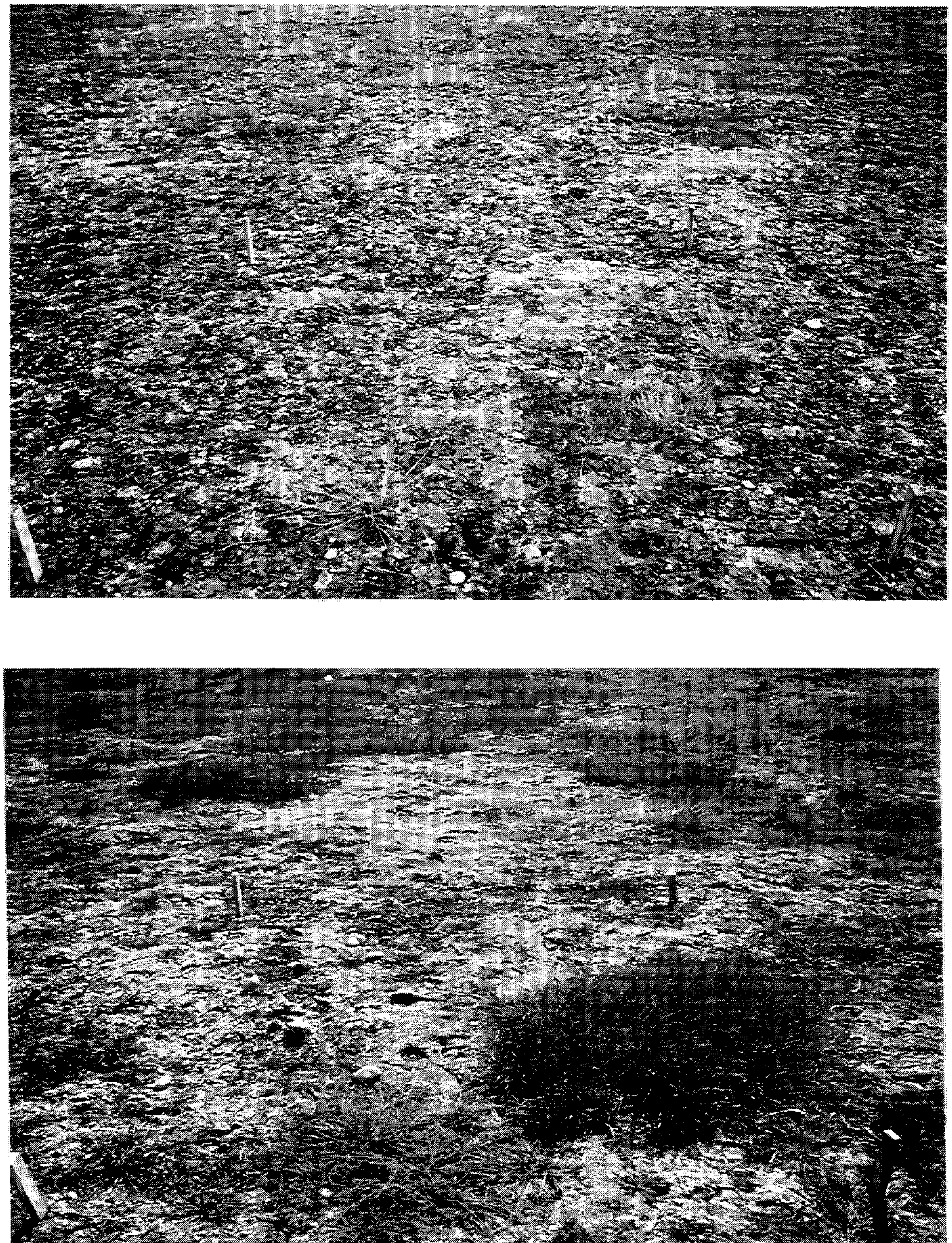

Figure 9. **Photos of *Dupontia fisheri* plot treated with LCA-II (6 September 1993, upper), at time of treatment and (7 August 1995, lower), two growing seasons after treatment.**

seeding and fertilizing. If natural tundra communities are the revegetation objective and soil erosion is not a threat, there is no ecological advantage to artificially accelerate the recolonization process by excessive applications of seed and fertilizer, especially if that results in persisting monocultures which resist reinvasion of natural tundra species. Recolonization on the flare pit site is occurring about twice as fast as that on drained lake basins. The dominance of *Puccinellia langeana* at X Pad is not typical of recolonization on most drained lake basins.

Unlike artificial revegetation with large quantities of seed and fertilizer, recolonization of naturally barren sites in the Alaska Arctic is a gradual process that begins with a few pioneering plants occupying the open area. Drained lake basins in the region subtly recolonize over a 25-35 year period. As the pioneer plants expand their territories by reproducing sexually and vegetatively, new individuals also establish in the open ground among these plants, adding numbers of individuals and species to the slowly developing community. This gradual recolonization strategy may be necessary to ensure a diversity of plant species occupies these drained lake basins as quickly as the environment will permit. Weather conditions favoring seed production for all vascular tundra plant species seldom occurs during a single growing season in this region. Weather conditions some years favors early-flowering plants, and other years favor mainly the late-flowering species. Thus, several growing seasons may be needed for the entire array of arctic plants to produce seed to colonize open ground. We have observed that once perennial grasses fully occupy an open site, such as where seeding and fertilizing were successful, some grasses persist, excluding other plant species. This dominance has been observed to persist for as long as 25 years. If a site remains relatively open over a number of growing seasons, there is greater chance for all tundra species to produce seed and thereby have opportunity to invade these barren sites.

Another benefit for the gradual recolonization strategy may be allowing colonizers to escape overgrazing by geese and caribou. Scattered individual plants, even though they may be palatable are less apt to attract grazers than dense stands of young seedlings, such as those resulting from artificial seeding and fertilizing. Thus, the natural recolonizing plants often escape heavy grazing and are free to mature and reproduce according to their inherent traits.

Conclusions

After two field seasons of testing, there is insufficient evidence to recommend LCA-II as an effective treatment for improving salt-damaged tundra soils. There are indications that it may stimulate seeded and existing vascular plants and mosses, perhaps by supplying nitrate nitrogen. Total canopy cover averaged about 64% after two growing seasons, where LCA-II had been applied to established vegetation. Long-term monitoring may reveal other benefits to vegetation from this chemical and that it does ameliorate soil salinity in the long term.

Seeded and established plants treated with the LCA-II chemical were preferentially grazed by geese and caribou. The increased palatability from the chemical treatment was attributed to increased succulence resulting from elevated available soil nitrogen.

Over a 6-year period more than 16 indigenous vascular species, tolerant of saline soil, have successfully colonized the study site. They have developed a functional stand that is producing inflorescences and surviving grazing pressures from geese and caribou. The canopy cover averaged about 37% in unseeded and untreated portions of the flare pit. Both natural recolonization and sparingly seeding the indigenous grass, *Puccinellia langeana*, have out-performed previous attempts to revegetate this site with the commercially-available grasses *Arctagrostis latifolia*, *Festuca rubra*, and *Poa glauca*. In contrast, natural recolonization has not occurred on salt-damaged portions of wet sedge tundra beyond the borders of the X

Pad flare pit, indicating that without some human intervention, natural recolonization is not universally dependable for revegetating salt-affected sites, at least in the short term.

Soil salinity conditions at this site are likely to change as the salts are leached over time. This will undoubtedly affect the composition of plant species on the site. Therefore, these short-term findings should be viewed cautiously, with respect to the effectiveness of the chemical in alleviating soil salinity and type of vegetation established thus far.

Fertilizer applications may be largely responsible for the relatively rapid colonization by native grasses on the X Pad flare pit site. Most likely the increase in soil fertility will cause grasses to persist and may slow the reinvasion of sedges, which originally dominated the area before the flare pit was constructed. According to our experience elsewhere in the oil field, this persistence by grasses deceases with site wetness.

These seeding tests demonstrated that hand-harvested seed from natural stands of *Puccinellia langeana* can be used to successfully establish vegetation on salt-damaged mineral soils in this region. The numbers of seed actually needed to introduce the species to such sites is relatively low, possibly a little as 2.0 kg/ha. With that application, the procedure of hand-collecting from natural stands becomes feasible in terms of seed costs. It remains to be demonstrated how well seeding *Puccinellia langeana* will imitate the natural recolonization of vegetation in this region.

Using indicators of trend, i.e., increases in plant cover, species numbers, and active sexual and vegetative reproduction should be considered in addition to cover for evaluating revegetation success in Alaska's Arctic environments. Currently, canopy cover is the standard condition criterion for judging success. Because time necessary for recolonization in the Arctic is protracted due to climatic constraints, relying only on the canopy cover standard may persuade industry and agencies to rely on seeding and fertilizing practices that could prove either incompatible with habitat conditions or contrary to the natural tundra recolonization process. If grazing pressures are intense on seeded sites, most of the canopy can be reduced, especially during the first three growing seasons. This causes canopy cover evaluations of grazed sites to greatly underestimate the true revegetation success.

Acknowledgements

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Native vs. Native

Panel Discussion Co-chaired
by
Wendell Hassell and Don Hijar

Considering the wide range of definitions that have been used to define native plants, "Native vs. Native" seemed an appropriate title for the panel discussion. The definition of a "native plant" has included: (1) a species native to this continent; (2) a species that is a part of the original fauna or flora of the area in question (Society for Range Management 1989); (3) a species that occurs and has evolved naturally in a region as determined by climate, soils, and biotic factors (Forest Service 1994); (4) a species that occurs naturally in a particular region, state, ecosystem, and habitat without direct or indirect human actions (Maryland Native Plant Society 1995); and (5) all species of plants naturally occurring, either presently or historically, in any ecosystem in the United States (Executive Order 11987 on "Exotic Organisms," 1994. Another definition from this executive order is (6) all species indigenous to or known to exist in a region at the time of European settlement.

Several different professions and interest groups were selected for the panel so that different viewpoints would be represented. The panel included four specialists: one geneticist, one plant ecologist, and two representatives from commercial seed and plant nursery companies. The panelist were as follows:

Pat Burk, Bitterroot Native Growers Inc.
Hamilton, Montana

N. Jerry Chatterton, Forage and Range Research Laboratory
Logan, Utah

Suzan Meyer, Forest Service Shrub Laboratory
Provo, Utah

David Stock, Stock Seed Farm Inc.
Murdock, Nebraska

Most plant characteristics are influenced by both heredity and environmental factors. Native plants should be diverse and self-sustaining. The panel focused on practical guidelines and concepts to consider when native plants are used for revegetation and restoration. It is important that each species be represented with a broad genetic base to enhance opportunities for natural selection processes to function.

The Importance of Using Site-Adapted Genotypes for Both Plants and Mycorrhizal Fungi in Restoration Projects

Pat Burke
Bitterroot Native Growers, Inc.
Hamilton, Montana

Abstract

Bitterroot Restoration's goal is the successful restoration of self-sustaining native plant communities on large, severely disturbed sites. We believe that the use of native, site-adapted genotypes is an essential part of a consistently successful methodology for achieving this goal. Because of the close relationship between most native plants and mycorrhizal fungi, site-adapted fungi should also be used to inoculate plants prior to revegetation. The inconsistent success of restoration projects is attributable in part to the failure to consider genetic issues and the role of mycorrhizal fungi. Successful use of site-adapted genotypes of both plants and fungi necessitates revegetation planning and adequate lead time. Initial project planning must take this into consideration. On-site propagule and fungi collection should be integrated with careful computerized tracking throughout the propagation and culture process. Special seed treatments, germination, and growing techniques are required to maintain genetic diversity and produce plants of consistent quality. Site-preparation, fertilization, planting and seeding techniques must be integrated with the overall restoration process. Additional costs associated with using site-adapted genotypes are modest and represent the price of consistent success. Both pragmatic and ethical concerns make site-adapted natives essential in restoration projects.

REVEGETATION - PLANT SELECTION AND BIODIVERSITY ISSUES

N. Jerry Chatterton

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Logan, UT 84322-6300

ABSTRACT

Fortunately, recent years have seen a surge of societal interest in preserving the biodiversity of plant communities. Problems often arise in defining and deciding how to preserve biodiversity and sustainability. Limited progress has been made in assuring their long-term preservation. A major problem is our limited ability to describe and quantify biodiversity on rangelands, parks, and wilderness areas. In many instances there are good detailed composition descriptions of plant communities and existing vegetation but biodiversity is not otherwise quantified. Some management agencies have mandated the use of seed from locally adapted populations in all rehabilitation, reclamation and restoration efforts in the absence of any knowledge about genetic variation within those species. New analytical methods must be used to help clarify genetic diversity issues. The staggering potential economic costs of using "native-site" plant materials should be sufficient incentive for society to move forward in acquiring the needed information. These native-site seed mandates may be ecologically counter-productive in that a narrow range of biodiversity may be perpetuated by that approach. Furthermore, if species have been previously eliminated from a site whether through natural processes or by man's activities, is it logical to reseed with <u>only</u> those species now on the site? The combination of species that exists on a site at some point in time may not be best for that site at some other point in time. Biotic and abiotic disturbances, deterioration in land conditions, weed invasion, and changes in land use determine the combination of species best suited to meet management objectives. It may be argued that seeding a number of germplasm types will result in an enhanced opportunity for natural selection. In any case, all interested parties must work cooperatively to determine the amount and kinds of genetic variation required for intelligent decision-making and responsible land stewardship. Too many issues and decisions are clouded with emotion and dogma. Let's work together and base our ethics on education, common sense and good science.

INTRODUCTION

The past several years have brought considerable interest and debate to questions related to the proper selection of plant materials for the seeding of rangelands, parks, and other public lands. Most people agree on the importance of preserving both plant genetic diversity and the biodiversity of plant communities. Efforts to preserve plant genetic diversity include the placement of thousands of plant species in long-term seed storage and in other repositories. For example, scientists in our ARS research unit have collected and placed into the national system over 4,000 accessions from domestic and foreign sources during the past several years. Furthermore, we and others have created many new gene combinations and effectively produced numerous improved varieties and even new "species". Thus, the many combined efforts are positively impacting both the preservation and a broadening of the plant genetic base. However, a better alternative is to preserve plant germplasm in situ through proper management. Before implementation of any management plan, the impact on biodiversity of all practices must be evaluated.

Differences in opinion are common among individuals and groups regarding the hows and whats related to preservation or restoration of biodiversity in plant communities. Difficult decisions often arise when seeding recommendations must be made. Although more revegetation/seeding options are now available than ever before, difficulties arise in trying to balance someone's ideal with economic reality and the availability of biologically suitable plant resources.

Goals-Needs

If our goal is to assure long-term preservation or sustainability of present plant community diversity in all rehabilitation/renovation and restoration projects, we must improve on our limited abilities to describe and quantify the biodiversity of large landscapes. The approach used by some management agencies is to simply mandate the use of seed from locally adapted populations in all restoration seedings.

Such approaches are being implemented in the absence of much knowledge about genetic variation within the plant community. First, it is imperative that we all realize that few, if any, communities in the western U.S. are what they were before man came upon the scene. Most plant communities are always in a state of imbalance or flux. Dynamic ecosystems may be more the norm than static ones. Regardless of the state of the plant community, one basic biological principle always applies--within a natural population, genetic changes are certain. Even within pristine native stands, genetic shifts (i.e. adaptive shifts) are continually occurring in response to the environment. Some alleles are driven to near extinction, while others increase in frequency.

Man's Influences

Man's influences have gone far beyond the composition of the plant community. In some instances soils have eroded, macro- and micro environments have changed, plants and animals are gone from the original ecosystem, and in many cases, new plants and associated biota have entered the ecosystem. As a minimum, the relative frequencies of the species present on most sites have changed. Often the natural successional patterns have been altered. In some instances plants have evolved and are thus adapted to the changes. However, plants once adapted to a site may no longer be able to compete with existing vegetation and site conditions. The rather large variations in both population and individual genetic diversity can be obtained simply by the way (i.e. time of year, environment, etc.) plant collecting is done even on the public lands for site specific native materials. Merrell (1981) reported that phenotypic differences in a population are often due to an interaction of multiple genetic and environmental factors.

Past Revegetation Efforts

Let me briefly review the history of Revegetation in the West. Only 20 years after the introduction of large numbers of domestic livestock to the Great Basin (around 1880), the editor of a rural Nevada newspaper suggested that the government should gather seeds of desirable plants and spread them on the range to restore productivity (Young & Spark, 1985). Government scientists who visited western ranges voiced the same opinions. In 1901 P. B. Kennedy verbalized the universal scientific assumption that the species selected should be the ones native to the sites (Kennedy & Doten, 1901). Over the next 30 years this procedure was tried and met with universal failure (see A. W. Sampson, 1913). Plantings of native plant seeds at over 500 locations in nearly 100 national forests in all western states were considered failures. Kennedy's assumption that native plant material was best because it had evolved in balance with the local environment was proven wrong. Why? Because conditions that governed stand establishment of native plants and those conditions that had initiated natural successional change had been altered by man's use.

Today, as in years past, there are many disturbed sites where man's uses perpetuate a secondary succession that was not present before his arrival. If we are ever going to be successful in our struggles to stabilize disturbed areas and to replace undesirable weedy/invader plant types with desirable species, there is one critical point we must realize. Man's activities have in fact introduced changes, not only in plant species composition but also changes in the quality and quantity of soils and altered microenvironments. Soil erosion and the associated loss of fertility, cation exchange capacity, particle size distribution, and water holding capacity have drastically changed seedbed and soil nutritional characteristics as well as site factors such as stream flows and water tables. Recognizing and accepting these changes and addressing their ramifications are critical to the success of every seeding effort. Some now argue that management of public lands should no longer be for forage production or plant cover. If that is true, there is need for alarm because in many areas every cow that is removed from grazing on public lands is being replaced by more than five buffalo or elk!

Use of Crested Wheatgrass

Why was crested wheatgrass used successfully to reclaim more than 10 million acres in the Northern Great Plains and millions more in the Great Basin during the 1930s? You may recall that disturbed areas were so vast and erosion so extensive that wind-carried soils from the West and Midwest darkened the skies in Washington, D.C. Although the use of native species had failed, the use of crested wheatgrass was successful because it was possible to produce the required seed and market it at an affordable societal price; furthermore, seedling vigor and establishment characteristics of crested wheatgrass allowed plants to become established and grow in the disturbed soils thereby stabilizing the area so natural nutrient cycling could be reestablished. In many instances crested wheatgrass was planted as a monoculture. Some plantings have remained monocultures by design while other plantings have been invaded by sagebrush and various native species.

It should be noted that, in spite of extremely narrow genetic diversity in the original crested wheatgrass introductions, its seeding on vast areas that represent a wide range of environments, was highly successful. No apparent biological problems have developed as a result of the use of large quantities of seed from plants with little biodiversity and a limited genetic base. Many argue that there have been ecological or aesthetic problems from those seedings, but certainly no one can argue that those problems resulted from its narrow genetic base. What significant effect does our knowledge of the success of plantings of narrow genetic-based crested wheatgrass across a wide range of environments on millions of acres have on our interpretations of biological diversity in rangeland ecosystems?

Biodiversity

Biodiversity has been variously defined and continues to be used in many ways--sometimes to suit individual or political group agendas. The unabridged dictionary tells us that bio = living and diversity is the condition of being different or having differences among living things--in this instance, plants. We must be careful to not use the origin of an organism in our attempts to determine its potential contributions to biodiversity, regardless of where it came from. We may know where a species occurs but in very few instances do we know where it originated. Jensen et al.(1995) demonstrated that bluebunch wheatgrass, which is considered native to North America, is in fact found throughout regions of Eurasia. These plant materials are morphologically indistinguishable and are comprised of the same genomes regardless of where they occur around the world. Morphological variations within collections of bluebunch wheatgrass from different countries is no greater than the variation observed in collections from one state. As more data become available, and germplasm exchange continues, we may find that current definitions of native have little meaning.

It is not logical to assume that a plant species cannot contribute to or have biodiversity because it is indigenous to site x, and does not occur at site y. Plants that are native to a different continent have the potential for the same degree of variation, biodiversity and differences as those that are native to central Colorado, for example. Biodiversity and native are not synonymous terms even though many people use them that way. As difficult as it may be to accept, it is possible to have "biodiversity" without "native" and "native" without "biodiversity".

Categorizing plant material on the basis of its origin is not a scientific issue. It is a political one. I would hope that we as scientists, land managers, and stewards of the land could be objective, ethical and use good science in our decisions about the proper approaches to providing adequate vegetative ground cover to meet aesthetic, erosion and weed control, germplasm preservation, and biota habitat/food needs.

Dynamic Ecosystems

By nature many rangelands areas are highly variable. The interactions of different soil types, slopes, aspects, and moisture conditions, combined with various levels of hybrid introgression within and between taxa result in genetically diverse ecosystems. A comprehensive analysis led Nowak et al. (1994) to conclude that many rangeland species have adapted to heterogeneous environments that have changed over long periods of time. The genetic exchange that occurs among the many interfertile species found on rangelands adds to genetic diversity (Wayne & Bazzaz, 1991) and imparts an inherent ability for rangeland ecosystems to evolve with natural and anthropogenic environmental changes.

Man came on the scene and found ecosystems that had evolved over time and had some degree of harmony among the various components. However, to the extent that changes were occurring in the environment and that genetic recombinations and mutations were occurring, the ecosystems were not static--but were ever evolving/living/dynamic systems.

Fire-Animal Use Impacts vs. Natives

Control of fires, the introduction of large numbers of domestic livestock and more recently large and increasing herds of wildlife, especially elk and buffalo, have impacted the balance within many western ecosystems. For example, sagebrush now dominates some sites at the expense of other plant species. Numerous landscapes have been changed by the introduction of competitive plant and animal species that now dominate some areas to the exclusion of more desirable species. This type of domination and exclusion of other species has also happened in the presence of only native species. For example, thousands of acres throughout the West that were previously dominated by grasslands are now dominated by mesquite, creosote bush, sagebrush or pinon-juniper. Thus, invasion and domination by a single or few species on sites previously inhabited by a diverse compliment of species is not limited to alien or foreign species. Native species can also become dominant in essentially undesirable monocultures if rangelands are mismanaged.

Are monocultures of introduced species inherently more undesirable than monocultures comprised of "undesirable" native species? Emphasis should be focused on realistic and affordable management objectives of which biodiversity can be a subset. If we want increased biodiversity, let's not create less diversity by uninformed recommendations. Does it really make sense to repeatedly plant sagebrush on cheatgrass ranges that burn over and over? It may be more logical to first focus on stabilizing a site and subsequently work to improve biodiversity. In the case of sagebrush plantings on cheatgrass ranges, neither biodiversity or site stabilization is being attained through present restoration efforts. However, we have been very effective in spending large amounts of money.

The need to assure biodiversity in a seeding must be evaluated relative to the size of the area. Obviously every square meter of land need not have representatives of all the taxa known to have previously occurred on a site - how about every 10 square meters?, 100 sq. meters?, 10,000 or 100,000 sq. meters? We observe in nature "undisturbed" areas, some are very large in size, that are monocultures or nearly monocultures of natives. Large tracts of conifers, or in some instances aspen, occur as monocultures. Normally, we do not consider those to be bad. I propose that, in some instances, it also is not bad to have seeded areas (if not extremely large in size) that are not maximally biodiverse.

Reality, Common Sense and Sound Judgment

An element of reality must be brought into our management decisions. I don't think that we can long afford to allow extreme views to dominate management plans without any regard for realistic management objectives or economics. How important is it that a roadside or mine reclamation site be seeded to a wide array of costly native species when revegetation costs may approach $50,000 per acre? Does the narrow roadway through a massive area really need to be seeded to all the same species present in the larger area? Is the first priority ever to effect site stability and stop soil erosion? Does the planting of species not previously on a site that will easily establish and persist hold any potential of adding to biodiversity? It is true that we cannot always predict the consequences of planting something new on a site. The same is true for natural genetic mutations and the results of natural seed dispersal by birds and wildlife. Some argue that man is also a part of nature. Hopefully we will always use past experiences and current knowledge to plan for the future.

Given an ever-changing environment and a real societal interest in preserving the environment, we must not be myopic in our approaches. The selection of plant materials for land restoration has been effective. Why not utilize the best plant materials available that will effectively protect and improve the environment by restoring depleted, stripped, and degradated lands to useful and stable conditions that will meet societal needs for the future whether they be production or conservation oriented?

The choice of plant material must be based on the objectives of the seeding. If the objective is immediate erosion control and soil stabilization, appropriate species should be chosen for those purposes. Maybe a vigorous and fast-growing annual cereal followed by overseeding with other species chosen to meet secondary site objectives is a viable approach. If a site is already dominated by "exotic weeds" the seeding of competitive "desirable exotic" germplasm capable of competing with the weeds may be the logical approach. If a site is truly "undisturbed" and has no exotic species present, it may not be logical to add exotics that are competitive with and may replace natives. There are surely sites where we should error on the side of being too conservative in efforts to retain strictly natives. At the same time there must be sites where the objective is to maximize production (i.e. soybean or corn fields). However, most sites will fall somewhere in between those extremes. The critical question is "what is the achievable objective for the site and what is the best affordable plant material available"?

I issue a plea for the following:

1. Mutual concern, understanding, tolerance, cooperation, and dialogue among all parties interested in maintaining stabilized, sustainable rangelands with genetic- and bio-diversity.

2. A scientific or objective determination of the kinds of practical genetic variation that should be included in seeding projects.

3. A recognition that biodiversity and native are not synonymous terms.

4. A better understanding of ecosystem dynamics and a recognition that things are not as they once were--nor will they ever be that way again.

5. A consideration for the potentially staggering economic and social costs incurred in effecting decisions based on a disregard of scientific knowledge and judgment (emotion vs. facts)--some individuals with economic stakes in the native seed business push the use of native seeds in the name of biodiversity.

6. A replacement of personal misunderstandings and misconceptions (emotion and dogma) with state-of-the-art information in all land use decision processes--thus, intelligent and informed land use decision-making and responsible as well as accountable stewardship.

I agreed with Greg Simmond's statement that we must develop a land ethic whose principles are grounded in education, experience and good science, not in inherited wisdom or a romantic myth of a perfect range that never was.

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NATIVE VERSUS NATIVE: AN ECOLOGIST'S PERSPECTIVE

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ABSTRACT

Restoration should initiate processes that will lead to the establishment of a native ecosystem with diversity, resiliency, and capacity for continued evolution, rather than try to create static, idealized predisturbance vegetation. In western North America, secular climatic change over the last ten thousand years has meant that native plant populations must continually evolve or migrate to keep pace. Year-to-year variation in the weather also results in adaptively significant polymorphism within populations. There may be as much genetic variation among individuals in a population as there is mean variation among populations. When choosing and propagating plant materials for restoration, it may be more important to ensure that each species is represented by a broad regional genetic base than to be overly concerned with exclusive use of local seed sources. On large-scale disturbances, local seed sources are often no longer extant. Direct seeding is usually the only economically feasible approach to such large-scale restoration. The quantities of seed required may sometimes be wild-collected, but more often field seed production in an agronomic setting is necessary. Care must be taken to preserve the genetic integrity of each population or ecotype through the seed increase process. The development, production, and use of regional ecotypes may represent the most practical middle ground between genetic purism on one hand and traditional plant breeding approaches on the other.

INTRODUCTION

In the past few years we have witnessed a remarkable increase in interest in using native species in reclamation and revegetation projects in the West. Whatever the reason for this interest, it is incumbent upon those who work in revegetation research to develop guidelines for the use of natives in different management contexts and to learn how to handle native plant materials to best achieve the objectives of particular kinds of revegetation projects.

For many years the primary objectives in revegetation have been expressed in terms of specific resource benefits, such as erosion control, livestock forage production, or habitat for game animals. These objectives are sometimes still implicit, but often the idea of using species indigenous to the predisturbance vegetation at a site carries with it some notion of attempting not merely to revegetate but to restore some semblance of that predisturbance plant community. Meeting the long term goal of restoring a functioning, evolving ecosystem is a much more complex process than revegetating for short term resource benefits. Restoration efforts should be aimed at initiating processes that will lead to the establishment of a native ecosystem with diversity, resiliency, and the capacity for continued evolution.

GENETIC STRUCTURE OF NATIVE WESTERN PLANT SPECIES

The present genetic constitution of any native species is the product of a long and complex evolutionary history. The most notable feature of evolution as it has taken place in interior western North America over the last ten thousand years is that it has occurred under nonequilibrium conditions. The climate has been changing continuously, relatively rapidly, and not always in the same direction over the period since the last retreat of the glaciers. Large areas of the West have been recolonized *de novo* by native plants over this period, not only areas that were formerly under ice but also those that emerged as the great inland pluvial lakes dried up. And even those areas that could be continuously occupied by plants through the last glacial period have undergone major changes in climate and vegetation. Superimposed on these relatively long term directional changes in climate, and thus in the selection pressures experienced by plant populations, are short term fluctuations, especially year to year variations in the weather.

Plant populations must be sufficiently specialized in their adaptations to survive under local environmental regimes. The difference in environmental conditions from place to place exerts disruptive selection, resulting in the evolution of locally adapted populations. If local conditions remained the same over a long period, normalizing selection would result in greater specialization and decreased genetic diversity within each population. But the fact that environmental conditions may be quite different from year to year at a single location exerts a type of selection pressure called temporally varying selection. Under these conditions genetic polymorphism is maintained, with the relative frequency of genes favoring survival and reproduction under given conditions shifting from year to year depending on conditions encountered. Moreover, the maintenance of within-population genetic variation through temporally varying selection means that a population is more likely to have the capacity to shift adaptively in response to long term directional selection as well. The net result of these processes of natural selection is the pattern of genetic variation that we observe in interior Western species.

There are numerous ways of quantifying and evaluating genetic variation. With the advent of sophisticated molecular biological tools, it has become possible to consider variation in the most fundamental sense, at the level of the DNA itself. These methods are most useful in consideration of certain kinds of evolutionary questions such as phylogenetic relationships and time scales for evolutionary change (Linhart, 1995). But there may not be a one-to-one relationship between bulk genetic difference and adaptively significant genetic variation. Phenotypic differences that have a major impact on survival may be the product of genetic differences at single or few loci, so that selection is operating directly on a relatively small subset of the total genome. More traditional methods that consider adaptively significant variation in phenotype may yield as much or more information about evolutionary processes as molecular tools. These studies are carried out under conditions that minimize the effects of phenotypic plasticity, thus permitting inferences about underlying genetic variation. Indeed, there is now evidence that the degree to which a particular trait exhibits phenotypic plasticity may itself be under genetic control and subject to selection (Schlichting and Pigliucci, 1995).

Common garden and laboratory studies with numerous plant species native to the interior West have amply demonstrated the existence of adaptively significant among-population variation. This variation may be manifested as differences in growth rate, growth form, palatability, frost hardiness drought hardiness, temperature optimum for growth, edaphic requirements, and reproductive characters such as flowering time, seed size, and seed germination syndrome, as well as other traits.

Local populations of a species can be considered to belong to a larger entity called an ecotype if they show similar adaptive responses to similar selection regimes. Thus one can speak of a high elevation ecotype of antelope bitterbrush, that generally shows a prostrate, layering habit and an ability to resprout after fire. This is in contrast to a low elevation dune ecotype, that has an erect growth form, does not layer, and is usually killed outright by fire. Antelope bitterbrush also shows ecotypic differentiation with regard to edaphic requirements, in that populations native to sites with acidic soils do not grow well on calcareous soils. There is little ecotypic variation in seed germination syndrome in this species. This example shows that the degree of ecotypic differentiation observed depends on the trait or adaptive syndrome being examined.

Rubber rabbitbrush provides another example. Achene weight varies in this species as a function of habitat, in this case seral stage and edaphic conditions. Ecotypes of late-seral communities on extreme soil types such as sand dunes and shale barrens have achenes up to eight times heavier than ecotypes of early seral communities on floodplains (Meyer, in press). Seed germination syndrome also varies as a function of habitat in this species, but the important aspect of habitat in this case is climate, namely the duration of the winter chilling period (Meyer et al., 1989). Both of these kinds of variation are genetically based and are maintained in common gardens, but they are not correlated with each other.

From these kinds of studies we conclude that differences among ecotypes within a species are not absolute but are a matter of degree, and that the degree of ecotypic differentiation observed depends both on the species and the adaptive syndrome under consideration. In practical terms, populations of a species that occupy apparently similar niches in similar habitats in the same geographic area can probably be considered as belonging to the same or similar ecotypes.

Any comparison of differences among populations must include a representative sample of each population and must express population attributes in terms of averages. But limiting consideration to average differences obscures the true nature of the variation. One of the most striking effects in common garden and laboratory studies with native species is the tremendous amount of among-plant variation observed. Extreme individuals in two different populations may be more similar to each other than mean population differences would suggest. The difference between populations can often be considered as a difference in the relative frequency of genotypes rather than as differentiation into unique, mutually exclusive sets of genotypes. From an evolutionary perspective this kind of variation represents the result of the temporally varying selection regimes discussed earlier. Understanding the significance of this variation may be a key feature in successful use of natives in revegetation.

IMPLICATIONS FOR PLANT MATERIALS DEVELOPMENT

The choice of plant materials more than any other aspect of revegetation depends on the objectives of the project and the intended post-reclamation land use. If immediate livestock grazing figures prominently in the post-reclamation plan, it makes sense to use introduced forage grasses that establish reliably, provide reasonably palatable and nutritious forage, and tolerate grazing. But if the goal is to restore a native plant community, then including any of these 'world native' grasses in the mix would be inappropriate. Choice of plant materials for restoration should include a consideration of what was native on the site prior to disturbance. It is also wise to consider which native species might possess the ability to function as early seral 'pioneer' species on disturbances that do not permit immediate recolonization by late seral natives.

Once a planting list of native species has been developed, the next decision is where to obtain the germplasm. Again, this depends on management mandates and objectives. The first consideration is to use plant materials that are adapted to the site and are likely to be able to establish, grow, and replace themselves through reproduction onsite. A second consideration is to use plant materials that can coexist with each other, i.e., to try to keep the competitive relationships among species in balance. Another consideration that is sometimes important, for example on National Park Service lands where protection of genetic integrity is a mandated goal, is minimizing the potential for change in the genetic composition of surrounding populations. What approaches to native plant materials development can be used to meet these considerations?

Cultivar Development

The traditional approach to plant materials development with natives closely parallels the procedure for crop plants (Munda and Smith 1995). A typical first step is collection and outplanting of numerous accessions of a species in trials at one or more locations. From these trials one or more accessions are selected as superior and worthy of continued development. The criteria applied are usually agronomic, e. g., growth rate, biomass production, seed yield, and breadth of adaptation. The goal is to find the accession that will perform best over the widest range of site types and will therefore have the widest utility. Selection within accessions is carried out, both intentionally and unintentionally, to make the plant more croplike, emphasizing such traits as early and complete germination, rapid and uniform growth rate, responsiveness to resource inputs such as fertilizer and irrigation, synchronous flowering and seed production, and high seed yield. It is easy to see that the artificial selection regime that produces a cultivar may be very different from the real world selection regimes experienced by populations of native plants in the wild. Such cultivars may establish spectacularly well in an artificial seeding in a good year, but their prospects for long term persistence are unknown. Cultivars of native grass species may also possess some of the attributes that make introduced forage grasses undesirable in mixed plantings, such as being overly competitive in the first years of the seeding, preventing establishment of the seeded natives. In this case it isn't whether the species is native or introduced that matters, but the degree to which it has been 'agronomized' in the process of cultivar development.

Some of the more recent cultivar releases of native species, particularly of shrubs, have followed a somewhat different path. These germplasm releases might more appropriately be called selected source-identified germplasm releases (Young 1995). There has been no deliberate selection within the selected accession, and it has been recognized that the high degree of variation present in the wildland collection is an asset in a seed source that is to be reintroduced to the wild. Another approach to getting a broadly adapted germplasm release is to mix multiple accessions into a single named germplasm. Munda and Smith (1995) have described a formal way of considering and maintaining genetic variation in the process of developing a release.

Wildland Seed Collection

The most common way to obtain seed of most native species is through direct collection from wildland stands. This seed is then used to obtain planting stock, is seeded directly onsite, or is used as the basis for seed increase. Where genetic integrity issues are important and disturbances are small scale, seed may be collected from populations immediately adjacent to the disturbance, thus assuring that the genetic constitution of the newly-established population will resemble that of surrounding populations, and presumably of the population that was lost, as closely as possible. On large scale disturbances this may not be an option, and the question of what population to use as a seed source becomes much more problematic.

Seed from wildland stands may be purchased in the marketplace, it may be contract-collected, or it may be collected by the parties that intend to use it. The latter two options provide some guarantee that the seed belongs to an appropriate ecotype, but this is not true of seed obtained on the open market. A system for source-identification of wildland-collected seed would help both buyers and sellers (Young 1995). Such a system would be voluntary, and the extra cost would be offset by the increased chance of a successful revegetation project. Buyers need to be educated regarding the importance of using seed of appropriate ecotypes. Careful planning a year or more in advance of the initiation of a project on the ground greatly facilitates the process of obtaining such seed. And because native stands do not necessarily produce good crops every year, an organized warehousing effort is also very helpful in ensuring that the correct seed will be on hand when needed. Seed quality issues must also be addressed, but in this case the regulatory structure is already in place (Stevens and Meyer 1989).

Propagation from Wildland-collected Seed

If wildland-collected seed is obtained in sufficient quantity to be seeded directly on the disturbance to be restored, then the problems inherent in nursery production or field seed increase can be avoided. High profile small to midsize disturbances are often revegetated at least in part with nursery stock. Care must be taken in the process of nursery propagation to avoid unintentional selection and consequent narrowing of the genetic base of the outplanted population (Meyer and Monsen 1993). The existence of within-population variation in seed germination syndrome in many species creates a real danger of inadvertent selection on these traits during propagation.

Large scale disturbances such as burns may be seeded with a mixture of wildland-collected and field-produced seed. Shrub seed is most often collected in quantity from wildland stands and seeded directly, while forb and grass seed can rarely be wild-collected in sufficient quantity and must undergo seed increase in an agronomic setting. Field seed production poses its own risks of inadvertent selection, for example for decreased seed dormancy (Meyer 1995).

In order to be cost-effective, seed production fields must be large enough to permit economies of scale to come into play. Opponents of the use of wild-collected ecotypes in revegetation often cite excessive cost as a major obstacle. Small scale field seed production of numerous locally-collected populations is far more expensive than production of large quantities of seed of each of a few ecotypes. If we could identify key regional ecotypes for each species to be placed into field production, perhaps ecological, evolutionary, and economic considerations could all be taken into account. This idea is based in part on the concept that more genetic variation increases the chances for adaptation to a range of site types. This may be especially important in a seed source to be introduced onto a disturbance that may present selection pressures different from those encountered by any single source population. The seed source could represent a mix of various populations from the region, thus assuring that it would be adapted in the broad sense and also that it would have the variation needed to respond adaptively to whatever selection pressures the newly-established population might encounter. The decision of what constitutes a regional ecotype should be based on available information on the distribution of adaptively significant genetic variation within each species. Clearly some species are more likely than others to form specialized ecogeographic races, and these species would need to be represented by a wider range of ecotypes in field cultivation.

What we need is for all the interested parties to work out the details of an effort that would lead to the regular availability of reasonably but fairly priced, ecologically appropriate seed supplies for several key native Intermountain species. These interested parties would include researchers in ecology, evolution, plant materials development, revegetation, and ecological restoration, land managers and revegetation practitioners in both the public and private sectors, commercial seedsmen, growers, and representatives of regulatory agencies. If we are serious about repairing damaged ecosystems in the interior West through revegetation with native species on a large scale, this kind of cooperation is a necessary next step.

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NATIVE vs. NATIVE
A PLAINSMAN PERSPECTIVE

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The question of "What seed source should I use" is one everyone must answer when planning a seeding project. When it is a prairie grass seeding project it may change from an economic and practical question to a philosophical or even a moral question. The issue of local ecotype versus cultivar seed source has been debated for over 25 years in the prairie states.

It has been the contention of some prairie enthusiast that when making native plant seedings or reseeding any disturbed site, only local native plant material should be used. It has been presumed that local ecotype plant material is the best suited plant material for any site. Cultivars have been accused of having a limited gene pool and therefore lack adaptability and are short lived. Cultivars have also been accused of being too aggressive and can carry disease that threaten local populations.

The real problem is our lack of understanding of either the genetics or the evolution of native plant material. There is none or very little experimental evidence to support the claims made for local ecotypes or the claims against cultivars. In spite of the lack of evidence, enough people have been convinced that local ecotypes are best that some governmental bodies have required local ecotypes be used in reseeding specifications.

Development of Cultivars

A brief history of cultivars is important to our discussion. The development of cultivars came about because of the failure to revegetate the Great Plains after the Dust Bowl by using native harvest prairie grasses. There were four main reason for the unsuccessful use of native material, 1) lack of seed supply, 2) poor seedling vigor, 3) lack of cultural practices and range drills, 4) unadapted plant material. Instead of the plains being returned to the original prairie grasses, vast acres were planted to bromegrass and crested wheatgrass in years following the drought of the 1930's.

With the failure of using native plant material fresh in their minds, a small group of dedicated conservationist and researchers started to develop improved and adapted native plant material for erosion control. The USDA Bureau of Plant Industry in cooperation with the Land Grant Colleges collected superior native plant material in the late 30's and 40's. They were looking for plants that had improved trait such as seedling vigor, forage production, economic seed production, disease resistance, and adapted to a wide range of soil and climatic conditions. The breeding of the plant material was simple compared to todays' modern techniques. Selection in space plantings and re-bulking over several generations was the common practice. They were tested at Plant Material Centers, University Experiment Stations and in large field planting. It was only after much testing and evaluation was the improved native material released as a certified variety.

Native vs. Native

Local ecotypes are the best adapted! While local plant material is adapted it may not be the best adapted. Dr. Ken Vogel, research Geneticist , USDA/ARS, University of Nebraska presented research at the 1996 Society of Range Management Annual Meeting that clearly shows that local ecotypes are not always the best or most fit plants. He collected big bluestem, switchgrass, indiangrass and Canada wildrye germplasm from 20 to 50 remnant prairies from 7 Midwestern states. The plant material was evaluated in space-planted plots for two years for biomass yield at three midwestern locations Nebraska, Iowa, and Indiana. Regression analyses was conducted to determine if the distance of the collection site from the evaluation site had an effect on individual plant yield. The results showed that in 9 of 12 tests moving plants North and South or East and West did not affect the individual plant yields. In 2 of 12 tests the results showed higher yields the farther the plant was from its home. In only one of the 12 tests did the yield match the presumption that the local ecotype was the best adapted. Why aren't local material always the best? Dr. Vogel concludes that the reason is that many of the evolutionary processes that result in a plant being located at a specific site are the result of chance. If the climate changes, local ecotypes will likely not be the best adapted to their current areas. He concludes that there may be better adapted plants in the next county, watershed, or state. The only way to determine if plant material is suitable for an area is to test it. The only way that you can have reproducible material to test is to have certified cultivars.

Cultivars have limited gene pools! Once again there is no evidence to back this claim. Just the opposite should be true, cultivars should have larger gene variations when you allow plant material from different sources to cross pollinate. Even if a variety has come from a limited parentage, that does not mean it lacks adaptability. An example of that is blackwell switchgrass, which is one of the most widely adapted variety we have available to us, originated from just one plant! Cultivars can be short lived if they are planted where they are not adapted. Factors such as winter hardiness, soil fertility, moisture conditions and humidity can cause a plant to be short lived. That is why testing is so important. Certified varieties give us a high degree of predictability whether a variety will adapt to a site.

Cultivars are too aggressive! Several years ago we were involved in a seeding project in Illinois that was using both local ecotype big bluestem and one of our cultivars from Nebraska. In the rich prairie soil the local ecotype big blue could not compete with high population of cool season annual weeds while the cultivars fought for its space and establish a stand in two years. When trying to establish a grass stand in todays world, being aggressive is not a bad attribute.

Cultivars are a threat to local populations? I could not find any information that showed where a cultivar had introduced a disease or insect into a native stand of prairie. There are very few pests that bother the prairie grasses and the ones that do are either native soil borne or are native insects. Certified varieties are selected with disease resistance as a factor. What about pollen contamination? Research done in 1945 by Dr. L. C. Newell on pollen dispersal has been the basis for the present day isolation standards for certified seed. He showed that the majority of pollen travels only 35 feet and very little goes past 75 feet when he examined the major prairie grasses. These same standards could be used in the preservation of high quality prairie remnants.

Commercialization of Ecotypes

Local ecotypes present a unique situation to the professional seedsman. From our personal experience, they are difficult to harvest and clean. This goes back to their low seed yield and lower test weight of the seed. The lower pure live seed(PLS) yield per acre makes the per unit cost several times higher then a certified variety. Another problem we have experienced is unstable germination making ecotypes risky to keep in inventory.

Another problem we face is the reluctance of the local ecotype marketer to sell on a PLS basis. Demand has been so great that a germ and purity has not been required by many Government agencies for local material. There appears to be a double-standard where seed companies operate under one set of rules and local harvesters are allowed to operate under another. The marketing of native seed by using Pure Live Seed basis is for the protection of the consumer and the taxpayer must not be compromised.

I believe in the protection of high quality prairie remnants. Many virgin prairies are in danger of contamination due to mechanical harvesting equipment. They are also in danger from harvesters digging up native plants. The increase demand for hard to find prairie forbs and grasses have put many plants at risk.

Conclusion

It is important that high quality prairie populations be identified and protected. A climax prairie can not be reproduced even when we start with ecotype plant material. Ecotypes may not be the best plant material for a given site because of climatic changes and cultural influences. Cultivars contain the agronomic traits needed for a successful seeding and are the most economic source for seed. We need to keep testing plant material for adaptability and further research is needed to expand our base of knowledge.

HOLISTIC RECLAMATION: A NATURAL REMEDIATION PROCESS USING CATTLE AND OTHER NATURAL TOOLS

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Abstract

This ecological approach to mine tailings reclamation, using cattle as a tool, is without a doubt the most significant paradigm breakthrough to reclamation in modern times. The process of managing nature has long given way to dependence on technology for being the prime answer to stimulate healing on disturbed sites. Technology, although important, has in itself proven to be very costly and ineffective.

We have now come full circle by employing the natural process to stimulate stability through the natural development of dynamic high successional plant and animal communities on once barren mine tailings. The use of cattle is one important part of this process that picks and chooses from a vast array of natural tools, in addition to technology, to achieve predetermined goals.

This new concept often referred to as the "Holistic Approach to Reclamation" is now being applied to nearly a dozen sites in the Southwestern United States. And as with any management methodology success is strictly proportional to the understanding and correct application of the method. Even with this caveat, this new advance of "Using Cattle in Reclaiming Mine Tailings" is producing exciting and lasting results.

Holistic Reclamation

In today's complex world where competition for space on the earth's surface is increasing by the day it is mandatory that industry, even though essential economically, be responsible for cleanup of aftermath or residue of an industrial process. For many years the knowledge of this cleanup wasn't readily available, was too costly, wasn't effective or a combination of these. Stability on reclaimed sites has always been a problem, but today there has been a break-through that can cost effectively handle most of these problems. The ability for nature to repair itself has been a part of the natural process since the beginning of time. We can now stimulate and speed up this natural process through the planned use of ruminant herbivores, particularly cattle, and other natural tools in context with applied technology.

Mining next to agriculture is probably the single most economically important industry not only in our nation but around the world. Yet in today's complex society these two disciplines are so interdependent on one another, as well as other disciplines, that it is often difficult to determine where one discipline starts and the other leaves off.

This is certainly the case with reclaiming land affected by mining and other industrial processes. Because these lands are a natural environment they are dependent on several agricultural disciplines to be successfully reclaimed. Even so, much of the success of reclamation work depends on work of a mechanical nature and other technology.

Natural environments are dynamic and when stimulated will progress or regress successionally as determined by an influence, whether that influence be mechanical, natural or a combination thereof. Therefore, natural progression toward successionally more complex and diverse plant and animal communities can be achieved through the application of appropriate planned influences. Knowing this, it is then possible to predetermine a reasonable future landscape description and then attain it by stimulating the natural process through the application of selected management tools in a timely manner.

Tools of management can be divided into two major categories; they are the natural tools (tools of nature) and tools of technology (mechanical tools).

During the mechanical revolution, especially in agriculture since World War II, the development of technology has been so fast, great and overwhelming that most of us in the natural fields have all but lost touch with the natural process. As a result we tend to look almost totally to technology for the answer to solve natural problems of agriculture and its related fields including reclamation. We do this when in actuality these fields are dependent on the natural process for not only success; they are dependent on the natural process for their very existence. We rely on the mechanical process and then wonder why success ratios with natural resource projects are so low as well as costly.

To compound the problem, Federal and State policies regulating reclamation more often than not create rules that stymie the use of a natural process to improve natural conditions. This can be a result of ignorance, a faulty paradigm, or a lack of knowledge regarding ecological processes. Many times, however, policy is influenced by big business in order to create markets for technology. A perfect example of policy influenced by big business are weed control laws in many states. These laws force the use of costly chemicals to control weeds that seldom present a problem where there are good farmers because they can be controlled by cultural methods. The result is that much money has been spent; water, soil, people, domestic animals and wildlife have been damaged by chemicals; and the weed problem is worse than before spraying because natural control systems have been poisoned and cultural control practices have been abandoned in favor of the chemical control.

The fact that we in the U. S., can, today, enjoy a prosperous economy buoyed by plentiful foodstuffs at the worlds lowest prices is not the result of superior agronomic skills based on intellectually superior natural resource knowledge. No, it is because we have the cheapest availability of fossil fuel combined with the most advanced and superior engineering capabilities the world has ever known. And although, on the face of things, agriculture and its many related fields are seemingly prosperous, a closer look will disclose that they are not. Soils once stable and fertile have been mined of their organic matter and are highly vulnerable to erosion. These soils are now dependent on vast amounts of chemical fertilizers to produce at all. The use of insecticides is at an all time high while at the same time insect problems are also at an all time high. Water is becoming contaminated with fertilizer, insecticide and herbicide residues. And because of these problems with technology, flawed governmental policies, and reduced use of natural practices we have wiped out a profit margin, have ruined many thousands of acres of productive land and have lost entire land based communities.

I have used this scenario to lay the groundwork for what I see as a mounting problem in the field of natural resources particularly as it refers to reclamation. We are now employing the same management paradigm, that is killing us in agriculture, to vegetate and stabilize, the worst case scenario, mine tailings.

Technology is neither good nor bad, but in itself is not the answer. Technology is just a large array of tools that if used in the right context can produce beneficial results. Many of today's resource problems would not exist if a more judicious use of technology were used.

Natural tools include rest, fire, grazing, animal impact, and living organisms. All except fire have been successfully employed in the new methodology termed "Holistic Reclamation" of using cattle for reclamation. The use of all of these tools, as well as technology, is part of a process that starts with the development of a three part goal. One part of the goal is a future desired natural landscape description that is managed toward, instead of creating an artificial landscape out of step with nature and, therefore, not sustainable.

Tailings are no more than ground up rock, the product of a mechanical process but basically no different than soil particles that resulted from a geological grinding process. The only real difference between the two mediums, i.e. soil and tailings, is the presence or absence of life. That mechanical stabilization more closely resembled a hydroponics unit rather than a natural stage of succession, and that in order to produce stability on tailings the natural process must be stimulated, by an outside source, to produce a diverse and complex landscape. The missing ingredient was life, particularly the micro-organisms that decay plant material and provide the nutrient base for plant growth and soil development.

The most obvious source this type of micro-organism was ruminant animals such as cattle. These microbes along with important enzymes, minerals and other nutrients are passed through the animal with the manure to provide life to the soil. This would be an excellent source of life for the tailings. Cattle and other grazers have other benefits as well. They provide the outside stimulus through hoof action which is extremely important for several reasons. It breaks the bare tailings surface creating miniature dams or air spoils that reduce air turbulence on the surface thereby reducing wind erosion. Farmers in the plains states learned this concept many years ago and when the winds began blowing dry bare fields they plowed them to provide the roughened surface to retard soil movement. When hoof action breaks soil capping it also prepares the surface to accept rainfall. It can prepare the seed bed by incorporating mulch (organic material) into the tailings surface, further stabilizing it, and planting the seed.

Cattle also remove old growth during the grazing process. This allows sunlight to penetrate to the growth points, of a grass plant, located near the base of the plant. This stimulates new growth and promotes the health and vigor of the plant. This concept has proven to be exceptionally important in the maintenance of reclaimed tailings.

In the last six years approximately 800 acres of mine tailings have been reclaimed using this method by several mining companies working with Arizona Ranch Management, Globe Arizona including Cyprus, Magma, Asarco and Kennecott.

Holistic Reclamation is also capable of solving several other problems that haunt traditional reclamation methods. For example, while many consider highly acid pyritic tailings nearly impossible to reclaim, this method can raise the pH level over two points. The micro-organisms incorporated into the tailings along with the mulch and straw create humic acid which raises pH and provides an environment for plant growth. In the process the blanket effect of the mulching robs the acid producing microbes of the oxygen necessary for them to function.

Although each reclamation effort is site specific and each offers different challenges, Holistic Reclamation methodology is flexible in its approach and makes the difficult process of reclaiming arid southwestern tailings more manageable. Failed reclamation projects of the past are being repaired and current mine operations have a more cost effective alternative to soil capping, hydro mulching, fertilizing, seeding and irrigating. Above all, this new management concept produces stable sites.

An unexpected but welcome side benefit of this management methodology is the wildlife. Tailings reclaimed in this manner have become magnets for wildlife of every size and description. Fauna observed on tailings dams in association with cattle include deer, javelina, coyotes, fox, other predators, burrowing animals, insects, raptors including bald and golden eagles and water fowl.

In conclusion, we have learned that using the hoofed animals the micro-organisms and other natural tools along with the planned used of technology has given us the ability to produce stability on sites that were thought to be too sterile and toxic to produce life. This process is being done in a cost effective manner that precludes expensive soil capping. Tailings material is being converted into living soil with the capability of not only sustaining life, but developing to higher stages of successional plateaus to support diverse plant and animal communities.

FUNCTIONAL SIGNIFICANCE OF FUNGI TO HIGH ALTITUDE REVEGETATION

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ABSTRACT

Fungi are abundant in almost all soils, including those at high elevations, and make important contributions to soil development, structure and fertility as well as plant establishment, growth and succession. Thus, restoration of functioning fungal communities is a critical component of successful revegetation of disturbed sites.

Chemical compounds produced by fungi and the vast networks of fungal filaments in soil form and physically stabilize soil aggregates. The ability of fungi to decompose plant and animal residues is vital to formation of soil organic matter as well as the cycling of essential nutrients.

Mycorrhizal symbioses formed by plant roots and certain soil fungi increase the ability of plants to obtain nutrients and water from soil and, thus, increase their growth and ability to tolerate stress. Nearly all plant species common to high altitude environments, including coniferous trees, woody shrubs and grasses, are dependent upon formation of mycorrhizas to reach their full growth potential.

Revegetation practices that can facilitate recovery of populations of soil fungi include organic amendments such as the application of straw, hay or sewage sludge (or a mixture of these materials) and hydromulching. Planting of seedlings with established mycorrhizal root systems can aid in reestablishment of mycorrhizal plant communities. Also, minimizing storage time prior to respreading topsoil results in greater fungal survival.

INTRODUCTION

Fungi are extremely important participants in terrestrial ecosystem processes (Christensen, 1989). Fungi as a group are the decomposer organisms primarily responsible for the breakdown and recycling of plant and animal residues (Paul and Clark, 1989), participate in mycorrhizal symbioses with the majority of land plants (Harley, 1971), and serve to stabilize soils through their contribution to soil aggregation (Tisdall and Oades, 1982). These activities make fungi critically important to successful revegetation of disturbed sites.

Fungi inhabit virtually all soils; high elevation or low, disturbed or undisturbed. Most fungi in soil exist as microscopic threadlike filaments which grow in the soil pore space, on and around soil particles as well as on and in soil organic matter. In fact, in many soils, fungi may may produce more living matter than any organisms other than plants (Stahl and Parkin, 1996). Fungi can form very extensive networks of hyphae in soil and their activities have extremely important effects on soil properties and plant growth which, in turn, can have direct effects on revegetation efforts.

To illustrate the abundance and diversity of fungi in high altitude ecosystems, a number of studies on fungal community structure in montane or alpine soils can be cited. Bissett and Parkinson (1979) isolated 128 different species of fungi from an alpine area vegetated by approximately 30 species of plants. In a study of the ectomycorrhizas of spruce trees in the Sumava Mountains of Czechoslovakia, Lepsova et. al. (1992) report the biomass of mycorrhizas to vary from 300-1000 kg ha^{-1} (1633-5446 lbs per acre). Because ectomycorrhizas are generally recognized to consist of at least 50% fungal tissue, this value represents from 150-500 kg ha^{-1} (816-2723 lbs per acre) of fungal biomass produced by ectomycorrhizal fungi alone. Scheu and Parkinson (1994) measured the amount of fungal hyphae in soil under an Aspen forest and found up to 2568 m of hyphae per gram of soil. This figure is equal to over 1.6 miles of fungal hyphae in a gram of soil. In terms of biomass, this amount of hyphae represents approximately 7.1 mg fungal biomass g^{-1} soil. Expressed in another way, the amount of fungal biomass in that aspen forest soil to a depth of 6 inches is approximately 5 tons per acre.

The objective of this paper is to discuss the role of fungi in the revegetation of high altitude sites by 1) illustrating their importance to soil quality and plant growth, especially soil development and stabilization as well as plant establishment and succession, and 2) to make some recommendations to facilitate reestablishment of fungi on disturbed sites.

IMPORTANCE OF FUNGI TO SOIL QUALITY AS RELATED TO REVEGETATION

Certain types of landscape disturbance (e.g. surface mining) result in severe disturbance to native soil profiles and associated biota. Restoration of certain impacted soil properties can only be accomplished by triggering the process of natural soil development. All soil inhabiting organisms, especially microorganisms, are involved in this process. Saprotrophic fungi contribute through such activities as weathering of minerals, decomposition of plant and animal residues and formation of humus and stable soil organic matter. The greatest single component factor controlling the productivity of soils is the amount and depth of soil organic matter in the profile (Paul and Clark, 1989). According to Tate (1985) loss of soil organic matter is a major problem in disturbed soils. As mentioned above, fungi are the organisms primarily responsible for decomposition of organic residues and formation of humus, thus, along with bacteria, they are crucial to the development of a productive soil.

Development of a plant-soil community that exhibits long-term stability is an important objective of most revegetation projects. This stability is enhanced by fungi in a number of ways; one of which is their involvement in the development and maintenance of soil structural stability. Fungi growing in soil both form and stabilize soil aggregates through two mechanisms, chemical and mechanical binding of soil particles. Extracellular viscous mucilage produced by fungal cells, composed of polysaccharides, polysaccharide-proteins, and glycoproteins, strongly sorb to clays and other particulates in soil and act as an adhesive which hold these particulates together in aggregates (Tisdall, 1991). In addition, the extensive networks of fungal hyphae in soil, commonly over 1000 meters of hyphae in a gram of surface soil, physically enmesh soil particles and act as a strong force to stabilize soil aggregates (Lynch and Bragg, 1985). Through these mechanisms, fungi contribute to a stable soil structure which minimizes erosion and surface runoff (Eash et. al., 1994).

A fertile soil, by definition, is one that supplies its plant community with an adequate supply of both macro- and micronutrients. In order for a restored plant-soil community to be sustainable, fertility should be the result of natural biogeochemical processes as opposed to anthropogenic fertilizer inputs. Again, as a result of their activity as decomposers of plant and animal residues, fungi are directly involved in the development and maintenance of soil fertility. Tightly linked to decomposition is the process of mineralization of the nutrients held in dead plant and animal tissues into forms available to growing plants and microorganisms. Fungi are directly responsible for a significant portion of the total nutrient mineralization that occurs in soil. Nutrient mineralization rate is an especially significant factor in high altitude systems, where short growing seasons can limit nutrient cycling. Fungi commonly uptake and immobilize a relatively large proportion of the nutrients they release from organic residues. This is often viewed as competition with plants, but can also be regarded as a nutrient conservation mechanism in that immobilization of nutrients in fungal biomass greatly reduces leaching and loss from the soil profile.

Another means by which fungi contribute to soil fertility is through their role in the formation of humus and stable soil organic matter as described above. Humus and colloidal soil organic matter acts as an important reservoir of nutrients and is greatly increases cation exchange capacity.

IMPORTANCE OF FUNGI TO PLANT ESTABLISHMENT, GROWTH AND SUCCESSION

The activities of fungi not only have major impacts on soil properties which affect revegetation but they also have direct effects on the establishment, growth and succession of plant communities. Fungi influence plant growth through their contribution to soil fertility, as discussed above, and by their participation in mycorrhizal symbioses and rhizosphere interactions.

The majority of plants in high elevation plant-soil communities, as well as most other communities, form mycorrhizal symbioses with many different species of mycorrhizal fungi. Most coniferous tree species develop ectomycorrhizas in association with basidiomycetous and ascomycetous fungi, while most deciduous trees, shrubs, forbs and grasses form arbuscular endomycorrhiza with zygomycetous fungi. Mycorrhizas improve seedling survival and growth by enhancing uptake of nutrients (particularly phosphorus) and water, lengthening root life and provide protection against pathogens (Harley and Smith, 1983). In these mutualistic symbioses, the fungal symbiont functions as an extension of the host plant's root system, increasing the volume of soil from which the host can obtain nutrients and water. In turn, the host plant provides the fungus with a source of energy in the form of carbohydrate.

Most species of plants are dependent upon mycorrhizas for growth and survival in their native habitats (Janos, 1980) and this symbiosis maybe especially critical to plant survival in disturbed soils (Reeves et al., 1979). A number of studies have demonstrated the benefits of mycorrhizas to plant growth in disturbed soils and especially in revegetation efforts (Williams et. al., 1974; Marx, 1975; Daft and Hackaylo, 1977; Amarantus and Perry, 1987). In high altitude revegetation sites where plant stress factors may be increased by elevation, mycorrhizas may be particularly beneficial to plant establishment and growth.

Mycorrhizal fungi also influence the succession of plant communities on disturbed sites (Reeves et. al., 1979; Allen et. al., 1989). The presence or absence of mycorrhizal fungi on a disturbed site can have a strong influence on the species of plants that can become established. Revegetation of a site with plant species which are mycorrhiza dependent (mycotrophic) may be unsuccessful because of the absence of the proper mycorrhizal fungi. The rate of plant succession on a disturbed site may be dependent on the rate at which mycorrhizal fungi increase with time (Allen, 1980). In general, late successional plant species are more mycorrhiza dependent than are early successional species.

Another group of fungi in soil which can have beneficial effects on plant growth are fungi which inhabit the plant rhizosphere. Fungi which are active primarily in the soil region immediately surrounding plant roots can contribute to plant growth in a number of ways. Rhizosphere fungi can add to the nutrients available to plants through mineralization of organically bound elements as well as solubilization of inorganic elements held in minerals. Additionally, fungi in the rhizosphere may produce growth factors required by plants and provide protection from plant pathogens (Curl and Truelove, 1986).

RECOMMENDATIONS FOR REESTABLISHMENT OF FUNGI ON DISTURBED SITES

The benefits of an active fungal community to soil properties and plant growth are outlined above. Restoration of these soil microorganisms to high altitude disturbed sites may be especially important due to short growing seasons where plants must exploit soil resources quickly to successfully establish (Perry et. al., 1989).

To reestablish fungal activity, or microbial activity in general, on disturbed sites, the presence of organic material is of extreme importance. The presence of organic matter in soil provides a source of energy for saprotrophic fungi and a more suitable environment for all types of fungi. Low organic matter content of disturbed sites can be increased by 1) establishing a vegetative cover that will ultimately result in the accumulation of stable organic matter through plant residue decomposition, and 2) ameliorating the disturbed site with an organic amendment followed by subsequent revegetation (Visser, 1985). Treatment of mine spoils with sewage sludge or peat have been shown to be effective for increasing fungal biomass and species diversity (Fresquez and Lindemann, 1982; Visser, 1985). These two organic amendments introduce not only large numbers of fungi, bacteria and carbon but also essential nutrients such as nitrogen and phosphorus which are required by microorganisms for growth and maintenance. Other organic treatments such as straw and hay also will provide a satisfactory substrate for growth of saprotrophic fungi, however, amendments most effective in facilitating restoration of saprotrophic fungi in soil will contain significant amounts of nitrogen and phosphorus as well as organic carbon.

Reintroduction of mycorrhizal and rhizosphere fungi to disturbed sites can be accomplished in a number of ways. On surface mine revegetation sites, respreading native topsoil is an effective means of reintroducing indigenous soil microorganisms. Stockpiling of topsoil, however, should be avoided or minimized to help retain soil fertility and viability of microorganisms. The use of native topsoil can be an efficacious method to reintroduce saprotrophic as well as mycorrhizal and rhizosphere fungi. The roots of seedlings can also be inoculated by several techniques: 1) using whole soil from established plant communities, 2) with root pieces containing mycorrhizal fungi or with 3) pure or pot cultures of desirable fungi (Perry and Amaranthus, 1988).

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HIGH ALTITUDE TAILING RECLAMATION PROJECTS

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Tailing, if present, is the most difficult aspect of mine reclamation. Physical characteristics of tailing generally are conducive to soil-plant water relations, but that quality is overshadowed by its high erodability. Chemical characteristics such as acidity, alkalinity, salinity, and heavy metals are common in metal mine tailing. Some tailing can be revegetated directly. However, when detrimental physical and chemical characteristics exist, a cover material may be required. The cover material should: 1) be relatively inert; 2) be deep enough for an adequate root zone for vegetation; 3) possess good plant-soil water relations; 4) be resistant to erosion; and, 5) not facilitate capillary movement from the tailing. In some instances the cover material must also act as a barrier to the movement of oxygen and water to and from the tailing.

Specific case studies of high elevation tailing reclamation are discussed, including relative difficulties, successes, and costs. Costs of these examples ranged from < $5,000 to > $5 million per acre. Also presented is a discussion of the status of the vegetation on the reclaimed Urad Mine tailing ponds after 21 years. Production and diversity on the ponds has always exceeded that of the control and vegetative cover on the ponds initially exceeded that of the control, but is now below that of the control.

INTRODUCTION

Some general distinctions will be helpful before describing various tailing reclamation projects.

High Elevation / High Latitude

Not many examples of truly high elevation tailing ponds exist, and only a few of those have been reclaimed. For purposes of this paper, high elevation will be defined as above approximately 2,450 meters (8,000 feet). Distinctions vary with latitude because high latitude sites exhibit somewhat similar climatic conditions at lower elevations. An equivalent north latitude to a 2,750 meter (9,000 foot) elevation in Colorado would be a 600 meter (2,000 feet) site north of the 60th parallel, i.e., the Yukon or Northwest Territories in Canada, and most of Alaska.

High elevation or high latitude sites are not necessarily more difficult to reclaim than other sites that have severe climates. Harsh winters and shorter, colder growing seasons at high altitude or latitude sites are not necessarily more limiting than conditions of a desert environment, they are simply different. Different species are required, planting times are different, mulches may be more important in the desert, and erosion control measures may differ. The major problems in revegetating tailing are related to chemical and physical limitations, and these problems are universal irrespective of climate.

Closure, Remediation, Reclamation, Revegetation, Rehabilitation, Restoration

Some distinctions among the terms should be considered. The terms are both hierarchical and categorical. **Closure** of a site consists of activities that resolve all the environmental and safety issues of a site for the long term. Closure includes reclamation and revegetation, and such things as the collection and treatment of acid mine waters as well as other long term activities at the site such as monitoring, maintenance, and security. The term closure is usually associated with the closing of an active site.

Remediation is the same as closure, except that it is performed on a different type of site, i.e., an inactive site. Remediation is a term generally used in association with Superfund clean-up activities at a site that has not been active in recent years. Remediation costs much more than closure because these sites must be studied to determine how they can best be remediated, and Superfund triggers extensive studies as well as additional involvement of lawyers to comply with very complex legal and governmental requirements.

Reclamation and revegetation are often used synonymously, when in fact they are different. Reclamation is a major part of closure and remediation, and revegetation is a part of reclamation. **Reclamation** includes site modifications, revegetation, and the establishment of functional ecosystems. **Revegetation** is simply the successful establishment of a permanent, self-sustaining stand of vegetation. **Rehabilitation** is essentially the same as reclamation. **Restoration**, if used in the same context as reclamation, is quite impossible. We simply do not have the technology to restore 300 year old Engelmann Spruce trees as yet.

Definition of Reclamation:

Reclamation continues to be the dominant term. When reclamation includes revegetation of a disturbed site to a natural system, it is defined as the activity that artificially initiates and accelerates the natural continuous trend toward ecological recovery (Brown, 1982).

Mother nature will reclaim all disturbed sites, in time, without man's intervention. Some sites will recover faster than others, but all sites will recover. Man's intervention in the form of reclamation simply speeds up the process of recovery. In most cases, the site will not return to the exact ecological composition it was before disturbance because slopes, aspects, and soils will have been changed. The area will, however, recover and function in a manner somewhat similar to that prior to the disturbance.

The natural continuous trend toward ecological recovery is initiated and accelerated by stabilizing the physical, chemical, and biological aspects of the disturbed land. Regrading, growth medium amendment, and revegetation are the basic reclamation activities that serve to stabilize the physical, chemical, and biological aspects of the ecosystem.

Problems in Reclaiming Tailing

Tailing, if present, is the most difficult component of mine reclamation. The major problems to be overcome in reclaiming tailing are erodability and potential toxicities, including acid producing potential.

Physical Characteristics:

Physical characteristics of tailing often provide good soil-plant water relations, but that characteristic is frequently overshadowed by its high erodability. The texture of mill tailing typically is that of silt. A significant percentage of the material will pass a 200 mesh screen.

These fine, relatively uniformly sized materials are very susceptible to both wind and water erosion. Unless physically stabilized, the tailing will blow when dry and will gully with a very small concentration of runoff. Besides the obvious problems of particulate pollution, blowing tailing will drift down-wind into revegetated areas. The blowing tailing can injure or sheer down-wind vegetation. In addition, tailing does not provide a very stable matrix for roots of woody vegetation.

Chemical Characteristics:

Chemical characteristics such as acidity, alkalinity, salinity, and high concentrations of heavy metals are common in tailing from metal mines. These chemical characteristics often result in sufficient toxicity to prohibit direct revegetation of tailing. Acid production is the most common problem. Oxidation of the sulfides produces acid, which in turn dissolves heavy metals from the tailing. These heavy metals may then be taken up by roots of terrestrial vegetation or carried into the watershed. The uptake of the metals by vegetation is seldom a problem, but entry into water ways can cause chronic or acute poisoning of aquatic life.

TAILING RECLAMATION PROJECTS

Partially or totally reclaimed high elevation tailing ponds with which the authors have had some level of involvement are:

Climax Mine, 3,175 to 3,975 m (10,400 to 13,000 ft), Leadville, CO
Alma-American Mill, 3,500 m (11,500 ft), Alma, CO
Urad Mine, 3,200 m (10,500 ft), Empire, CO
Keystone Mine, 3,050 m (10,000 ft), Crested Butte, CO
Henderson Mill, 3,000 m (9,500 ft), Kremmling, CO
Idarado Mine, 2,750 to 3,200 m (9,000 to 10,500 ft), Telluride and Ouray, CO
Black Eagle Mill, 2,500 m (8,200 ft), Idaho Springs, CO

Other tailing ponds, either partially or totally reclaimed, with which the authors have some knowledge include:

Sunnyside Mine, 3,050 m (10,000 ft), Silverton, CO
McLaren Mine, 2,150 m (7,000 ft), Cooke City, MT
Sheldon Mine, 1,975 m (6,500 ft), Prescott, AZ
Annie Creek Tailing 1,975 m (6,500 ft), Lead, SD
Nevada Gulch Mine, 1,825 m (6,000 ft), Lead, SD
Inco Mine, 300 m (1,000 ft), Sudbury Ontario, Canada
Contwoyto Lake Mine, 300 m (1,000 ft), NWT Canada

Types of tailing reclamation not discussed include copper tailing in Arizona, Utah, and Montana, iron tailing in Minnesota, and phosphate tailing in both Idaho and the southern US.

CASE STUDIES

The two basic approaches to reclaiming tailing ponds are: 1) revegetate the bare tailing, or 2) cover the tailing with overburden, waste rock, or soil and revegetate that material.

Revegetating Bare Tailing

Bare tailing has been successfully revegetated at Idarado, Nevada Gulch, Inco, various copper mines in Arizona, Utah, and Montana, and at iron mines in Minnesota.

Nevada Gulch:

Wharf Resources' successfully reclaimed bare tailing in Nevada Gulch, near Lead South Dakota. The small 1.6 hectare (4 acre) tailing pond was a remnant left from gold mining during the early 1900's. The tailing was neither acidic nor toxic, and the primary concern was erosion control.

A water course adjacent to the pond was cleaned, reconstructed, and rip-rapped; all slopes were reduced; and, the bare tailing was revegetated. The only soil amendments used in the program were 4.5 tonnes per hectare (2 tons per acre) of hay mulch and some inorganic fertilizer. The project was completed in 1986, and the material has been successfully stabilized. The cost of reclamation was about $35,000 per hectare ($14,000 per acre).

Inco:

The International Nickel Company in Sudbury, Ontario has reclaimed in excess of 1,010 hectares (2,500 acres) of tailing during the last 42 years, and continues to reclaim tailing with ongoing production at the mine. This is the premier example of bare tailing revegetation. The techniques for revegetating the Sudbury tailing have evolved through the years (Peters, 1984). In early years, limestone was applied every second year, or so, for some years to maintain a high enough pH to support vegetation. Acidification potential of the Inco tailing and the concomitant amount of limestone required to neutralize the tailing are within the realm of economic realism.

The sequence currently followed in revegetating the tailing at Inco is: surface preparation (contouring), discing, liming, seeding, fertilizing, tree planting, and a follow-up maintenance program (Heale, 1991). On the average, 25 tonnes per hectare (11 tons per acre) of finely ground agricultural limestone is mixed into the tailing surface prior to seeding. At the time of seeding, additional limestone (quantity as needed) is spread and disced into the surface. After seeding, vegetation growth and development is monitored and a follow-up application of approximately 11 tonnes per hectare (5 tons per acre) of limestone may be applied to the more difficult areas, as necessary. This approach eliminates the need for maintenance liming. It is estimated that Inco applies an average of 34 to 38 tonnes per hectare (15 to 17 tons per acre) of limestone to the tailing. The results have been astonishingly good. The vegetation is healthy, permanent, and self-sustaining. Trees are planted and have invaded, and species diversity is high.

Idarado:

The Idarado Mine, located near the towns of Ouray and Telluride, CO, has a number of tailing ponds, all of which are being remediated under a settlement agreement in a Superfund lawsuit initiated by the state of Colorado in 1982.

Revegetation research projects and successful bare tailing revegetation demonstrations have been ongoing at the mine for many years, each adding to the body of knowledge on revegetation of tailing. The final revegetation recipe that is being implemented is the application of lime as necessary (generally <10 tonnes per hectare [5 tons per acre]) to neutralize the pH of the tailing, about 225 tonnes per hectare (100 tons per acre) of limestone to maintain a neutral pH in the future, 90 tonnes per hectare (40 tons per acre) of manure (dry weight), 45 tonnes per hectare (20 tons per acre) of hay, and inorganic fertilizer at an approximate rate (N-P-K) of 56-284-90 Kg per hectare (50-253-80 lbs per acre). The tailing is effectively being transformed into a soil. Incorporation of these quantities of amendment into the top 25 cm (10 in) of tailing requires about seven passes with a large farm rototiller. A nurse crop is grown and incorporated, then the area is reseeded and mulched with two more tons of hay, the dam faces are netted, and the area is irrigated as necessary for germination and plant establishment. This is the most elaborate revegetation recipe in our experience.

The large quantities of organic matter effectively convert the tailing to a soil, and revegetation has been very successful. The vegetation and litter effectively control both wind and water erosion on the tailing surface and dam faces.

The cost of the reclamation effort at the Idarado Mine could be determined in a number of ways. The highest estimate could be the total sum of the $ millions being spent by all entities on the multiple law suits plus the $ millions being spent on the reclamation itself, divided by the number of acres being reclaimed. That number could eventually be in the range of $432,000 to $556,000 per hectare ($175,000 to $225,000 per acre) for the overall site. Because more effort and expense is expended on tailing reclamation, the cost per acre for reclaiming the tailing will be some greater value.

Covering the Tailing

Another accepted tailing reclamation technique, especially when the physical and chemical characteristics of the tailing are detrimental to plant growth, is the placement of a cover material over the tailing and revegetation of that material. The cover material should: 1) be relatively inert; 2) be deep enough to act as an adequate root zone for vegetation; 3) possess good soil-plant water relations; 4) be resistant to erosion; and, 5) not facilitate capillary movement from the tailing surface into the cover material. In some instances the cover material must also act as a barrier to the movement of oxygen and water to and from the tailing.

Climax:

The Cyprus Amax Climax Mine dates from 1918. Since that time, more than 360 million tonnes (400 million tons) of molybdenum ore have been milled and tailing has been deposited in ponds covering nearly 810 hectares (2,000 acres). The mine is located near Leadville, Colorado, and the mine permit encompasses nearly 49 square kilometers (19 square miles). The elevation of the site ranges from 3,175 to 3,975 m (10,400 to 13,000 ft) and straddles the Continental Divide at the headwaters of three major watersheds.

The overall tailing reclamation plan at Climax is very similar to the Urad plan discussed later. In essence, the plan is to cover the tailing with waste rock and revegetate the rock with the aid of organic and inorganic amendments.

Much reclamation has been implemented at the Climax Mine in recent years. However, the mine is so large and spread out that much of the progress is either not very obvious or is out of view of the general public. In an effort to consolidate and modernize the ore processing facilities, a large number of the old buildings and conveyors have been dismantled and salvaged. Two of the five major tailing ponds have been covered with overburden and are in various stages of revegetation. One of the dams required extensive regrading and slope reduction for stabilization.

A complicating problem at Climax is that not only is the tailing an acid generator, but some of the waste rock also generates acid. Much of the waste rock cover has been treated with limestone or kiln dust. In addition, a large number of lessor disturbances throughout the mine site have been reclaimed.

An estimated average cost of reclaiming all disturbances at the mine is in the range of $25,000 to $37,000 per hectare ($10,000 to $15,000 per acre). Reclamation of the tailing is more expensive, however, than reclaiming most of the other types of disturbances.

Keystone:

The Keystone Mine is a relic silver-lead-zinc operation. It was acquired by AMAX Inc. when the Mount Emmons (Molybdenum) Project was purchased in the late 1970's. The 22 hectare (54 acre) mine site is located near the town of Crested Butte, Colorado, at an elevation of about 3,035 m (9,000 ft). Four small but highly acidic and erosive tailing ponds existed at the site.

AMAX implemented state-of-the-art reclamation of the ponds in 1981, including the use of filter fabrics, installation of extensive water diversion facilities, construction of a $16 million water treatment plant, and the placement of an engineered, compacted, low-permeability cap over the tailing (AMAX Inc. 1981). Upon completion, the surface of the cap had all the characteristics of a pavement. The cap was successfully revegetated by simply ripping the surface 8 to 15 cm (3 to 6 in) with a crawler tractor and revegetating the material with the aid of hydromulch, sawdust, manure, limestone, and hay mulch.

A gross comparison of closure, reclamation and revegetation costs for this project is possible. Revegetation alone cost approximately $3,700 per hectare ($1,500 per acre); reclamation cost about $74,000 per hectare ($30,000 per acre) for the tailing ponds including drainage systems to the water treatment plant; and, closure of the Keystone Mine (including water treatment) has cost about $2.5 million per hectare ($1 million per acre) to date. However, this cost continues to increase because of the continuing cost of treating the mine water.

Henderson:

Mining at Henderson was initiated in 1976. To date, the mine has processed approximately 105 million tonnes (115 million tons) of molybdenum ore. The mine, located on the eastern slope of the Continental Divide, is connected to the mill, located on the western slope, by a 15.5 kilometer (9.6 mile) railroad-haulage tunnel. The tailing is a weak acid generator. Because the mine is isolated from the mill, no waste rock is available within a reasonable distance to serve as a cover for the tailing. The most available cover material is soil in the area. Therefore, a sufficient quantity of soil is being stripped and stockpiled from within the tailing basin to cover the tailing to a depth of 30 cm (1.0 ft).

The tailing dam has been covered with soil and revegetated as the tailing pond has grown through the years. In addition, tailing revegetation plots were established in 1982 to test the validity of the reclamation plan. The plots have been monitored carefully for the past 12 years, including analysis of the soil at different depths. All indications are that 30 cm of soil over the tailing will be sufficient to successfully revegetate the tailing (Trlica, Brown, Jackson, and Jones 1994).

The tailing deposition area is presently about 425 hectares (1,050 acres) in extent and the estimated cost of reclaiming the tailing is presently about $10,500 per hectare ($4,200 per acre).

Sheldon:

The Sheldon Mine is located near Prescott, Arizona, in an historic (1863-1940) gold and silver mining area similar to many other mine camps in the West. A small (1.6 hectare, 4 acre) tailing pond was the source of significant sediment to a reservoir and the objective of the reclamation project was to eliminate the sediment source.

In this instance, the tailing was highly acidic. Reclamation consisted of the installation of interceptor channels, applying 74 tonnes per hectare (33 tons per acre) of limestone to the tailing, and covering the tailing with about 15 cm (6 inches) of topsoil.

Much was learned from this relatively early (1970's) project. Recommendations after the completion of the project included the application of significantly more lime or limestone, incorporation of the lime material into the surface of the tailing, and a greater depth of soil cover. Thames (1984) summarized the results of the project by stating: "Two follow-up treatments of lime were required after the initial work and maintenance of peripheral drainage channels has been necessary. Despite the excellent appearance of the site after treatment, it is anticipated that annual maintenance of this type will be necessary for several years before the site can be declared successfully reclaimed."

Contributions and volunteer help kept the costs of reclaiming this tailing to about $5,000 per hectare ($2,000 per acre).

Black Eagle Mill:

The Black Eagle Mill tailing were one of about twenty sites deemed to be contributing sediment to the watershed in the Clear Creek/Central City Superfund Site (which essentially entailed the entirety of Clear Creek and Gilpin Counties, CO). Ms. Fabyan Watrous inherited the Black Eagle site (and the concomitant liability), and voluntarily cooperated to prepare all the required engineering and reclamation plans and legal documents associated with Superfund, and to implement and pay for the remediation. The tailing was regraded to 3:1 slopes, the base of the tailing was rip-rapped to protect the stream against a 100 year flood, runoff interceptors were installed, the tailing was covered with 51 cm (20 inches) of imported overburden material and 10 cm (4 inches) of imported soil, and the site was revegetated.

The total cost (including attorneys, etc.) of remediation for the approximately 1.4 hectare (3.4 acre) site was about $220,000 to $250,000 per hectare ($90,000 to $100,000 per acre). Ongoing monitoring and maintenance will be required for years, as is the case with all Superfund sites, but costs should not be excessive for this site because remediation was done correctly.

Contwoyto Lake:

The Echo Bay, Inc. Contwoyto Lake project is a relatively large modern gold mine located just south of the Arctic Circle in the Northwest Territories of Canada. The elevation at the site is low, but the latitude is high. The authors know very little about the project, but the reclamation plan is mentioned because of it's uniqueness.

The original reclamation plan was to deposit the tailing in a natural depression, allow it to freeze, cover the tailing with overburden, and revegetate the overburden. The tailing, which was potentially toxic, would become a part of the permafrost, forever frozen in place. The plan was implemented, but problems were encountered in permafrost integrity, and a more conventional disposal system had to be designed and constructed.

Annie Creek Tailing:

Wharf Resources, as with many modern mines, inherited another small relic tailing pond near Lead, South Dakota referred to as the Annie Creek Tailing. The pond contained about 109,000 tonnes (120,000 tons) of tailing and occupied less than 0.5 hectare (1 acre). The area is high is arsenic and some of the tailing had eroded down the drainage since being placed there between 1903 and 1916. Wharf had voluntarily isolated this tailing from the environment from 1987 to 1990 by stabilizing it with a rock buttress, isolating subsurface drainage from the material with a French Drain, and by covering the tailing with a low permeability cap. In the meantime, the site was brought into the Superfund process and in 1991 was proposed for the National Priorities List (i.e., the list of the approximately 1,300 most contaminated sites in the USA).

The Superfund process is unrelenting. Once a site is brought into the process, there is essentially no way out even if the threat to human health and the environment is negligible. Richard Long (1994) of the EPA stated "once scored and proposed for the Superfund national priority list, EPA is obligated to characterize the site, assess the risk, and implement controls necessary to mitigate the risks." At the onset, the Annie Creek tailing appeared to pose negligible threat to human health and the environment and the EPA and Wharf worked very hard to minimize bureaucratic and legal entanglements. The effort to minimize the bureaucracy was successful, but extensive biological studies were still deemed necessary by the EPA.

After four years of study, the threat to human health and the environment was indeed deemed to be negligible. The final remediation required at the site consisted of capping about 0.14 hectares (0.33 acres) that had eroded down the watershed and perched on the flood plain. The studies cost in excess of $ 2 million. The final remediation cost was about $35,000. Twelve million dollars per hectare (± $5 million per acre) makes this the most expensive of our reclamation examples.

The final irony is that without the joint agency-company effort to minimize the bureaucratic and legal entanglements the costs to the Company could easily have been twice this amount. (The final remediation would not have changed.) Long (1994) stated "Although Wharf Resources incurred substantial costs, it is a fraction of what would have been spent under the normal circumstances (and in one third of the time)."

L.F. Brown editorial note: This waste of time, money, and effort must be referred to as atrocity -- and, it is an atrocity to the environment. It is probably safe to say that the activities of performing $2+ million in studies caused more harm to the environment than the Annie Creek tailing itself. And, the $ billions spent to date on such projects as a result of Superfund have arguably caused more damage to the environment than the projects it has targeted for remediation. Something is drastically wrong with such a process. If helping the environment really is the goal, environmental organizations might consider lobbying to eliminate Superfund.

URAD RECLAMATION PROJECT

The Urad Reclamation Project is discussed more thoroughly than other projects because it was the first large scale comprehensive reclamation project of its kind. Both authors have been intimately involved with the project from inception in 1974 to present and the vegetation and soils both have been monitored. Urad has been studied fairly extensively through the years and the things learned at Urad have been particularly informative.

History

Molybdenum became a high priority metal with the U.S. Government during World War I. The molybdenum orebody within Red Mountain, about 80 kilometers (50 miles) west of Denver, Colorado near the Continental Divide, was first developed and mined from 1914 to 1919 by the Primos Exploration Co. Later, the Urad Mine was worked intermittently by the Molybdenum Corporation of America during World War II. Climax Molybdenum Company (then a Division of AMAX Inc.) purchased the property in 1963 and put the mine back into production in 1967. The orebody was depleted and the mine closed in 1974 after processing about 12.7 million tonnes (14 million tons) of ore and producing 22 million Kg (48 million lbs) of molybdenum. The ore grade and processing efficiency resulted in the recovery of about 1.8 Kg per tonne (3.5 lbs per ton) of molybdenum.

Tailing produced in the milling process during World War I was deposited directly into Woods Creek. Most of the tailing was contained in a pond during the World War II period of production. There was no reclamation law in effect when Climax reopened the mine in 1967. Still, the company made a commitment to the local community to stabilize, revegetate, and reclaim disturbed areas at the end of mining.

Two tailing ponds, (totaling about 50 hectares or 125 acres) posed the most difficult reclamation problem when mining was completed in 1974 (Brown 1974). This was the first full-scale program to stabilize and reclaim tailing at a high elevation. Little was known about reclaiming sterile tailing at a 3,175 m (10,400 ft) elevation and with a frost free growing season of only about 20 days per year. There were no examples to follow, so the entire reclamation program was somewhat experimental.

Reuse of Waste Products

Three major waste products were used to reclaim the tailing:

- Development waste rock from the new Henderson Mine;
- Sewage sludge from the Denver metropolitan area; and,
- Wood chips from a sawmill in Fraser, Colorado.

The source of the Henderson Mine waste rock was 1,200 to 1,525 m (4,000 to 5,000 ft) underground where it was being excavated to develop access to the Henderson ore body. The granitic rock was a sterile growth medium that would require addition of organic matter and nutrients to create a plant growth medium. The Urad reclamation project utilized 1.4 million tonnes (1.5 million tons) of waste rock, 3,800 tonnes (4,200 tons) of sewage sludge (dry weight), and 18,350 cubic meters (24,000 cubic yards) of wood chips to provide a surface material suitable for plant growth.

Adding these amendments resulted in an increase in organic matter, nitrogen, and phosphorus, all essential for plant growth and development. The effort was quite successful, and the project resulted in Climax Molybdenum Company receiving the 1981 National Environmental Industry Award from the Presidents' Council on Environmental Quality.

Bare Tailing or Waste Rock

The first and most important decision in the reclamation plan was whether to attempt revegetation of the bare tailing or to cover the tailing with rock and revegetate the rock. Both rock and tailing were initially sterile, but rock offered several advantages over tailing as a plant growth medium. Waste rock provided a capillary barrier to potential migration of acids or salts from the tailing. The rock eliminated wind and water erosion, thus stabilizing the tailing and eliminating drifting and sand sheer of vegetation by tailing. Rock also provided a rooting zone for tap roots of trees and shrubs. Darker colored waste rock absorbed more heat and maintained higher surface temperatures than the white colored tailing. The rock material also acted as a mulch, reducing water loss from the surface.

The rock was available from the Henderson Mine, and stabilizing the Urad tailing with rock was deemed the best approach. In addition to the above characteristics, using waste rock for tailing reclamation provided the added benefit of eliminating the rock as a reclamation liability at the Henderson Mine site.

Wood chips mixed into the surface provided additional mulch, organic matter, and storage for some of the excess nitrogen from the sewage sludge for future plant use. The added sewage sludge provided the necessary nutrients and more organic matter to form the complete waste growth medium. Because of the high C:N ratio of this organic matter, additional ammonium nitrate fertilizer was projected to be necessary for some years, but has been applied only twice in the 21 years since inception of the project.

Monitoring Objectives

The waste rock growth medium, heavy metal uptake by the plants, and vegetation characteristics on the tailing ponds at the Urad Mine have all been monitored through the years. The objective in monitoring the waste rock was to determine to what extent chemical constituents of this plant growth medium had been modified as a result of additions of sewage sludge, wood chips, inorganic fertilizers, and vegetation; to follow waste material development into a soil; and to observe trends that might cause the revegetation effort to fail in the long term. The objective in monitoring heavy metal uptake by the plants was early detection of potential vegetation and animal toxicities. The objective in monitoring vegetation characteristics was to quantify the development of the plant community, as related to soil development and metal uptake, and included quantifying the rate of plant invasion from the surrounding area.

Waste rock used in reclamation of the Urad tailing was expected to be high in molybdenum (Mo) and some other metals, as some of this waste material came from the orebody itself. High concentrations of Mo in plants can cause molybdenosis in ruminants and may cause molybdenum toxicity in plants (Dye and O'Harra 1959). Forage with molybdenum levels as low as 5 ppm have been reported to cause molybdenosis in cattle. Generally, forage containing concentrations greater than 10 ppm Mo are considered toxic to cattle. Availability of Mo to plants is highly correlated with soil pH. Under the slightly basic conditions of the plant growth medium covering the Urad tailing reclamation areas, molybdenum solubility and uptake by plants could be appreciable. Since deer and elk sometimes utilize forage on the tailing reclamation areas, molybdenosis or other toxic chemical constituents could potentially become a problem to these ruminants. For these reasons, a study was initiated to determine if certain toxic compounds, elements, and heavy metals were being concentrated in vegetation established on the waste rock growth medium covering the Urad tailing. It was also possible to determine whether older plants with deeper root systems were concentrating more toxic constituents than were younger plants.

AMAX Inc. had a significant amount of high elevation reclamation to conduct in the future and it was important for the Company to know whether seeded species at Urad were increasing, decreasing, or simply maintaining themselves in stands. It is probable that introduced species will eventually be replaced with invading or planted native species on reclaimed areas. Therefore, species composition, cover, diversity, and production on various reclaimed areas as related to length of time since seeding were studied. This information was compared with data from a nearby native community to establish successional trends within the stands.

Soil trends and heavy metal uptake by vegetation are reported elsewhere (Trlica and Brown 1992). We will concentrate on characteristics of the plant community through time in this paper.

Methods and Procedures

The two tailing ponds were covered with the waste mine rock from 1974 through 1978. The rock was spread 0.9 m (3 ft) deep on the surface and 1.5 to 6.1 m (5 to 20 ft) on the dam faces. Small hills were created with the rock to break the flat contour of the surface for purposes of aesthetics, provide wind breaks for vegetation, and for avalanche protection for the road. Forty-five tonnes per hectare (20 tons per acre) of wood chips (dry weight) and 67 tonnes per hectare (30 tons per acre) of sewage sludge (dry weights) were then applied and mixed (by ripping) into the rock surface with a crawler tractor. Dead timber was also spread onto the surface for additional wind protection. Reclamation efforts followed the preparation of the plant growth medium with successive areas being seeded from 1975 through 1979.

The tailing areas were seeded with a mixture of grass and forb species at a density of 56 Kg per hectare (50 lbs per acre). The seed mixture included smooth bromegrass *(Bromus inermis)*, timothy *(Phleum pratense)*, meadow foxtail *(Alopecurus pratensis)*, creeping foxtail *(Alopecurus arundinaceus)*, orchard grass *(Dactylis glomerata)*, red top *(Agrostis alba)*, red fescue *(Festuca rubra)*, hard fescue *(Festuca ovina)*, Kentucky bluegrass *(Poa pratensis)*, cicer milkvetch *(Astragalus cicer)*, white clover *(Trifolium repens)*, and an annual ryegrass *(Secale cereale)*. Only one of the species (hard fescue) was native to the area. Native species would have received greater emphasis, however commercial quantities of seed of other native high altitude species were unavailable in the late 1970's.

Seeded areas were irrigated during the first growing season to ensure good germination and plant establishment. The areas were hand planted with trees and shrubs the second year. Approximately 40,000 seedlings were planted through the years. Seedlings of Engelmann spruce *(Picea engelmannii)*, lodgepole pine *(Pinus contorta)*, bristlecone pine *(Pinus aristata)*, limber pine *(Pinus flexilis)*, subalpine fir *(Pseudotsuga menziesii)*, aspen *(Populus tremuloidies)*, and willows *(Salix spp.)*, all of which are native to the area, were planted on the tailing ponds. Survival of tree seedlings was poor the first season, primarily because high winter winds resulted in ice abrasion and desiccation of exposed foliage and buds in this open and harsh environment. If a seedling survived the first winter, it generally was established well enough to continue to survive. However, tree seedlings in this environment only maintain themselves for 15 to 20 years before putting on much height growth. Even then, the growth rate is very slow.

Vegetation Sampling:

Data collected for vegetation on reclaimed and control areas included species composition, frequency, cover, and production. Sampling was done using two different methodologies. A 0.1-m^2 rectangular quadrat (Daubenmire, 1959) was used to sample composition, cover, frequency and production. Individual species encountered within 50 quadrats in each of two replications per stand were recorded, cover and production estimated, and 10 percent of the quadrats were randomly chosen and clipped to determine actual production. This double sampling procedure (Pechanec and Pickford, 1937) for estimating production was employed to determine total community standing crop. The U.S. Forest Service paced transect technique (Range Analysis Handbook, 1979) was used as another measure of species composition and frequency of occurrence over larger areas of the stands. The 0.1-m^2 quadrats were used within 10x10-m plots on the reclaimed tailing ponds, whereas paced transects covered more total area of these stands.

Vegetation on segments of the Urad tailing ponds seeded in 1975, 1976, and 1977 were all sampled in 1979, 1985, and 1992. In addition to reclaimed tailing ponds, the vegetation on a south-facing road cut near the Henderson Mine office building that had been seeded in 1972 was sampled. A native community in a circa 1879 burned-over area above the Urad tailing ponds was also sampled as a control to compare vegetation of a native community with that on reclaimed sites.

Data Analysis:

Data for the vegetation sampling were analyzed using standard analysis of variance and t-test techniques (Steel and Torrie, 1980). When significant differences ($p < 0.05$) were detected among variables or years of seeding, Newman-Keul's Range Test was used to separate these differences. Some data were not appropriate for statistical analyses (frequency and diversity), but were summarized and means calculated.

Results and Discussion

Aerial Cover:

Aerial cover for grasses and forbs of each stand was sampled using a slight modification of the Daubenmire (1959) technique. Total cover on tailing ponds exceeded that of the control and roadcut areas in 1979 and 1985, but cover of the control area exceeded that of all reclaimed areas in 1992. This was probably caused by the increase in forb cover in 1992 in the control area, with little change occurring on reclaimed areas.

The summer of 1992 was excellent for wild flowers in the Rocky Mountains because there was no extended period of drought. The control appears to have reacted more positively to the continuous moisture than did the reclaimed areas. Forbs were more prevalent on the control in both 1979 and 1985 than on any of the seeded stands. In 1985, forb cover was less than 2 percent on all tailing reclaimed areas compared with more than 13 percent on the control area. Forb cover was greater on the control than on reclaimed areas during each sample year. In addition, visual observation of the vegetation and analyses of the growth medium both indicated that vegetation on the ponds was suffering from nitrogen deficiency. The tailing ponds were fertilized with ammonium nitrate at 112 Kg per hectare (100 pounds per acre) of 33-0-0 during the summer of 1992. This was only the second time the ponds had been maintenance fertilized since inception.

Hard fescue *(Festuca ovina)* was the only seeded species common to both seeded stands and the control. Of the various areas sampled, total cover of hard fescue on the tailing remained fairly constant between 1979 and 1985 and increased by 1992 . Cover of this species declined between 1979 and 1985 on the roadcut, but then showed a small increase in 1992. Cover of fescue was low and constant through time in the control. The taller introduced grass, smooth bromegrass *(Bromus inermis)* declined through time on all reclaimed areas. The greatest rate of decline was between 1979 and 1985.

Smooth bromegrass, hard fescue, and timothy *(Phleum pratense)* dominated the cover of the seeded areas in 1979 and 1985. There was always a concern that the tall introduced species would continue to dominate. Some hypothesized that the taller grasses would eventually shade out the shorter stature species, such as hard fescue. This could cause the shorter stature species to decrease in importance and, theoretically, might lead to a situation similar to that of intensively managed mesic meadows or irrigated pastures. Conversely, it might be hypothesized that withholding nitrogen fertilizer would allow for better expression of shorter stature species.

The latter hypothesis appears to be correct. Hard fescue increased in cover between 1979 and 1992 on the seeded areas, probably because supplemental nitrogen was not applied between 1979 and 1992. By 1992, the tall introduced species had decreased leaving the tailing reclamation area dominated by the native hard fescue. However, this has resulted in reduced total cover on tailing ponds.

Production:

The seeded Urad tailing ponds and the road cut area have consistently produced significantly more aboveground biomass than the control. Production on the reclaimed tailing ponds was much greater than for the control area in all three years of sampling. In general, there was an increase in production on the tailing reclamation area between 1979 and 1985 even though vegetation cover declined somewhat. Production on the tailing ponds and road cut area was similar to that of shortgrass prairie in 1985; whereas, production of the control area was more like that of a desert grassland or sagebrush-grassland type (Sims, Singh, and Lauenroth 1978).

Production at all three sites increased from 1979 to 1985 and decreased from 1985 to 1992. The reason for this trend was the decrease (die back) of the introduced species on reclaimed areas and differences in weather. The reason the introduced species decreased was that the relative nitrogen requirement of introduced species is greater than that for native species. Production of the native grass species has increasing with time, but that increase will never equal the high production initially exhibited by the introduced species.

Frequency of Occurrence:

Using the U.S. Forest Service pace transect method (Range Analysis Handbook, 1979), rock and litter were frequently encountered on the reclaimed tailings during the 1985 and 1992 sampling years. Bare soil and moss cover were not encountered on transects in these seeded stands in 1979. Moss was encountered on seeded areas by 1985 and increased through 1992. Litter encountered in 1979 was not as evident during the 1985 and 1992 samplings, as the wood chips were decomposing.

With an increase of occurrence of vascular plants and moss in 1985 on seeded areas, there was a corresponding decrease in the occurrence of rock on the surface. The amount of erosion pavement and bare soil did not vary greatly between 1979 and 1985. The pattern of frequency of occurrence of plants on seeded areas compared much more favorably with that of the 1879 burned area (control) by 1985, indicating that seeded areas had definitely improved between 1979 and 1985. Frequency of occurrence of plants decreased somewhat from 1985 to 1992 on all sites.

Diversity:

Species diversity was estimated by recording invading species occurrence along transects through the study areas. Species that were planted at each particular site were not included in diversity determinations. When the planted species were excluded from the analysis, the data indicated that the burn area (control) was the most diverse community. Twenty-six species occurred along transects through this community in 1979, and 30 species were recorded in 1985. The Urad tailing ponds seeded in 1975 had 19 invading species in 1979 and was thus slightly less diverse than the control, and frequency of occurrence of these species was low. Species diversity of other stands was low, but increased between 1979 and 1985. No invasion of stands seeded in 1977 was noted in 1979. By 1985, however, 15 species had invaded the 1977 seeded area. Some of these species might be considered by some to be weeds.

These data indicated that invasion was fairly rapid within five years of seeding and that improvement continued through 1985 and 1992. It will be interesting to determine whether the invading species increase in cover and production in the future, as their importance was still fairly low in 1992. If both invading and planted species are considered, then diversity of reclaimed areas has consistently exceeded that of the control in every year.

Costs

The following table shows the approximate breakdown of the reclamation, revegetation, and closure costs for the Urad Mine:

Item	$ (millions)
Rock Haul	$2.2
Flood Control	$2.9
Structure Salvage	($0.3)
Revegetation	$0.5
Taxes, mgmt, etc.	$0.9
Reclamation	$6.2
Post 1980 costs (est)	$1.0
Closure to date	$7.2

The total acreage reclaimed was about 95 hectares (234 acres), plus about 24 kilometers (15 miles) of road. Therefore, the overall average reclamation cost was about $62,000 per hectare ($25,000 per acre). However, most of the money was expended on the 125 acres of tailing, providing a value in the range of $111,000 to $124,000 per hectare ($45,000 to $50,000 per acre) to reclaim the tailing. The average cost for revegetating the tailing was about $5,200 per hectare ($2,100 per acre) in mid-1970's dollars.

Closure costs have been ongoing since 1980. The property has required maintenance; the Urad portal was plugged; a water treatment plant has recently been constructed; and, water treatment will continue indefinitely. Therefore, the closure costs of the mine are greater than the reclamation costs, and continuously increasing.

SUMMARY AND CONCLUSIONS

As with the paper, there are general conclusions and summary comments regarding the Urad Project.

Generalizations

Bare tailing can be reclaimed, or tailing can be covered and the cover material revegetated. Reclamation of tailing ponds at high elevations is usually much more difficult than reclaiming similar ponds at lower elevations, mainly because of the restrictions presented by the severe climate and short growing season. There are, however, some advantages to working at high altitude / latitude. Equipment access onto unstable or wet pond surfaces is often a problem. At high altitudes, the tailing freezes during winter months which allows heavy equipment to work the surface with little or no problem. And, an advantage of revegetating at the very high elevations is that weed control usually is not necessary because most "weeds" are not adapted to this environment.

Introduced species may have difficulty maintaining vigor over long time periods at high elevations because they may require more nitrogen than is commonly available in cold climates with thin and rocky soils and slow mineralization rates. Therefore, the use of native species appears to be more important at high elevations than at low elevations. More high elevation native species can and should be included in seed mixes today because high elevation natives are now commercially available. Tree seedling survival is low and the survivors can take as long as 15 to 20 years to initiate "significant" growth.

The costs of tailing reclamation / closure / remediation can vary by a factor of about 2,500; from as low as $2,000 per acre to as high of $5,000,000 per acre. Superfund status adds another dimension to the costs. It is safe to say that none of the mines with extraordinarily high closure / remediation costs ever produced those amounts of profit.

Urad Summary and Conclusions

Covering the tailing with waste rock and improving that growth medium with sewage sludge and wood chip amendments has been very effective. Wind and water erosion of tailing has been essentially eliminated. Seeded grasses are well established and produce more forage than in a nearby burned-over spruce-fir community. Cover of vegetation on reclaimed tailing often equaled or exceeded that of the native plant community.

Vegetation on the tailing ponds and road cuts is more diverse than naturally occurring communities, if the planted species are included in the analysis. Reclaimed areas have matured from domination by introduced species to domination by a native species. Forbs continue to occur infrequently, but are increasing. Species diversity has increased with time since the areas were seeded in 1974-1979. Invasion of the seeded stands by native species is occurring and diversity may be expected to continue to increase with time. However, diversity of the nearby undisturbed area in this habitat is not high. Fertilization with inorganic nitrate fertilizer should be used, but used sparingly to prevent the tall introduced grasses from regaining dominance and competing with native invading species. For a more thorough discussion of Urad reclamation data, please refer to the paper by Trlica and Brown (1992).

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ACCURATE ARD PREDICTION: THE IMPORTANCE OF GEOLOGICAL DATA INTEGRATION

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ABSTRACT

Traditional methods of predicting ARD (i.e. static and kinetic testing) provide important information, but they do not require any geological data from the mineral occurrence being tested. Although at first this may appear to be an advantage, there are geological factors that can refine the prediction of ARD if integrated into the standard tests. Useful geological information includes host rock and alteration mineralogy, structural characteristics, textural relationships, relative proportions and spatial distribution of rock types, and relative order of mining.

Accurate knowledge of the host and alteration mineralogy provides data regarding the inherent acid generating and neutralizing capacity of the rocks, and is similar to data generated by traditional static tests. Mineralogical investigations also give some indication of the relative stability of sulfide minerals and the long-term neutralizing capacity that may be contributed by minerals other than carbonate. Since textural information describes the grain size, fabric and relationships between minerals, it can provide insights into how the rock will behave during weathering. Although geochemical computer modeling has been used to estimate acid generating potential through consideration of mineralogy and associated thermodynamic data, its major drawback lies in its inability to consider textural and structural relationships, which often play an important role in ARD generation.

INTRODUCTION

Acid rock drainage (ARD) is the most serious single environmental issue facing the metals and coal mining industries today. Most companies operating open pit metal and coal mines, and mines that dispose of mill tailings or waste rock on the surface, will have to determine the potential for ARD. The mine permitting process has become much more onerous, in part reflecting the regulatory mandate that there should be no long-term environmental impacts to water quality from ARD. Many state agencies require large reclamation bonds to ensure adequate monetary resources are available for control and treatment of ARD once the mine has closed. At least some of the mines that were permitted prior to the current regulatory climate would probably not have been developed if they recognized the financial commitments they would be forced to make to treat ARD issues at closure. Because of the large costs involved in treatment and control of ARD, mining companies and the regulatory community alike have strived for development of accurate methods for its prediction.

Static tests are commonly employed as a first step in ARD prediction. Static tests are so-called because they are not concerned with how such samples may behave over time. They simply represent a snapshot of the relationship between the acid generating and acid neutralizing potentials of a rock. The most common method of predicting potential for ARD in mining wastes today is the acid base accounting test (ABA; Sobek et al., 1978). This test was originally developed for coal mining waste in the late 1970's, although it was co-opted by the metal mining sector as an inexpensive way to satisfy the regulatory community regarding ARD potential. Perceived shortcomings of the ABA test led to the development of several other static test methods (Duncan and Bruynesteyn, 1979, among others), all of which have their proponents. Several studies have compared the various tests and discussed interpretation of the results (Lapakko, 1993; Callow et al., 1995). We in the mining industry have reached the point of sober reflection with ARD predictive testing. It is the goal of this paper to describe the importance of geological data in accurate prediction of ARD.

GENERATION OF ARD AND LIBERATION OF METALS

ARD is the result of the oxidative breakdown of sulfide minerals, which are common ore and gangue minerals in many metal and coal mines. Not all sulfide minerals produce acid when oxidized. Acid-producing dissolution reactions are those that involve minerals containing ferrous iron, or that are initiated by ferric iron from another source. Oxidation/reduction and hydrolysis reactions involving iron are the primary cause of ARD. Since pyrite (FeS_2) is the most common sulfide mineral, its dissolution is primarily responsible for ARD. Oxidation of pyrrhotite ($Fe_{1-x}S$), chalcopyrite ($CuFeS_2$), and sphalerite ((Zn,Fe)S), among others, can lead to ARD. Direct oxidative dissolution of galena (PbS) and molybdenite (MoS_2), among others, does not generate acid (Reaction 1).

$$PbS + 2O_2 \rightarrow Pb^{2+} + SO_4^{2-} \qquad (1)$$

galena + oxygen → lead + sulfate

Oxidation and dissolution of pyrite produces ARD by the following set of reactions (Stumm and Morgan, 1981):

$$FeS_{2(s)} + 3\frac{1}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \qquad (2)$$

pyrite + oxygen + water → ferrous iron + sulfate + acid (protons)

$$Fe^{2+} + \frac{1}{4}O_2 + H^+ \rightarrow Fe^{3+} + \frac{1}{2}H_2O \qquad (3)$$

ferrous iron + oxygen + acid (proton) → ferric iron + water

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \qquad (4)$$

ferric iron + water → ferric hydroxide + acid (protons)

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (5)$$

pyrite + ferric iron + water → ferrous iron + sulfate + acid (protons)

Direct oxidation of pyrite by oxygen (reaction 2) is a relatively slow process. At pH greater than three, ferric iron (Fe^{3+}) is insoluble, resulting in its hydrolysis and precipitation as ferric hydroxide, releasing additional acidity (reaction 4). When pH falls below three, Fe^{3+} is soluble, and can be recycled as a powerful oxidizing agent of pyrite (reaction 5). This oxidation reaction proceeds much more rapidly than reaction 2, and can proceed in the absence of free oxygen (Singer and Stumm, 1970). The acidity produced by oxidation of pyrite can dissolve other sulfide and silicate minerals, releasing their associated heavy metals, along with Al, Mn, etc.

Bacteriological interactions involving the species *Thiobacillus ferrooxidans* (*T. ferrooxidans*) also influence the rate of pyrite dissolution. The bacteria can act directly or indirectly to promote pyrite dissolution (Gökcay and Önerci, 1994; Evangelou, 1995).

Direct metabolic oxidation involves physical contact between pyrite and the bacterium. Indirect metabolic oxidation proceeds by conversion of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}), helping catalyze reaction (5). The effects of *T. ferrooxidans* are most pronounced when pH is between 2½ and 4½, although direct oxidation of sulfide minerals by *T. ferrooxidans* does not occur above pH=4. Estimates suggest rates of pyrite oxidation are increased by up to six orders of magnitude (10^6) in the presence of *T. ferrooxidans* (Singer and Stumm, 1970). It is difficult to arrest ARD once the process has begun and bacteriological communities have become established.

Acidity released through oxidative dissolution of sulfide minerals is a secondary impact of ARD. The primary threat to the environment arising from ARD is the metals (Cu, Pb, Zn, As, etc) that are released from accessory and trace sulfide minerals (chalcopyrite, galena, sphalerite, arsenopyrite, etc.) as they are attacked by acid and oxidized by ferric iron.

The most efficient neutralizers of ARD in the natural environment are carbonate minerals such as calcite ($CaCO_3$; reaction 6). Dissolution of calcite generally buffers pore water pH between 6½ and 7½ (Blowes and Ptacek, 1994). The relative kinetics of calcite and pyrite dissolution are such that calcite may be exhausted long before pyrite is consumed. Aluminosilicate minerals (plagioclase and potassium feldspars) may provide longer-term neutralizing capability when they undergo hydrolysis reactions (Walder et al., 1996), although research along these lines is in its infancy.

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^- \qquad (6)$$

calcite + acid (proton) → calcium + bicarbonate

MOBILITY, TRANSPORT AND ATTENUATION OF METALS IN ACIDIC DRAINAGE

Since metals and other contaminants in mine wastes are generally bound within the crystal lattices of minerals, the stability of those minerals under conditions of weathering determines the availability of the contaminants. As sulfide minerals like pyrite dissolve by the above reactions, metals are released to the immediate environment. Whether they migrate any distance from the source depends on several factors, including geology (mineralogy, texture, etc.) of the ore and surrounding rocks, climate, and the geological characteristics of the water course through which the water travels (Plumlee and Smith, 1995).

If the neutralizing capacity of the host rocks in the immediate vicinity is sufficient, acid produced by dissolution of sulfide minerals can be neutralized, reducing the likelihood that other minerals will be attacked. Knowledge of the mineralogy of the host rock will provide some indication of the short-term (carbonate) versus long-term (aluminosilicate) neutralizing capacity of the rocks. The way in which static test methods determine acid neutralizing potential (ANP) can lead to overestimation of the carbonate (short term) buffering capacity of the rock (Callow et al., 1995). The EPA ABA test uses hot HCl to determine ANP, but this can lead to dissolution of carbonate minerals like siderite ($FeCO_3$), which can increase the rate of pyrite oxidation when dissolved. Knowledge of rock mineralogy can be used to interpret static test results and anticipate where over- and underestimation may have occurred. Mineralogical data can also help in assessing kinetic factors, the relative contributions from short- and long-term acid neutralizers, and whether remedial measures should be taken to address concerns about availability of long-term neutralizers.

Climate is an important factor in determining the mobility of metals produced by sulfide oxidation. Not only is precipitation a prerequisite for generation of ARD, but the manner in which the precipitation occurs is important in determining how metal loading in the drainage will occur. If precipitation is constant throughout the year, it is likely that concentrations of metals in the resulting leachate will remain roughly constant over time. If precipitation is concentrated in one particular part of the year, while hot, arid conditions prevail during the remainder of the year, oxidation products of pyrite and other sulfide minerals will be stored in soluble metal salts and other secondary minerals. These can redissolve and be flushed from the system during high precipitation periods, leading to a pattern of high metal concentrations during the rainy season (Alpers et al., 1994; Plumlee et al., 1995). Metal *concentrations* can be lowered somewhat if dilution is significant, although the same *mass* of contaminants may still make its way through the system. Knowledge of which secondary minerals are forming in mine waste can lead to predictions about their solubility and the loading that can be expected based on different climatic situations.

Mobility of metal contaminants in mine waste systems can be controlled by attenuation processes, including precipitation and adsorption (Smith et al., 1994; Plumlee and Smith, 1995). Geological information regarding the water course through which the contaminated water flows is an important tool in evaluating the mobility and degree of attenuation of metals. If Pb, Zn and Cd contaminated waters draining a Mississippi Valley base metal sulfide deposit travel down a stream valley underlain by Paleozoic sedimentary rocks (including carbonate rocks and redbeds), it is likely that mobility of some metals will be affected by the elevated pH generated by dissolution of carbonate rocks (Leach et al., 1995). Since Zn, Cd and Pb do not experience significant attenuation until pH of the water is moderately alkaline, the degree of attenuation is a function of mineralogy and how they interact to buffer pH. Metals may attenuated through adsorption onto particles of iron oxide within the redbeds, or through co-precipitation with iron or aluminum oxides and/or hydroxides (Zhu et al., 1996).

Precipitation of secondary soluble salts can provide temporary storage for acidity and metals during arid conditions. When precipitation and flushing of the waste pile occurs, these salts are rapidly dissolved, released the stored contaminants (Alpers et al., 1994; Plumlee et al., 1995). Unless the nature of such secondary minerals is understood and prepared for, there could be unpleasant surprises during sudden rainfall events.

GEOLOGICAL FACTORS CONTROLLING THE RATE AND MANNER OF ROCK WEATHERING

There are several geological factors whose interplay helps determine the rate and manner in which rocks weather, including mineralogy, texture and structural characteristics of the rock. All too often these geological factors are ignored when predicting the potential for ARD.

Since different minerals have different stabilities, depending on their thermodynamic properties, mineralogy is an important factor controlling the rate of rock weathering rates. Although pyrite is the most abundant iron sulfide mineral, other species such as marcasite (orthorhombic FeS_2) and pyrrhotite ($Fe_{1-x}S$) are also common in some ores. Crystallographic differences are usually invoked to explain the stability of pyrite versus marcasite (e.g. Evangelou, 1995), although others indicate pyrite is less resistant to oxidation than marcasite (Brock et al., 1984) due at least in part to its stability at elevated temperature. The rate of pyrrhotite oxidation under ambient conditions is estimated to be two orders of magnitude greater than that pyrite (Nicholson and Scharer, 1994).

When two or more sulfide species are in contact in the presence of an electrolyte, galvanic cells can form, leading to preferential dissolution of one mineral over another (Kwong, 1995). The results of weathering in a galvanic cell situation may differ considerably from those anticipated on the basis of mineral stability alone.

The stability of silicate gangue minerals and the relative rate at which they break down is important when considering the potential contribution from acid neutralizers. As discussed earlier, the rate of carbonate mineral dissolution is greater than the rate at which sulfide minerals dissolve, meaning that a source of long-term neutralization is required to avoid acid generation. Silicate minerals that may be appropriate for this purpose include plagioclase and potassium feldspars, clinozoisite, magnesian chlorite minerals, and zeolites, among others. Although the familiar Bowen's reaction series was developed to explain crystallization from a magma, inversion of the mineral relationships essentially describes mineral stability during weathering (Figure 1). Knowledge of specific mineralogy will avoid choosing long-term neutralizers that can accelerate sulfide weathering or those that may contribute to the degradation of water quality (i.e. epidote proper, siderite, and other ferric iron-bearing minerals).

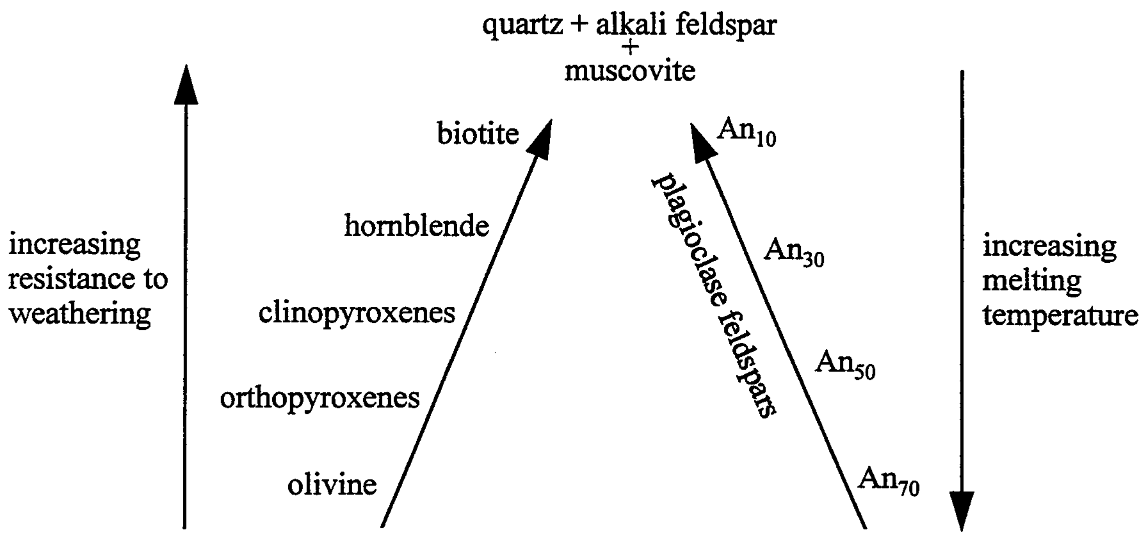

Figure 1. Inverted Bowen's reaction series emphasizing relative resistance of silicate minerals to weathering (after Klein and Hurlbut, 1985). The "An_{XX}" notation refers to the percentage of the anorthite molecule ($CaAl_2Si_2O_6$) in the plagioclase.

The micro- and macroscopic texture of a rock play a large role in determining how it will weather. Texture in this context refers to the form, grain size and physical interrelationships between the different minerals that make up a particular rock. Oxidation of pyrite appears to be surface controlled phenomenon (Singer and Stumm, 1970), and as such there are several instances in the literature where the form grain size of pyrite has been interpreted to exert a powerful influence on weathering behavior (e.g. Caruccio et al., 1977).

Physical interrelationships amongst minerals are also important. If pyrrhotite is located at grain boundaries in a layered mafic complex it is more likely to be available for weathering because of the relative instability of the mafic minerals that constitute the rock, the relative reactivity of pyrrhotite, and because pyrrhotite is located at structural weaknesses in the rock (grain boundaries). On the other hand, if a fine-grained, silicified limestone (jasperoid or similar) contains 2% fine-grained pyrite encapsulated within the silica, only pyrite on the surface will be available for oxidation. The resistance of quartz to mechanical and chemical erosion would inhibit further oxidation of pyrite. If pyrite were surrounded by calcite, any acid generation over the short term would probably be neutralized, until all carbonate buffering capacity had been exhausted. Of particular interest is the situation where fine-grained sulfide minerals are encapsulated by coarse grained aluminosilicate minerals (i.e. orthoclase). The rates of aluminosilicate dissolution are slow enough to effectively limit the amount of sulfide available for oxidation at any given time. Furthermore, hydrolysis of K-feldspar is an acid consuming reaction (reaction 7).

$$2KAlSi_3O_8 + 9H_2O + 2H^+ \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_4 + 2K^+ \qquad (7)$$

orthoclase + water + acid (protons) → kaolinite + silicic acid + potassium

The overall structural characteristics of a rock play a large role in determining the mineral interrelationships discussed above. Joint and fault planes represent planes of weakness that are the loci for hydrothermal mineral precipitation, particularly quartz, carbonate minerals and sulfides. The degree to which planar structures act as groundwater conduits or barriers to flow depends to a large extent on the mineralogy and texture of the rock material occupying the structure (Fetter, 1994). The presence of such structures invariably alters the normal groundwater flowpath, regardless of whether the structure behaves as a conduit or barrier.

The development metamorphic structures in regimes of elevated temperature and pressure can affect how a particular rock behaves during weathering. Metamorphic layering develops by dissolution and migration of silica, resulting in formation of alternating quartz-rich and sheet silicate-rich bands. The alignment of sheet silicate minerals makes the micaceous bands sites for preferential disintegration of the rock. Should sulfide minerals be sited within these bands, their surface area will substantially increase during rock disintegration, increasing the likelihood that ARD will be generated. A case study of ARD risk described a friable rock within a particular orebody that was assigned a higher ARD risk potential for just these reasons (Ferguson and Robertson, 1994).

APPROPRIATE USE OF GEOLOGICAL DATA DURING THE LIFE OF A MINE

Geological information useful in the prediction of ARD can be gathered at each step of a mine's life, from initial grassroots exploration to pre-feasibility, development, operations and closure. All too often such information is collected midway through the life of an orebody, when it may be difficult or impossible to modify the way mining and placement of waste is performed. This is at least partly a reflection of recent regulatory requirements and new advances in understanding the implications of ARD.

There is an increasing level of effort underway in economic geology circles to address environmental issues. Recent publications (du Bray, 1995; Plumlee and Logsdon, in press) present the geoenvironmental signatures of minerals deposits and discuss the environmental aspects of mineral exploration. Further refinement of the geoenvironmental mineral deposit models will make prediction of ARD more accurate.

Perhaps the earliest use of geological data comes when formulating a grassroots exploration program. In addition to making decisions regarding what commodity the exploration will focus on, what type of orebody and geological terrain to concentrate on, there should be a discussion of the general geoenvironmental signature of the ore deposit type being considered. The geoenvironmental signature would consist of the types and proportions of acid generating and acid neutralizing minerals present, the types and concentrations of contaminants that are typically produced in drainage from such orebodies, the regional geological setting characteristic of the orebody, etc. In this way there is a conscious decision made regarding the level of environmental risk you as an explorationist are willing to live with at the outset of the program.

As exploration progresses and information regarding the prospect becomes more abundant through mapping, sampling and drilling, the ARD generating potential of the ore and host rocks can be reassessed and compared to the model to determine if significant departures are present. Data pertaining to the ARD generating potential of each rock type can be compiled and plotted. At the pre-feasibility and feasibility stages the information collected during exploration can be used as part of the environmental impact statement in anticipation of applying for the necessary permits. Information pertaining to individual rock types can be integrated with static and kinetic testing as required by the regulatory authorities. Mine planning activities can use geological data to help refine the mining sequence and placement of waste. Continuing characterization can answer questions pertaining to the ARD potential posed by spent (leached) ore, etc.

Reevaluation and updating of the testing and geological databases should be performed periodically during the operating life of the mine to ensure the ARD potential continues to be managed in an effective manner. If proactive steps to measure and manage ARD are consistently taken during the life of the asset in preparation for closure, it is possible that the operation will be treated differently by the regulatory agencies than one who behaves irresponsibly. In any case, such measures are certainly best management practices. There are those who contend that these activities add significantly to the costs associated with exploration and development, although the cost is minuscule compared to those associated with long-term active water treatment after a mine has closed and no longer has the ability to generate cash flow.

There have been several attempts in recent years to predict the quality of leachate from waste rock and tailings using computer models. These studies fall into two categories: (1) new computer code developed specifically for prediction of ARD (Scharer et al., 1994; White and Jeffers, 1994), incorporating modules and equations specific to dissolution of sulfide minerals, and (2) those adapting existing code to fit situations involving ARD (Kaszuba et al., 1995). The ARD specific models often incorporate bacteriological effects and undergo calibration against real data to validate their assumptions. Studies using existing code do not generally consider the effects of bacteria, and by their nature are not calibrated. Although both types of models rely on mineralogy and underlying thermodynamic databases, their major drawback is in their failure to consider textural relationships and rock structure. The most accurate method of predicting ARD remains collection of samples in the field and careful interpretation of the results.

SUMMARY AND CONCLUSIONS

Traditional attempts to predict acid rock drainage (ARD) generally involve static and/or kinetic testing. Although these tests provide important information, they generally do not require any sort of geological information from the mineral occurrence being tested. Although at first glance this may appear to be a positive factor, there are many geological factors that can refine the prediction of ARD if integrated into the standard tests. Pertinent geological information that facilitates accurate prediction of the acid generating potential of rocks includes host rock mineralogy, alteration mineralogy, structural characteristics, textural relationships, relative proportions and spatial distribution of rock types and relative order of mining.

Accurate knowledge of the host and alteration mineralogy gives some indication of the inherent acid generating and neutralizing capacity of the rocks, and is similar to data generated by traditional static tests. Mineralogical investigations also give some indication of the long-term neutralizing capacity that may be provided by aluminosilicate minerals such as potassium feldspar. Static testing only considers short-term neutralization provided by carbonate minerals. Static and kinetic tests do not consider texture, and may misrepresent actual conditions, since crushing of samples may significantly alter textural relationships. The inability of static tests to accurately predict ARD is reflected by the differences in interpretation that can occur when static test data is presented. An understanding of sulfide mineralogy provides information regarding their relative stabilities and the source of trace and heavy metal contaminants.

Geochemical computer modeling has been used to estimate acid generating potential through consideration of mineralogy and associated thermodynamic data. Although this approach offers some advantages, its major drawback lies in its inability to consider textural and structural relationships, which often play an important role in ARD generation.

At least some of the blame for the persistence of one-dimensional waste characterization and inaccurate ARD prediction lies with industry. In many instances we have taken the path of least resistance with the regulatory authorities to obtain the necessary permits to operate. Rather than answer all our questions, we do just enough to satisfy the regulators and get by. This is a very short-sighted and potentially costly approach to an issue that could become an overwhelming liability for a company if it is improperly managed.

Accurate prediction of ARD boils down to an issue of risk management. Not only should we attempt to gain smooth regulatory approval through traditional approaches to ARD prediction, we should be more concerned with gathering as much data as possible so that we can make an informed decision regarding the potential for ARD and how best to manage any risk. Our major responsibility lies with protecting our *shareholders* against unnecessary financial liabilities that may occur in the future, particularly those occurrences that can be avoided or minimized through adoption of a more rigorous approach to ARD prediction.

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EFFECTS OF BACTERICIDES ON ACID MINE DRAINAGE AND REVEGETATION OF MINED LANDS

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ABSTRACT

Bacteria, predominantly *Thiobacillus ferrooxidans*, catalyze the oxidation of pyrite and other sulfides in mine soils to sulfuric acid that is leached out by infiltrating water and dissolves heavy metals and other toxins to form acid mine drainage. By inhibiting these bacteria, acid formation and therefore metal solubilization can be controlled and reduced by as much as 98%. Anionic surfactants are practical bactericides because they are relatively inexpensive, easy to use, selectively bactericidal and do not create an environmental problem of their own. The biogeochemistry of coal and non-coal materials is similar and treatability studies have confirmed the efficacy of bactericides for hard-rock mining. The longevity of bactericide treatment is increased by many orders of magnitude by controlled-release technologies. Bactericides control acid production in fresh materials and improve the effluent quality from weathered materials. Results from 1,000 sq m reclamation test plots on weathered coal refuse run from 1992 to 1994 show that, at the end of two years, the effluent from the bactericide treated plot had a pH of 7.2, acidity of 27 ppm and iron and other metals were negligible. Normally, water leaving the site had a pH of 3.2, acidity of 13,100 ppm, and iron of 2,490 ppm. At a 2 ha reclamation project, among other parameters, vegetation was monitored by comparing biomass from the treated and untreated sides over a 10 year period after a single treatment was applied in 1984. After 10 years, biomass from the bactericide treated side was more than 2 to 9 times greater than from the untreated side, which has large areas where vegetation no longer exists.

INTRODUCTION

The inhibition of *Thiobacillus ferrooxidans* bacteria can significantly reduce acid production from pyritic materials. Anionic surfactants, organic acids and food preservatives (Onysko et al. 1984) act as bactericides; however, bactericides biodegrade over time and are lost because of leaching and runoff. To overcome this short duration effectiveness of spray applications, controlled release systems to provide the bactericide slowly over a long time period were developed (Sobek et al. 1985). Control of acid generation for prolonged periods greatly enhances reclamation efforts and can be an economical alternative to large quantities of topsoil and lime that often do not work.

Bactericide application encourages three natural processes resulting from strong vegetative cover to continue to break the acid production cycle even after the bactericide is exhausted. These processes are: (1) a healthy root system competing with acid producing bacteria for both oxygen and moisture; (2) reestablished populations of beneficial heterotrophic soil bacteria and fungi forming organic acids that are inhibitory to *Thiobacillus ferrooxidans* (Tuttle et al. 1977); (3) plant root respiration and heterotrophic bacteria activity that increase CO_2 levels in the soil, resulting in an unfavorable microenvironment for growth of *Thiobacillus ferrooxidans*.

The beneficial effects of bactericides is illustrated here from two applications. The first is a reclamation test plot study run for two years. The second is the reclamation of an abandoned coal refuse site, reclaimed in 1984 by the Ohio Department of Natural Resources, which was monitored for the first five years and then revisited ten years after reclamation.

RECLAMATION TEST PLOT STUDY

A coal company in southern Ohio, has a 40 ha refuse disposal area that was started in 1974 and received both coarse and fine coal refuse and filter cake from the nearby preparation plant. The site was inactivated in 1989. Refuse samples from the site showed pyritic sulfur content of 1.5% and neutralization deficiency of 76.5 kg of $CaCO_3$ equivalent/1000 kg of material. The paste pH was 3.2, and the water discharging from the site was highly acidic (13,100 ppm) and rich in metals (iron at 2,490 ppm and aluminum at 109 ppm).

Prior to finalizing a reclamation plan for this site, the company decided to run two plot tests with the following objective in mind: To establish a treatment method that would minimize post reclamation acid production so that the need for any perpetual water treatment could be minimized or even eliminated.

The company elected to test two treatments; a limestone application treatment, and a bactericide treatment. Identical, side by side 1,000 sq m plots were made by first removing refuse to a depth of about 1.5 m. Two pan-lysimeters were installed at the bottom of each plot and the area backfilled with the same refuse. The limestone treatment consisted of crushed agricultural limestone was applied at the rate of 1,360 mt/ha as approximately a 10 cm layer on top of the refuse at a cost of $9,520/ha ($3,800/acre). The bactericide treatment consisted of a powder product and three forms of controlled release products. These were applied at the following rates at a cost of $7,000/ha ($2,800/acre).

Powder 88% active - 450 kg/ha	Pellets 16% active - 450 kg/ha
Pellets 20% active - 225 kg/ha	Pellets 28% active - 225 kg/ha

After backfilling with refuse, the plots were covered with a 45 cm soil cover. The soil was limed, fertilized, seeded and mulched using standard reclamation practices. The plots were completed in October 1992 and vegetation on both plots looked very good after two years. Results of water quality from the lysimeters after two years are shown in Table 1 and Figure 1. The bactericide treatment far outperformed the alkaline addition because limestone does not stop acid production and is unable to neutralize it should it become armored or if the reaction kinetics favor acid production over the rate of neutralization.

Table 1. Water quality from reclamation test plots after two years (in ppm except pH)

Sample	pH	Acidity	Sulfate	Iron	Mn
Limestone Treated	5.4	3,592	12,591	2,311	30
Bactericide Treated	7.2	27	5,680	2	0.4

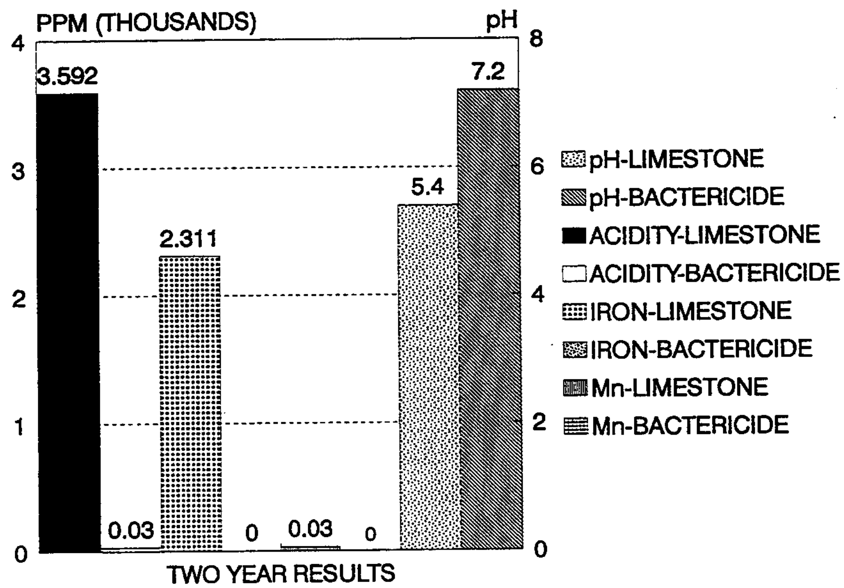

Figure 1. Water Quality results from reclamation test plots after two years.

TEN YEAR RESULTS FROM RECLAIMED SITE

The Rt.43 site in Southern Ohio is an abandoned coal refuse site last used in 1960. This site contains coal refuse to a depth of 15 m and was polluting streams and the nearby Wolf Creek with highly acid (1,034 ppm) and metal contaminated (iron at 72 ppm) run-off. Paste pH of the coal refuse was less than 3.0 across this site while 10:1, water:refuse extracts had pH values ranging from 2.5 to 3.5. A composite sample of refuse was analyzed for sulfur forms with the following results: pyritic sulfur=0.43%; sulfate sulfur=0.11%; organic sulfur=0.78%; total sulfur=1.32%.

Site Treatment

No amendments were added to the regraded refuse pile before bactericide was applied. One half of the site was left as a control plot while the other side was treated with bactericide (Figure 2). The treated side received a bactericide dosage of 225 kg/ha of 88% active bactericide powder made into a water based solution and 575 kg/ha of the first generation of controlled release bactericide formulations containing from 16% to 28% active ingredient that had a release life of 2 years. The bactericide application was made in a single step using a hydroseeder after the refuse had been graded, but before the soil cover was applied.

Both control and treated areas were covered with 15 to 20 cm of topsoil obtained from the same borrow area adjacent to the site. Using pan loaders, material was taken from the borrow area and dumped and spread in a left to right direction starting at the bottom of the slope across and up both areas at the same time. The topsoil was fertilized with 336 kg/ha of a 16-16-16 fertilizer and 6.9 mt/ha of lime. The area was seeded with 61.6 kg/ha of seed mixture followed by an application of 4.5 mt/ha of hay mulch.

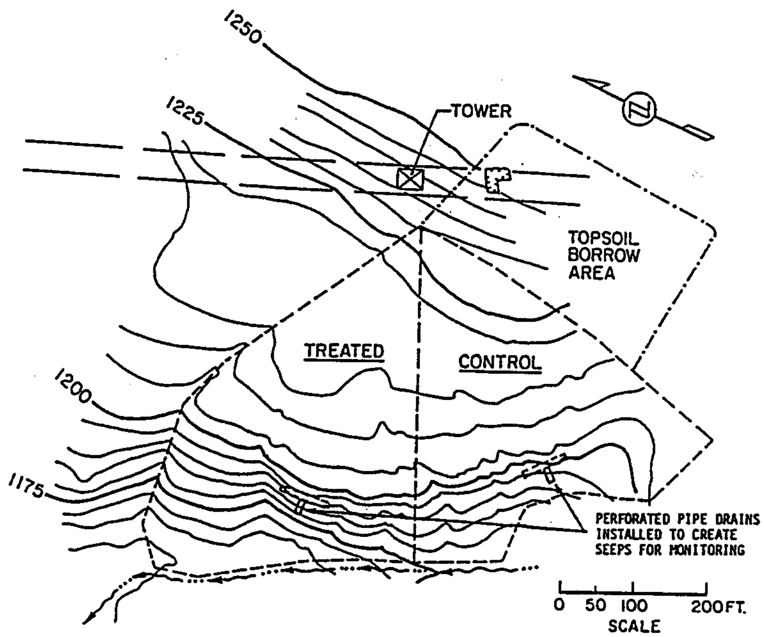

Figure 2. A sketch of the Rt. 43 site in southeast Ohio that was reclaimed as a demonstration site in 1984. The sketch shows the layout of the bactericide treated side and the untreated control side and the locations of the drains installed to create artificial seeps for monitoring.

Site Monitoring

The site was monitored from 1985-1989 for water quality, soil microbiology and vegetative biomass. Results of those analyses were previously reported (Sobek et al. 1990). Following the report of that data, monitoring was terminated at the end of 1989. In 1994 it was decided to revisit the site to conduct a ten-year evaluation.

In June 1994, photographic comparisons of the control and treated sides were made, and soil samples were collected to determine presence of heterotrophic and *Thiobacillus ferrooxidans* bacteria. Vegetation was collected to compare biomass production, and an attempt made to obtain water samples from two pipe drains originally installed to create artificial seeps for sampling. A slight trickle allowed for a water sample to be taken on the control side, however, no water was flowing on the treated side.

Observations

Within the first year after reclamation had been completed, it was evident that areas existed on both the control and treated sides that would have difficulty supporting vegetation. During the 1985-1989 monitoring period, vegetation was burning out in an expanding area on the control side. After 10 years, 35-40% of the area on the control side was barren, resulting in deep erosion gullies. On the treated side, one area (less than 10% of the treated side) had sparse to no vegetation, and no significant erosion had occurred.

In 1994, perforated PVC pipes that were used to create artificial seeps for water sampling exhibited a marked contrast in appearance. The pipe on the control side had no vegetation growing below the drain and the bottom of the interior of the pipe showed heavy red staining. The lack of vegetation and the stain were both indicative of iron rich ferruginous acid mine drainage that continued to occur after reclamation from the untreated-control side. The pipe on the treated side, however, was overgrown by vegetation and exhibited no staining. This indicated that no iron rich water had flowed from the treated side.

In addition to the grasses that were used to seed both sites, volunteer vegetation was also very evident on the treated side that had 1 to 1.5 m tall locusts and rhododendrons.

Microbiology

It has been found that specific classes of microorganisms are better presented as a ratio of the total population (Horowitz and Atlas, 1976). These bacteria will increase (or decrease) in number as a result of a total increase (or decrease) in the bacterial population. It is, therefore, important to examine the ratio of *Thiobacillus ferrooxidans* to heterotrophs for the bactericide treated and the untreated-control sides. These ratios, for the first five years and for 1994, are presented in Table 2. These data are the arithmetic means from five samples from each side chosen from random locations.

Two important observations can be made. First, the impact of bactericide treatment on change in the microbiology of the site continued to persist beyond the two-year life of the controlled release pellets. Second, that after ten years the *Thiobacillus ferrooxidans* bacteria count is very small on both sides. However, higher heterotrophic bacteria population on the treated side is a reflection of the better vegetation resulting from the bactericide treatment. The effect of bactericides was not short term. It is possible that the low populations of *Thiobacillus ferrooxidans* on both treated and control sides is due to the depletion of their food source (pyrite) over time.

Table 2. Ratio of *Thiobacillus ferrooxidans* to heterotrophic bacteria over ten years (in MPN/g of dry soil).

Side	1985	1986	1987	1988	1989	1994
Bactericide Treated	5 x E-2	3.5 x E-1	2.2 x E-1	2.5 x E-1	4.3 x E-1	1.4 x E-4
Untreated-Control	7 x E+1	1 x E+1	1 x E+3	1.2 x E+0	4.1 x E+1	2 x E-4

Water Quality

Table 3 shows water quality from the drains in 1989, five years after reclamation, as well as the sample that was obtained from the control site in June, 1994. At that time the bactericide treated side was not running and so no water sample was available. There is marked improvement in water quality from the treated side in comparison to the control side.

Table 3. Water quality from drains (in ppm except pH, and conductivity, which is in umhos).

Sample	pH	Conduct.	Acidity	Sulfate	Iron	Mn	Al
1989-Treated	5.9	590	19	100	0.2	0.3	0.5
1989-Control	2.6	2,910	844	2,040	104	6.1	38.7
1994-Control	3.4	851	112	9	16	1.6	9.3

Vegetative Ground Cover Evaluation

Table 4 shows the biomass data obtained in 1989, five years after reclamation and then again in 1994. Biomass results were obtained by harvesting three 1m x 1m plots on each side. The biomass collected was oven dried at 105^0 C until a constant mass was reached. Because of the large areas where no vegetation exists on the control side, biomass production is expressed in a range from 0 to the maximum measurable amount. There is tertiary volunteer vegetation on the treated side consisting of rhododendrons and locust trees.

Table 4. Comparison of biomass yield in kg/ha from the bactericide treated side and from the untreated-control side.

1989		1994	
Bactericide Treated Side	Untreated-control Side	Bactericide Treated Side	Untreated-control Side
2,915	0 to 315 max	4,118	0 to 1,895 max

It is difficult to discuss vegetation quality without photographs. Perhaps the best indication of effects of bactericide treatment at this site can be shown by observing the drains installed to create artificial seeps. Two important results would be observed. First, the quality of vegetation on the treated side is much better in terms of health and density over the life of the site. Second, the drain on the untreated-control side and the ground around it show staining from iron rich flow over the years, whereas the drain on the treated side shows no evidence of polluted effluent. Photographs of this site are available in the proceedings of the 1995 National Meeting of the Society for Surface Mining and Reclamation (Splittorf and Rastogi, 1995).

Discussion

What is evident in studying this site over a ten-year period is the importance of the reclamation plan in dealing with acid abatement. If the initial revegetation is not successful, serious site degradation will occur over time. The first few years are a critical period in determining the ultimate success or failure of a reclamation site. Although successful results were obtained at this site with first-generation 2-year pellets, third-generation, 6-year pellets are now in use.

The following conclusions are based upon field observations, and laboratory analyses:

1. Bactericides were an effective means of preventing acid drainage at this site.
2. The effect of bactericides thus far had lasted 10 years that is beyond the life span of the controlled release systems.
3. The use of bactericides encourages the development of heterotrophic bacteria populations and promotes strong, healthy vegetation.
4. The use of bactericides significantly improves water quality by preventing acid formation and the leaching of metals.

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RECLAMATION AND WATER QUALITY CHALLENGES
NEW WORLD MINE SITE - Cooke City, Montana

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ABSTRACT

Mining in the New World District began in the 1870's with most significant open pit activities occurring from the 1930's to the 1950's. Historic mine disturbances include both open pit and numerous small underground mines. Acid drainage from the area affects the headwaters of the Clarks Fork of the Yellowstone and the Stillwater Rivers. Crown Butte Mines, Inc. began exploration in the New World District near Cooke City, Montana in 1987 and made significant discoveries of gold and copper mineralization.

Crown Butte has begun reclamation of much of the historical mine disturbance and undertaken hydrologic studies to evaluate sources of acid drainage. Revegetation techniques developed by US Forest Service research over the last 20 years have been successful in re-establishing self sustaining alpine vegetation. However, similar solutions to the extensive acid drainage are not available. Substantial evidence of natural acid drainage that pre-dates any mining activities further complicates potential solutions to the water quality issues. In October 1995 a Federal District Court judge found that discharge permits are required for several of the historic mine disturbances.

Concurrent with Crown Butte's reclamation efforts on historic mines, the company has been trying to obtain permits to begin mining the newly discovered ore bodies. Baseline data collection for permitting began in 1989 and a permit application was submitted to the Montana Department of State Lands and the US Forest Service in 1990. This application was declared complete by Montana Department of State Lands in April 1993 officially beginning the joint state and federal Environmental Impact Statement. The Draft EIS is expected to be released in 1996. Significant issues involved in the analysis of the project are its closeness to Yellowstone National Park, water quality, tailings disposal, wetlands and potential impacts to grizzly bear.

INTRODUCTION

Crown Butte Mines, Inc. (Crown Butte), is a Montana corporation with offices in Missoula, Montana. Crown Butte is involved in the permitting and development of a proposed hard-rock underground gold mining project located north of Cooke City, Montana, in the historic New World Mining District. The company has invested approximately $40 million in the exploration, development, and permitting of this proposed operation since 1987, including considerable expenditures for reclamation of historic mining disturbances.

Mining and exploration activities began in the New World District in the early 1870's. Silver, lead and gold were mined and smelted on a small scale through the early part of this century. Although Cooke City was named after a railroad promoter, the line was never built. The remote location and high transportation costs limited development. The district is located about three miles from the northeast corner of Yellowstone National Park at an elevation of about 9,000 feet in an area of high snowfall. The McLaren mine operated from 1933 to 1953, when the mill burned; this open pit gold/copper mining operation is reported to have produced over 60,000 oz. of gold during this period. The New World District was excluded from the adjacent Absaroka-Beartooth Wilderness area in 1978 because of the extent of private land, past mining disturbance and the area's mineral potential.

After consolidating a land position in the New World District in the 1980's Crown Butte began an exploration program that lead to the discovery of significant gold and copper mineralization. Current minable reserves are estimated at 5.5 million tons grading 0.27 oz/t gold and 0.65% copper. Baseline data collection began in 1989 and a permit application was submitted to the US Forest Service and the Montana Department of State Lands in 1990. This application was declared complete by the State of Montana in April, 1993 officially beginning preparation of the joint state and federal Environmental Impact Statement (EIS). The Draft EIS is expected to be released in mid-1996.

The proposed mine is an underground operation that would produce approximately 1500 tons per day. The mill will recover the metals by a combination gravity separation and a two stage flotation process that does not require cyanide. Because the milling process does not use cyanide about 10% of existing geological reserves, which are oxide ore, will not be mined. Tailings will be used to backfill underground mine openings and the remainder (approximately 50%) will be disposed of in a surface tailings impoundment.

Total surface disturbance required for the mine, mill and tailings impoundment is about 200 acres. The proposed operation would have a life of approximately 10 to 12 years and would employ 175 people year-round with an annual payroll of 7 to 8 million dollars. There would be an additional economic impact of 8 to 10 million dollars in local purchases of goods and services.

Permitting requirements for the New World project involves three National Forests, the State of Montana and the State of Wyoming. Wyoming provides the principle access to the area, is the location of a new power line and is where many of the workers would live. In addition, the Bureau of Land Management, the US Corps of Engineers, the US Environmental Protection Agency and the National Park Service are involved with the EIS. The major permits required for the project include; an operating permit from the Montana Department of Environmental Quality (DEQ), a water discharge permit (MPDES permit) from Montana DEQ, an air quality permit from Montana DEQ, an operating permit from the US Forest Service, a 404 permit for placement of the tailings impoundment in wetlands and a decision from the US Fish and Wildlife Service relative to grizzly bears and other threatened or endangered species.

Crown Butte recognized the controversial nature of the proposed project from its inception, and has made substantial efforts to address the environmental concerns of this sensitive location. Crown Butte's proposal includes a non-cyanide process circuit, a mandatory work camp to reduce impacts to local communities and a commitment to capture and treat water from historic mining disturbances. Water treatment associated with the mining operation would be located in the headwaters of Fisher Creek. Additionally, Crown Butte has proposed to keep mining operation facilities out of drainages that flow towards Yellowstone Park and has abandoned plans to mine open pit reserves. A review of the proposed mining plan by the Montana Water Quality Bureau resulted in the conclusion that the mine would result in net water quality improvement. However, in spite of the economic and environmental benefits, opposition to the project has continued to grow.

RECLAMATION ACTIVITIES

Reclamation of historic mining disturbance in the New World District has been the subject of considerable study for the last twenty years. US Forest Service research on high elevation revegetation has resulted in development of techniques and seed mixtures that allow successful revegetation of acid material even though there is no soil available for the seed bed (Brown and

Johnston, 1976; Brown, Johnston and Chambers, 1984). Addition of lime to the acid material is essential to reestablishment of vegetation. Liming to a depth of two feet results in greater plant biomass than shallow liming (0.5 feet). However, plots with shallow lime addition, now 19 years old, show self-sustaining native vegetation communities and evidence of soil profile formation (Brown *et al.,* 1995). Fertilization, mulching and organic mater incorporation all provide significant benefits in establishment and growth of reclamation plant communities. Several native grasses, sedges and forbs adapted to climatic and acid soil conditions are key to successful revegetation of acid soils in the New World area.

In 1993 Crown Butte began reclamation of several historic mine disturbances building on the techniques developed by the USFS research. The McLaren and Como pit areas and the Glengarry Mine waste dump consist of sulfide rich materials that have resisted natural plant invasion for the last 50 to 80 years. Approximately 27 acres of historic disturbances at these three sites were regraded in the fall of 1993. The regraded area was limed, seeded, fertilized and selectively mulched in 1993 and 1994. Several acres were dedicated to additional research plots providing an extension of the USFS high elevation reclamation research program. In addition to the revegetation, a system of lined and rip-rapped drainage diversion ditches was installed to reduce run-on and control flows on the reclaimed areas.

Because of the difficult site conditions and highly acid coarse grained soil material, reclamation is difficult and expensive. Soil amendments include between 2 and 18 tons lime, 500 pounds of organic fertilizer (Biosol) and 10 tons sawdust/woodchips per acre. Lime and sawdust were worked into the soil with a chisel plow and/or the ripper tooth of a dozer; seed was broadcast and then dragged with a harrow or dozer tracked. Fertilizer was applied at the rate of 45 pounds of nitrogen per acre following germination. Cost of reclamation, including runoff control, averaged between $8,000 and $10,000 per acre. Additional work scheduled for 1995 was delayed by the US Corps of Engineers which required an individual 404 permit for additional reclamation activities, and then took over 18 months to act on the permit application. This additional work, including regrading of some remaining disturbed area within the McLaren Pit, construction of diversion channels and reclamation of historic mine waste dumps, is scheduled to recommence in 1996.

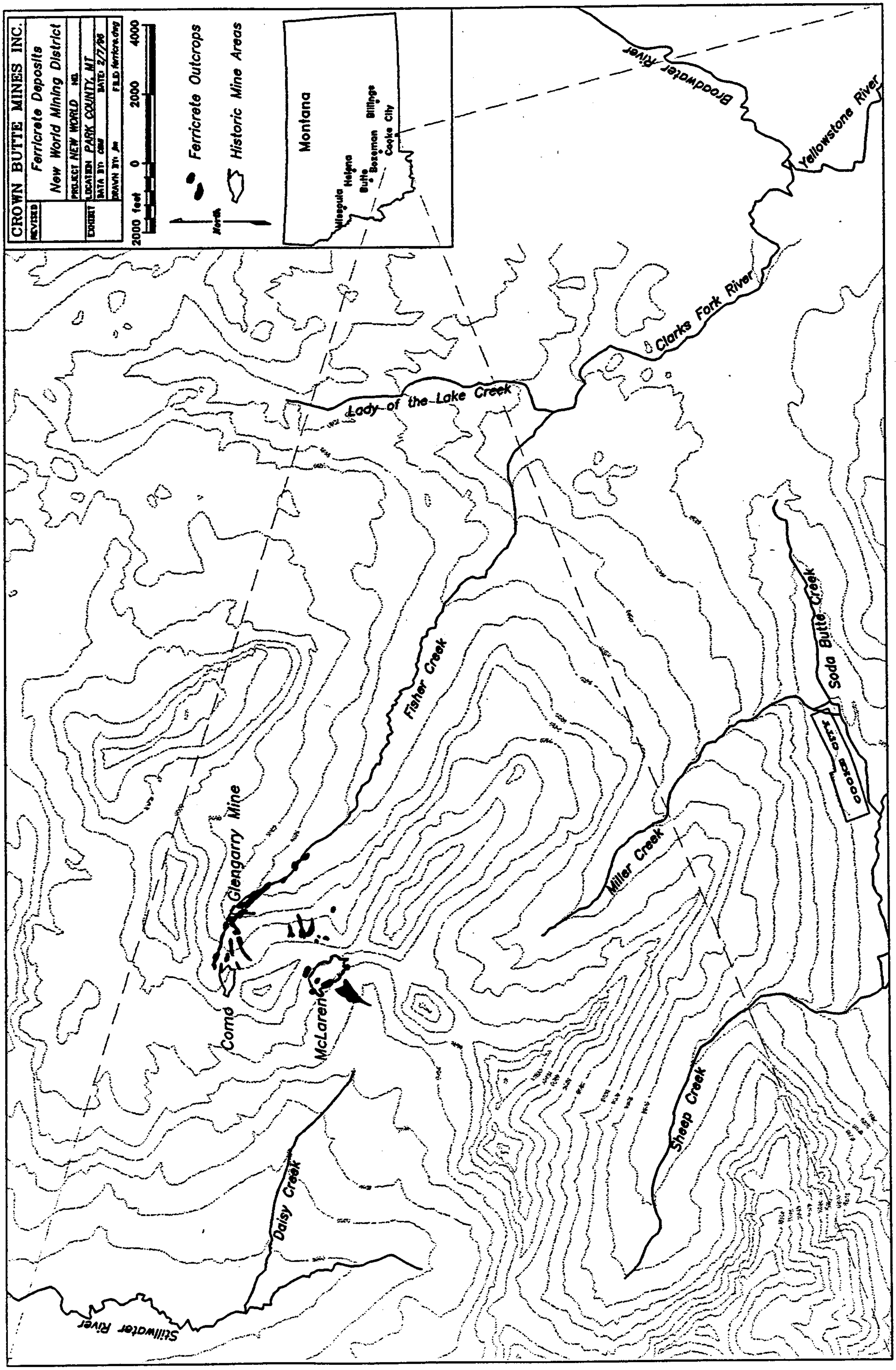
WATER QUALITY ISSUES

Although reclamation and revegetation techniques promise to return historic mine disturbances to surface conditions similar to pre-mining, the water quality impacts in the New World District appear to be a greater environmental challenge. Metal loads from headwater drainages in the New World District affect Fisher and Daisy Creeks to the extent that there are essentially no aquatic organisms or fish in the upper several miles of each of these streams. Acid drainage with pH values as low as 2.5 contains elevated levels of metals including copper, iron and zinc. As the acid waters mix with unaffected water, orange-colored metal oxide deposits precipitate and coat the stream beds. Copper, which is the primary metal of concern for fish, occurs in concentrations as high as 10 to 30 milligrams per liter (mg/l) in mineralized areas; copper levels remain above established aquatic life criteria for many miles downstream.

Significant evidence of natural acid drainage has been found in the New World area. The Glengarry Adit at the head of Fisher Creek discharges an average of some 50 gallons per minute of pH 3 water with copper concentrations in the 10 mg/l range. However, an adjacent drainage that has essentially no mining disturbance has recorded copper loads higher than the adit during snow melt runoff. Springs affected by mineralization in this unmined area have measured pH values as low as 3.5 and copper concentrations as high as 2 mg/l. Deposits of iron oxide below these acid springs and in the drainage bottom have been dated, from encapsulated wood, at between 1,670 and 8,620 years before present (Furniss; 1995, 1996). These iron oxide deposits, formed by cementing clastic alluvial or colluvial materials with precipitated iron oxide cement, are known as ferricrete.

The New World District is highly mineralized and the historic mining focused on extensive sulfide mineralization essentially exposed at the surface. Recent glaciation has exposed significant areas of mineralized rocks which has resulted in oxidation and natural acid drainage throughout the New World District. Acid drainage contributes metal loads to two headwaters drainages that leaves both of these streams (Fisher and Daisy Creeks) biologically dead for several miles downstream. However, the iron oxide deposits provide evidence of naturally elevated levels of metals in these streams over the last 8,620 years.

Ferricrete deposits are widespread in the New World District, with a mapped surface exposure of many acres in the mineralized areas of the Daisy Creek and Fisher Creek headwaters (Figure 1). Iron oxide deposits in the headwaters of Fisher Creek are as much as 20 feet thick in places. Geochemically these relict iron oxide deposits are essentially identical to the oxide precipitates presently forming downstream of acid discharges. The relict iron oxide deposits indicate that acid drainage has been occurring in the highly mineralized terrain of the New World District since shortly after the


CROWN BUTTE MINES INC.
Ferricrete Deposits
New World Mining District
PROJECT NEW WORLD
LOCATION PARK COUNTY, MT
DATED 2/7/96
2000 feet 0 2000 4000
North
Ferricrete Outcrops
Historic Mine Areas
Montana
Missoula
Helena
Butte
Bozeman
Billings
Cooke City
Broadwater River
Yellowstone River
Clarks Fork River
Lady of the Lake Creek
Fisher Creek
Soda Butte Creek
Miller Creek
Sheep Creek
Glengarry Mine
Como
McLaren
Daisy Creek
Stillwater River

retreat of the last alpine glaciers. The degree to which present acid drainage is the result of natural processes or has been influenced by mining activities has not yet been determined. Source areas for present day acid drainage are associated with intense sulfide mineralization that outcrops at or near the surface. Down gradient of these geologic deposits are the secondary iron oxide deposits indicating pre-mining acid drainage. Indeed, early reports of the District include reports of iron stained water and even secondary copper deposition (Lovering, 1929).

Regulatory Implications

The Clean Water Act and the Montana Water Quality Act require point source discharges to have permits. Until recently few , if any, historic or abandoned mining discharges had or have been required to have NPDES (National Pollution Discharge Elimination System) or equivalent state permits. Recent changes in policy, program emphasis, regulatory interpretation and legal interpretations have changed this picture. The US Environmental Protection Agency (EPA) has provided states with guidance that discharge from adits or seepage from historic mines is a point source and requires a discharge permit (USEPA, 1995). Adits, seeps, waste rock piles, pits, haul roads and tailings impoundments may be considered point sources from active mines and be required to have permits.

Crown Butte was sued by a consortium of environmental groups under the citizen suit provisions of the Clean Water Act alleging drainage from historic adits, seeps, springs, culverts, roads and waste piles in the New World Mining District are point sources which discharge pollutants and that a discharge permit is required for these sources. Crown Butte contested these allegations. In October 1995, a US District Court judge found that the McLaren and Como pits and the Glengarry Adit were point source discharges requiring a permit regardless of the fact that Crown Butte had applied for a stormwater permit in 1992. Crown Butte is currently attempting to appeal this ruling.

From Crown Butte's perspective one of the major difficulties with the requirement for obtaining discharge permits for waters from the historic mining disturbances is the misclassification of the area streams. Montana has classified these streams, including the acid drainage, as suitable for (among other things) bathing, swimming, recreation and the growth and propagation of salmonid fishes and associated aquatic life. The water quality standards for this classification include numeric levels for metals protective of trout and sensitive aquatic organisms. Even though these uses clearly have not been historically supported in these streams, Crown Butte would currently have to meet these standards under a Montana discharge permit. The numeric standard for copper is 0.003 mg/l. Treatment of acid water to meet these values may only be possible through sophisticated active water treatment such as neutralization/precipitation or ion exchange. Not only are these technologies expensive, but they require infrastructure such as power and access for constant maintenance that are not available at the New World site.

Reclamation and revegetation does not result in compliance with numeric water quality standards immediately, or even over a period of several years. In the New World District, where acid drainage has been occurring for thousands of years, source control and passive treatment techniques that could reduce metal loads seem to be the most reasonable approach to water quality improvements. However, the existing regulatory structure does not seem to be easily adapted to such an approach. The precedent set and policy implications of whatever solutions are implemented at New World will be of interest in relation to the thousands of existing abandoned, inactive and historic mine discharges elsewhere in the US.

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POTENTIAL THREATS TO YELLOWSTONE NATIONAL PARK BY THE NEW WORLD MINE PROPOSAL

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Over 120 years ago, men with an extra ordinary sense of vision and insight conceived the idea that natural wonders such as those found in Yellowstone should be protected in perpetuity for all generations to enjoy. Thus was established the National Park idea; an idea that has been called the best idea that America ever had! A uniquely American idea that has been embraced by over 100 nations worldwide. Just think of it, every national park and related preserve in the world owes its existence to Yellowstone National Park and the idea it represents. Yellowstone is truly the Mother Park of the world, and represents an international icon in land conservation.

The years since have proven the worth and wiseness of setting aside these superlative examples of naturalness, especially in the face of increasing human populations and the ever increasing competition for the world's finite resources. Ironically, the more successful the quest to preserve these resources, the more pressure there is to exploit these remaining resources, and the more important these special sanctuaries become as reminders of our natural heritage. Unfortunately, the areas surrounding Yellowstone are not immune to these exploitive activities and associated impacts. With each potential impact comes a direct threat to the core of the Greater Yellowstone Ecosystem, Yellowstone National Park. If not individual impacts, then certainly in a cumulative fashion. The National Park Service Organic Act of 1916 can be interpreted as empowering, indeed requiring, the National Park Service to address external operations threatening to impact resources inside its boundaries. It is no wonder, then, that the National Park Service fights so zealously to preserve and protect its parks and all that they mean for this and all future generations.

Even as large as Yellowstone is, managers have long known that if its integrity is to be kept sacrosanct, it must be done along ecological and geological boundaries rather than along political borders. Wildlife that have historically and traditionally migrated do so along ecological boundaries, not political borders; earthquakes care not where state lines end and national park boundaries begin; hot springs and their aquifers do not stop at park borders. And so, in Yellowstone's quest to protect the beating heart of the Greater Yellowstone Ecosystem, we must be concerned beyond political boundaries.

The proposed New World Mine is one of those many concerns. It is not the only concern, but coupled with others, places Yellowstone in danger. It is both fitting and proper that the park speaks out, with a strong voice, as to these concerns. The World Heritage Committee, an international group that examines similar situations all over the world agreed this past December that the proposed mine, in conjunction with other threats, does constitute real problems and voted to place the park in a "World Heritage In Danger" status. Under the World Heritage Convention, the "State Party,", (in this case the United States), has an obligation to "do all it can....to the utmost of its resources" to ensure the "protection" and "conservation" of areas designated as World Heritage Sites within the United States and to "endeavor, in so far as possible,...to take the appropriate legal, scientific, technical, administrative, and financial measures necessary for the...protection, (and) conservation...of this heritage." It is important to note that the duties under the World Heritage Convention rests with the United States, not solely with the National Park Service. The United States has the obligation to fulfill this international commitment.

The concerns of the proposed New World Mine development from Yellowstone's perspective are many. They include:

> The potential for the mine to affect water quality and quantity and related aquatic resources of the park.
>
> Increased occupation of habitat and the displacement and disturbance to the federally threatened grizzly bear and to other related wildlife.
>
> Loss of high elevation wetlands (the company's proposal entails the loss of over 80 acres of wetlands).
>
> Loss of scenic and recreational values adjacent to Yellowstone.
>
> Noise and light intrusion.
>
> Degradation of air quality and scenic vistas around Yellowstone.
>
> Socioeconomic changes to the gateway communities of Silver Gate and Cooke City that will directly affect Yellowstone.
>
> Cumulative effects of this development on what is presently the least-visited entrance of the park.

The threat of possible future contamination problems (Crown Butte has stated publicly that open pit mining and cyanide leaching are possible in the future).

The potential of future mine expansion toward the park (the Miller Creek ore body may extend further than has already been delineated, and much of that land may be open to claim location).

There has been much talk about "letting the EIS process work" then subsequently making a decision on the mine's proposal. This concept we fully support:

IF there is adequate data (and when there isn't, proper studies are arranged to obtain the necessary data)
IF there is full disclosure on the company's plan
IF there is a complete analysis of the alternatives and their impacts
IF reasonable and foreseeable actions are declared and discussed, and
IF the engineering and planning is not flawed,

The computer adage "garbage in and garbage out" has been very true in this process. Any agency charged with writing an EIS can "cook the books," so to speak. In an effort to rush the process, important concerns have been missed or glossed over. For example, if the USFS wasn't involved, the State of Montana, under the Hard Rock Mining Act, would have 365 days from the date the permit was judged complete to take public comment on the scope of the project, collect needed data, analyze data, draft the EIS, take public comment on the draft, and make a final decision to permit or not to permit! This time table is to be maintained regardless of the complications inherent in the lack of, and quality of data for the project. The Wolf Reintroduction EIS took 5 years! Does that sound like a process that attempts to ferret out all the facts and then skillfully analyze them to consider impacts to the resource? Unfortunately, the USFS appears to be on that same fast track because of political pressure generated by the parent company, Noranda, and the State of Montana, and it may explain their drive "to just get something out the door to relieve the pressure" attitude.

Let me take a few minutes and discuss a few of the problems we have in "letting the process work" with this EIS.

1. We have been reviewing the preliminary draft chapters. Unfortunately, in an effort to speed the process along, the lead agencies have chosen to send out the material chapter by chapter for review as they are written. The problem lies in the organization of the PDEIS, as the chapters are interdependent. Some chapters refer to other chapters that have not been written yet. Commenting on the PDEIS in a piecemeal fashion means comments may need to be modified when they are looked at in relation to the whole document at a later date. Reviewing a document in the "whole" avoids unnecessary duplication of time and effort.

2. Our comments on what we have seen to date have addressed many deficiencies. For example, the most controversial portion of the proposal is the tailings impoundment. The PDEIS **only** looks at the company's proposal despite the NEPA process that requires all alternatives get equal treatment in discussions and analyses. We know from company and agency comments that if the mine tailings were to be placed in one of the other locations, the design would have to be significantly different. Presumably the reason the lead agencies are looking at different locations for the tailings pile is to minimize environmental impacts. To date, the PDEIS doesn't even discuss the potential of those various alternative locations.

3. There is little or no discussion of potential effects due to the mine, the improved access, and the increased population on Yellowstone's infrastructure, the communities that rely on park visitors and people who value Yellowstone for its mere existence (we call that the non-use factor).

4. In the section outlining bonding of the project, there is no discussion of what the implications are for the American public, or if the bonds are sufficient to mitigate resource damage. Is Summitville such a hard lesson to learn? Apparently it is, for the State of Montana's lead person on the project in their Department of Environmental Quality, Mike DaSilva, spoke to the media on February 14 and stated that no bond was needed for the New World Project! His stated reason was "If it is reasonable to assume something could happen, we will bond for it." So by inference, the tailings pile will never fail and therefore there is no need to bond. I wish we could be that sure.

5. There is a total of five sentences devoted to the analysis of the social impacts of the proposed mine to people outside the two county area of Park County, Montana, and Park County, Wyoming. There is no discussion of the non-use values of the park to the people of the United States, and in fact, they are dismissed by the last of the five sentences by stating that people outside the two county area "need to be educated." For sure, non-use values are difficult to define, but they are there. What is it worth to know that Yellowstone is here and forever protected whether a person ever comes here or not?. Non-use values have been calculated for Grand Canyon use and the Wolf Reintroduction EIS, is this any less controversial and important?

6. This limited approach to impacts again comes to light in another section that states "Some effects of the proposed project could extend beyond the study area, but would be negligible and not significant." We believe this kind of statement demonstrates that an arbitrary determination was made to exclude from consideration any impacts of the project that have the potential to adversely affect the people of the United States. If impacts beyond the study area were in fact "negligible and not significant", would there be numerous environmental groups

with national constituencies interested in whether the project goes forward or not? Would we have had the President of the United States fly over the area and ask to be briefed on the situation if there was no national interest?

7. The United States and the State of Montana have entered into a Water Rights Compact establishing, among other things, protection of instream flows for streams that flow into Yellowstone and the hydrothermal system within Yellowstone. Yellowstone's water rights date from 1872 and are senior to most users in the area, including the States of Montana, Wyoming and Idaho. To protect instream flow rights within the park, the Montana Compact governs the use of surface water and ground water which is hydrologically connected to surface water outside the park and within the Soda Butte Creek basin. There is no discussion of injury to the water rights of the US in quantity, quality, or seasonality in the document. For example, we want to know what amount of groundwater under Henderson Mountain will be diverted because of mine operations to the Fisher Creek side that would have normally flowed into Miller Creek and into the park. What effect will the placement of any mine facilities have on surface water flow in any portion of the Soda Butte Creek basin?

8. In the wildlife section, grizzly bears are discussed but no other wildlife. Surely there are other wildlife concerns and impacts in the proposed area.

Yet another concern is the manner in which technological information has been handled. Technological Work Groups were formed to examine the available data, suggest how and what data remained to be collected, analyze the data once collected, draw conclusions from the data and make recommendations for the process. The Work Groups were slow in being formed by the Lead Agencies and in several cases the groups had never been formed, or those formed never met, by the date set by the Governor of the State of Montana for the release of the draft EIS! That alone gave us cause to wonder if the process is a serious attempt at writing a good EIS.

In fact, a very important work group, the Mineral and Mining Work Group, examined the engineering of the tailings impoundment and has since reported that the reroute of Fisher Creek (a diversion) that has been the mine's proposed location for the tailings, is basically flawed, and as engineered, will purely and simply not work. They state the gradients are insufficient to allow the system to flush itself and thus doomed to fail. And this from an engineering work group that includes subcontractors hired by Noranda.

The Summitville tailings impoundment was engineered to never present a problem. We are currently living with the McLaren Tailings, a pile of leaching toxins upstream from the park on Soda Butte Creek that represent only a 20th the size of the proposed New World tailings impoundment. Frankly, the nature of the "figure it out as you go" means of final design scares us.

I would like to conclude with a few thoughts which seem to me to make a very common sense argument concerning risks.

The engineering and stability of the project must withstand the tremors, earthquakes, and other seismic manifestations of the most active area in the Rocky Mountain region (it does not take a rocket scientist to realize that right next door to this proposed project site is one of the most thermally active areas in the world). For example, over the last July 4th weekend, over 4,000 tremors were recorded, some in the magnitude of 3.5. In 1959, the nearby Hebgen Earthquake killed a number of people when a mountain slid down and covered a campground. The vanity of engineering a dam nine stories high in front of a pile of rubble the size of 11 football fields in a seismically active area, and then to say it will be safe forever, amazes us!

Secondly, it seems to me that if there is a complicated technology involved, as there was in NASA's Challenger or Three Mile Island nuclear power plant, and **is in the New World mine and tailings design**, then common sense says there WILL be accidents sooner or later. There is no middle ground; if the facility is placed there, it is not a question of **if it fails**, but when! Accidents are statistically inevitable. Several small things happen at the same time, any one which on its own is not a problem, but in conjunction with other single, but seemingly innocuous problems, can spell a major catastrophe. Or perhaps a number of small accidents, each rather unimportant, over time does indeed lead to a major unavoidable catastrophe. So the Challenger blows up and it should never have happened! Three Mile Island has a melt down and it never should have happened!

I am reminded of a good friend that selected Army flight school when I selected the Army Chemical, Biological, and Radiological Corps for our required military obligation upon graduating from college. Some years later we were reminiscing about those Army experiences. He, unfortunately, was trained as a Mohawk aircraft pilot that flew the Ho Chin Min trail each night in Viet Nam with about a million dollars worth of infrared equipment. His mission was to gain intelligence of nightly movements that were used the next day in American bombing raids. Needless to say, he was not very popular with the enemy and therefore was a constant target. On several occasions he had heat seeking Sam missiles launched at his aircraft. The Mohawk aircraft is very powerful and highly maneuverable, but could not outfly the Sam missiles. The tactic employed to avoid being blown up was to perform a series of intricate maneuvers; twists and turns, if you will. The theory was that the Sam missile could not make the twists and turns and would loose the aircraft. Unfortunately, he had to wait until the Sam missile locked onto his aircraft and a red light came on in the cockpit signifying it had happened. In fact there were two lights in the cockpit that he became keenly aware of. The first came on when the Sam was launched, and the second when it had locked onto his aircraft. Only when the second light came on, and not before, was he to execute the intricate maneuvers that would mean survival. His concern on those occasions was always, what if the first light is burned out, or the second! Flying a multimillion dollar aircraft with another million dollars worth of equipment in its belly, things do happen, as was summed up on a t-shirt I once saw; "Scat Happens!" So, if the proposed mine is sited, we must be resigned to the fact that an accident will happen, and what if the warning lights don't go on or are burned out?

Many uncertainties still surround this proposal. This mine proposal is fraught with engineering complexities, many quite unresolved, and the odds are that in time, "scat **will** happen." We just do not see how the company can guarantee a plan to store and treat the tailings in a safe condition in perpetuity. This high level of uncertainty will eventually yield high negative impacts to the region. Tourism is an industry that is sustainable over the long term. Yellowstone is truly the goose that lays the golden egg for the region, and managed properly, will continue to do so forever. The mining project has a limited economic life of maybe 22 years. Mining is a boom or bust economy in the west, Yellowstone is set to celebrate its 125th birthday in 1997 on its way to forever. Which in the long run is best for the region? The basic question is, should the American people take the risk of allowing the mine to develop with very real impacts to the Greater Yellowstone area and the park? Even if the consequences are completely unknown at this time, should we even take the chance of initiating some irreversible action that will forever harm this international symbol?. As Superintendent Finley recently said "We are not going to trade short term economic gain for the long term quality of Yellowstone. " The mine's life is predicted to be up to 22 years, Yellowstone's life should be forever!

ECOLOGICAL RESTORATION OF ACIDIC MINE SPOILS AT HIGH ELEVATIONS: LONG-TERM SIGNIFICANCE OF REVEGETATION AND NATURAL SUCCESSION

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ABSTRACT

Revegetation research on the McLaren Mine near Cooke City, Montana was begun in 1972 to determine the relative effects of different techniques and methods on plant establishment and plant community development. The McLaren Mine is an abandoned gold-silver-copper mine that has been inactive since about 1953. The mine is located in the Beartooth Mountains at an elevation of about 9,800 ft. in a geologic intrusive complex of highly mineralized materials characterized by high concentrations of metal sulfides and acidic mine spoil. Plant colonization and succession on exposed minespoil has occurred only in a few locations where iron pyrite concentrations are minimal. Observations of these active successional sites revealed that only approximately 10 native grasses and forbs are sufficiently adapted to consistently complete their entire life-cycle on these spoils under natural conditions. Seeds of six native species were hand-collected and used in a seeding experiment in 1976 that also included use of various amendments (e.g., incorporation of lime, fertilizer, and organic matter, and a surface mulch of straw following seeding) to ameliorate limiting spoil conditions. Frequent assessment of revegetation results on the site since installation suggests that depletion of soil nutrients occurs rapidly following application, and that re-acidification can occur on small areas with high concentrations of pyrites. Further, the data show that initial fertilization at heavy rates of application may favor the establishment of a dense grass sward that excludes colonization of other native species over time. Results so far also suggest that re-fertilization, and possibly re-liming, may be required at infrequent intervals over the long-term to encourage natural nutrient cycling, soil building, and native plant community successional development. By 1995, 19 growing seasons following revegetation, colonization and succession have resulted in the natural establishment of over 40 native species on the site as a result of the various treatments applied, whereas adjacent untreated spoils continue to remain free of vegetation. Cover and biomass of the area track that of adjacent native communities, fluctuating with trends in climatic variables. Soil genesis of the revegetated spoil is active within the rooting zone, with significant organic matter accumulation and nutrient cycling evident in the upper 3-5 cm of the substrate.

INTRODUCTION

The ecological restoration of severely disturbed lands is one of the most critical challenges confronting land managers. Demands for natural resources by virtually all segments of society are accelerating throughout the western U.S., and are reflected by growing rates of disturbance. Impacts from growing human use are particularly evident in mountainous regions of the West where human activities such as mineral exploration, mining, road construction, recreation and construction of associated facilities, home and townsite expansion, and other activities are proliferating. Such activities can create severe disturbances that result in the loss of natural vegetation, soils, and parent materials, and may disrupt surface and subsurface hydrologic pathways. In addition to spiraling human impacts, natural disturbances from such phenomena as fire, seismic events, catastrophic climatic events, and others can result in equally severe disruptions of ecosystem structure and function.

Whether from human activities or natural events, in the most serious cases raw geologic rocks and debris containing toxic chemicals may be exposed at the surface, leaving behind materials bearing little resemblance to natural soil. Human activities such as mining often concentrate such materials in the form of spoils and tailings. Erosion by wind and water results in sediment transport, and may lead to contamination of adjacent downslope plant communities, streams, rivers, reservoirs, and riparian and aquatic ecosystems. Ultimately the integrity of vital watersheds, including such resources as water quality and quantity, wildlife habitat, aesthetic resources, and other environmental attributes may be threatened. The significance of these effects is intensified in regions such as the arid and semiarid West where human population density is accelerating.

Restoration is viewed here as the process of reestablishing the self-sustaining fundamental ecological mechanisms responsible for ecosystem stability that were disrupted or destroyed as the result of disturbance (e.g., see- Jackson et al. 1995; MacMahon and Jordan 1994). Further, we view natural succession as the primary "driver" or energy-source of restoration. Succession is considered here as the natural universal process of ecosystem genesis and development, and is responsible for the evolution, formation, and development of such ecosystem components as flora, fauna, microorganisms, soils, nutrient cycling, hydrologic properties, and other constituents, and their interactions.

The severity of some disturbances may be so great as to suspend or deflect successional processes and thus lead to apparent intensification of disturbance-effects. Under such conditions, the practices of revegetation and reclamation can be viewed as tools by which succession can be initiated, enhanced, and accelerated, and thus inaugurate restoration. This approach is viewed as "active" restoration, the process of intentional intervention where restoration is operatively undertaken to reverse the effects of disturbance. The converse, or "passive" restoration, is viewed here as the implementation of latent management policies designed to protect impacted sites from further abuse, and may involve site protection or withdrawal from use until mitigation occurs by natural (succession) processes. Unfortunately, such an approach is often adopted for economic reasons rather than ecological ones. We urge the more aggressive approach of active restoration of severe disturbances where accelerated erosion, sediment movement, and other problems are current.

In this paper we present evidence that the practices of revegetation and reclamation can be harnessed to initiate succession, and use data gathered from a mine site at high elevations in southern Montana as examples of this approach. Although the research summarized here relates to a specific location, we suggest that the principles discussed here are equally applicable to a broad range of conditions where severe disturbances have suspended or arrested succession.

THE ROLE OF REVEGETATION AND RECLAMATION

Typically, revegetation and reclamation techniques are applied on disturbed areas in order to ameliorate limiting conditions, or to alter existing conditions, to meet some predetermined state. For example, land recontouring and shaping, fertilizing, mulching, liming, organic matter incorporation, and similar methods are used to achieve a condition regarded as suitable for a desired perceived plant cover or condition. Numerous technological improvements have enhanced the effectiveness of some of these treatments in recent years, and generally these treatments are especially beneficial on extreme or severe disturbances. Local climatic conditions, soil.chemical and physical properties, and management objectives generally dictate required cultural practices and rates of application. Experience has shown that these techniques can be manipulated to modify disturbance conditions in order to meet many predetermined objectives.

One of the major limiting problems with traditional forms of revegetation remains plant species selection. Experience has shown that the initial species seeded or planted on disturbed sites significantly affects successional development over extended periods of time (e.g., Brown 1994). Traditional species selection criteria, in spite of other cultural methods used, are largely unsuitable for true ecosystem restoration of severe disturbances in the extreme environments typical of wildlands in the West. A major handicap to successful restoration can be traced to the traditional revegetation concept that the use of "adapted" plant species alone is sufficient to insure that "nature will take its course" and ultimately lead to site stability and recovery. This approach assumes that a plant cover composed of apparently adapted species, regardless of origin or ecological compatibility, will *a-priori* result in surface stability, and that stability will result in self-sustaining communities, soil building, and the eventual replacement of biological, chemical, and physical ecosystem components. Unfortunately, mounting evidence in numerous wildland western ecosystems illustrates that this approach can be unsuccessful either because unadapted and unsuited species were used, or because the use of highly competitive adapted introduced species led to the successional exclusion of native species. Results of this practice, even 20 to 80 years after revegetation, shows a dramatic loss in species diversity and altered successional trajectories in many regions.

The term "adapted" is widely misinterpreted to mean the ability to survive, grow, and reproduce in a given environment. Adaptability is typically a more rigorous physiological concept referring to heritable modifications in structures or processes that enhance the probability of survival, or the genetically defined ability of plants to adjust physiological tolerances to variability in environmental conditions (e.g., the ability of plants to modify their water relations characteristics to meet increasing water deficits during the growing season: Conrad 1983; Kramer 1980). It can be argued that many species, indigenous natives as well as introduced, have adaptations suited to a wide range of environments. Hence, it is not uncommon that many plant species are physiologically suited to environments widely distant from those in which they evolved (e.g., the use of *Agropyron cristatum*, an introduced species from eastern Europe, used for the revegetation of rangelands and highway rights-of-way throughout the western U.S.; Johnson 1986). A more appropriate term than adaptability for the capability of plant species to survive, grow, and reproduce in an environment may be "physiological fitness", an abstraction that integrates physiological tolerances and adaptations, ecological amplitude, and other attributes of plant longevity in a given environment.

Physiological adaptations alone may not be sufficiently sensitive indicators upon which to base plant species selection in all cases of revegetation, but especially not in cases where the intent is to re-establish natural succession that leads to the development of native communities. In wildland management, the major objective of revegetation and reclamation is the eventual recovery of a disturbance to a non-maintenance condition of self-sustainability where natural succession is the primary force controlling community and ecosystem function and structure. Use of otherwise adapted, but unsuited or ecologically incompatible introduced species may indeed result in a stable community that effectively secures a disturbed site, and thus minimizes erosion, but the physiological traits of such species may not be compatible with indigenous species or the successional forces that could lead to the development of native plant communities. Many vigorous and well-adapted introduced plant species are highly competitive with local native species, and thus may totally consume limited essential resources that effectively deflects successional trajectories away from progressive and compatible local community development. Thus, it may not be considered "wrong" in all cases to use some introduced species in revegetation, especially if the goal is to minimize erosion or improve forage production for grazing, but use of such species may be incompatible with returning a disturbance to a self-sustaining natural state. Clearly, the creation of alien communities composed of ecologically incompatible species cannot be considered successful restoration of a disturbed ecosystem if succession is deflected or suspended, even if soil stabilization is achieved.

A more pertinent issue in plant species selection for revegetation where the goal is to return disturbances to a natural state is to confine selections to those species that are most interactive and involved in natural succession. Part of the objective in revegetation under these conditions includes the initiation of natural succession, which can be viewed as the process that guides the development of natural plant communities, and hence the genesis of soils, nutrient cycling, and other attributes of compatibility with overall ecosystem form and function. Although many indigenous native successional species may be highly competitive and aggressive on disturbed sites, these species generally have evolved under pressures of natural selection in the local climatic environment and are thus compatible with the rest of the plant species and the interacting chemical and physical ingredients controlling local succession. Local climates and other environmental conditions are not static and change is universal. The local indigenous species appear to be most closely aligned with the local biotic and abiotic forces that impact native community development. We recommend, therefore, that species selections be guided by local observation and study of succession on disturbances (road cuts and fills, old mine sites, etc.) in the local area to be restored (e.g., Brown et al. 1978, 1988; Brown and Johnston 1979, 1980a; Chambers et al. 1984). Use of early- or later-seral species appears to have significant promise as a guide for species selection, and these species appear to integrate more suitably with local successional development than do most introduced species. We suggest that observations of active succession will be helpful in identifying those species that are ecologically compatible with long-term successional trajectories and overall ecosystem development, or those best suited for ecological restoration of disturbances.

STUDY SITE DESCRIPTION

Restoration research was begun on the McLaren Mine, a high elevation abandoned copper-gold-silver mine in southern Montana's Beartooth Mountains, in 1972. This mine is part of the so-called New World Mining District near the town of Cooke City, Montana, located at an elevation of about 2980 m (9800 ft). Mining endeavors at the McLaren Mine were abandoned in about 1952, leaving behind highly diverse mine spoil piles and other debris forming a hilly irregular and heterogeneous topography over the approximately 15 ha (35 ac) area. The over-all aspect of the mine faces variably south to west in the upper headwaters of the Stillwater River. The geologic materials exposed at the surface are composed of pyritic iron sulfides containing relatively high concentrations of metals such as copper, iron, and aluminum with pH ranging from about 2.5 to 3.5 in most areas, but in some localized areas pH was observed as high as about 6 to 7.

The area around the McLaren Mine is in the classic subalpine ecological zone, characterized by open subalpine-alpine meadows of forbs, sedges, and grasses, interspersed by finger-islands of *Pinus albicaulis* (whitebark pine) and *Abies lasiocarpa* (subalpine fir) perpendicular to the slopes. Steep topographic features strongly influence the distribution of native vegetation in the area which ranges from riparian and bog-like communities of sedges (*Carex spp.*) and willows (*Salix spp.*) along streambanks and on lower-slopes, forb-dominated communities largely confined to lower and mid-slopes with occasional tree islands, to cushion-plant and rock-scree communities along ridgelines above treeline near the crest of mountains. The total number of vascular plant species identified in the New World complex is about 100, although only about half that, or less, have been observed within any one particular plant community.

The climate of the New World District is generally considered to be harsh, and although not quantitatively verified, is suspected of being limiting in some cases to plant establishment and growth on severe disturbances. The climate is characterized by short growing seasons ranging in length from 45 to 60 days, although there are few true frost-free days at this location. Growing season temperatures are typical of subalpine-alpine environments, ranging from below 0°C (32°F) at night to as high as 20-25°C (68-77°F) on clear storm-free days. Growing season frost activity in the form of needle-ice is observed commonly, especially in early mornings with clear sky conditions following previous afternoon thunderstorms. Frequent afternoon thunderstorms visit the area throughout the growing season and tend to follow the generally westerly flow of air currents in that region, often accompanied by strong high winds. Obvious Krummholz "flag-trees" are common near treeline throughout the area on upper slopes and in passes along divides. Winter snow is the major form of total annual accumulated precipitation, often reaching depths of 3-5 m (10-15 ft). Total annual precipitation is variable, but may range from 1000-1500 mm (40-60 in) of water. Avalanche activity is common in some areas, and is conspicuously highlighted by "avalanche chutes" on the steeper slopes of some mountains.

RESEARCH METHODS

Two primary hypotheses were addressed in this research: 1) appropriate revegetation and reclamation techniques that initiate active succession can be applied to high elevation acidic mine spoils, and 2) active secondary succession can be enhanced or accelerated by application and/or re-applications of intensive treatments that will ultimately lead to the restoration of processes responsible for native community development. Although the research and results discussed here are specific to the New World study site, we anticipate that the general principles described have equal applicability to other similar environments throughout the northern Rocky Mountains of the western U.S.

In 1972 research was confined to the study of soil properties on the McLaren Mine, to surveys of native vegetation, and to initial research on plant succession on the acid mine spoils and other geologic materials in the area. Between 1972 and 1976 numerous small revegetation plots were established at various locations on the McLaren and other mine sites in the District to determine the cultural techniques and species mixtures best suited for revegetation in the area.

Based on the data and information learned from these early studies, a larger "Demonstration Area" was established on the McLaren Mine in 1976 that attempted to specifically address the two hypotheses listed above. An area about 0.7 ha (1.7 ac) was selected for establishment of the Demonstration Area on the northern-most end of the McLaren Mine, adjacent to a relatively undisturbed forb-dominated plant community on a southwest-facing exposure. Although the procedures of installation of this study site have been described elsewhere (e.g., Brown and Johnston 1978, 1980a), a brief summary is provided here for reader convenience and to clarify errors published earlier (e.g., Brown and Johnston 1978).

1. The abandoned spoil piles over the entire study site were shaped and contoured with a bulldozer in August 1976 to approximate the over-all slope and aspect characteristics of surrounding native slopes and plant communities. No specific effort was made to bury or remove the more acidic spoil concentrations found on the area. The mine spoil material was graded and integrated into the periphery of the adjacent plant community on the north side of the area, and all surface topographic irregularities were removed to duplicate natural slope angles of about 15% with a southwest aspect.

2. Based on earlier soil-spoil analyses, hydrated lime and sterilized steer manure were uniformly applied with an agricultural fertilizer spreader at the rate of 4480 kg/ha (4000 lb/ac or 2 tons/ac), and then incorporated into the top 15 cm (6 in) of spoil with a spring-toothed harrow pulled by a small bulldozer. Spoil analyses had shown that surface spoil pH averaged about 3.2 prior to shaping and contouring, and a brief incubation of spoil material with graded amounts of hydrated lime in the laboratory indicated that the applied rate would be sufficient to raise pH to about 5.5 (that of natural undisturbed soils in the area). Our intent was to adjust spoil pH using hydrated lime in the least amounts required to approach native soil conditions.

   The addition of sterilized steer manure was based on data that were unpublished at that time collected in an on-going greenhouse bioassay study of McLaren Mine spoils (Brown and Johnston 1980b). These data showed definitively that manure greatly improved plant growth and development in these spoils when combined with lime and fertilizer.

3. Inorganic granular fertilizer with an N-P-K ratio of 18-46-5 also containing 0.8% Zn, was applied at the rate of 112 kg/ha N (100 lbs/ac N), or at a bulk rate of about 622 kg/ha (554 lbs/ac total) using the same spreader as above. The fertilizer was also incorporated into the upper 15 cm (6 in) of spoil similarly.

4. Throughout the late summer and fall of 1976, seeds were collected of native grasses and a sedge species commonly observed on successional areas of disturbed sites in the New World District. Observations and studies of succession throughout the area illustrated that of the nearly 100 vascular species comprising the flora in the area, about 10 are common constituents of successional communities found on mine spoil with similar properties as that found on the McLaren Mine, and these include grasses, forbs, and one sedge. These species are:

Grasses:

Agropyron trachycaulum
Deschampsia caespitosa
Phleum alpinum
Poa alpina
Trisetum spicatum

Sedges:

Carex paysonis

Forbs:

Agoseris glauca
Epilobium alpinum
Potentilla diversifolia
Sibbaldia procumbens

Only the grasses and one sedge species were included in the seed collections because we found that forb seed was difficult to collect in the quantities required, and seed abundance was highly variable among species and on different sites. Although it was recognized that the deletion of forbs from the seed mixture would result in an unrepresentative lifeform composition, we believed that succession would eventually restore that imbalance.

Relative seed availability of the species that were included in the seed mixture was also highly variable over the area and among species. Seed production varies greatly on different sites and between species from year-to-year, and 1976 proved to be unexceptional. We did not attempt to collect uniform quantities (or quality) of seed among species, but rather gathered as much and from as many different representative successional communities as possible during the narrow window of seed gathering opportunity provided in this harsh climatic zone.

All seed was collected at maturation by hand-stripping individual or groups of culms; grasses tend to be particularly suited for this type of collection, although entire seedheads of some (e.g., *Agropyron trachycaulum, Phleum alpinum, Trisetum spicatum,* and the sedge *Carex paysonis*) were routinely removed by clipping with scissors. Seed collection was initiated when phenological observations verified post-anthesis development, and in most cases seed maturation was estimated on the basis of seed color and by ease of seed removal or free seed-drop. Seeds were collected by species in paper sacks or plastic buckets, but were stored and air dried in cloth pillow cases in Cooke City. Prior to seed application on the Demonstration Area, the seeds were weighed by species, then mixed together in large cloth (clothing) bags.

5. In the late fall of 1976 (e.g., mid-September) the seed mixture of local native species was broadcast uniformly over the area at the rate of about 75 kg/ha (67 lbs/ac). Only about 0.4 ha (0.98 ac) was seeded; the remainder of the site was transplanted with plugs of native species (the transplanted portion of the study area will not be discussed further here). Table 1 is a summary of the list of species, number of seeds per unit mass, seeding rates, and approximate seed density per unit area applied:

Table 1. Summary of species and seeding rates used on the McLaren Mine Demonstration Area, September 1976.

Species	No. Seeds kg^{-1}	Seed Rate kg/ha	No. Seeds m^{-2}
Agropyron trachycaulum (slender wheatgrass)	391,300	8.00	313
Carex paysonis (Payson's sedge)	219,356	7.31	161
Deschampsia caespitosa (tufted hairgrass)	3,335,900	41.94	14,003
Phleum alpinum (alpine timothy)	2,292,100	4.80	1,101
Poa alpina (alpine bluegrass)	3,149,000	11.77	3,709
Trisetum spicatum (spiked trisetum)	4,669,500	1.71	801
Total		75.53	20,088

Following broadcasting, the entire seeded area was cultipacked with a Brillion Seeder-Packer pulled with a small bulldozer to firm the seed into the upper 2-5 cm (0.75-2 in) of spoil. This process improves contact between the spoil fine particles and the seeds, and is interpreted to improve water and nutrient availability during seed germination. It also minimizes seed exposure to light; in 1976 we were unaware that *Carex paysonis* is photoblastic (requires light for germination, e.g., Haggas et al. 1987), hence we may have unintentionally hindered its ability to germinate.

6. The seeded area was then surface-mulched with straw mixed with a water-base asphalt emulsion as a tackifying agent, blown on with a Finn straw blower, also pulled by the small bulldozer. We used 4500 kg/ha (4000 lbs/ac, or 2 tons/ac) of baled straw, and the tackifying agent acted to reduce wind redistribution of the straw fibers. This amount of straw provided a light surface covering over the spoil, and is interpreted to have provided protection against wind and water erosion of spoil fines and seed. It is expected that the straw also minimized surface evaporation the following spring during

seed germination, and may have also acted as a heat-trap to minimize surface frost and needle-ice formation.

All site installation work was completed in late September, 1976. The Demonstration Area was covered with snow throughout the winter of 1976-77, and the first assessment of vegetation characteristics began in August, 1977, one year after installation. From 1977-1982, assessment consisted of measuring plant density (number of individual plants by species per unit area), biomass by lifeform (grasses, forbs, sedges, etc.), and estimates of aerial plant cover, all using 0.1 m^2 quadrat frames randomly located over the area. After 1982 density measurement were discontinued because individual plants were commonly difficult to discern. Assessments are now performed with numerous 0.25 m^2 quadrat frames, and include periodic measurements of biomass by species (although in some years only biomass by lifeform is recorded), and cover by vertical photographic techniques that permit partitioning total cover into measures of live plant, litter, rock, and bare ground components. In most years we attempted to identify all vascular plant species that occur within the seeded portion of the Demonstration Area, whether or not they were encountered during assessment.

Also beginning in 1977 following assessment, the entire Demonstration Area was refertilized at the same rate and with the same N-P-K fertilizer as used during initial installation (Brown et al. 1984). Refertilization was continued for three consecutive years over the entire area, 1977-1979. In the forth year, 1980, the seeded area was divided into four nearly equal sections from top-to-bottom across the slope. Re-fertilization was continued each successive year, but the next section down-slope was withdrawn from the schedule each year until 1982, when all refertilization was permanently discontinued. The following schedule by years was observed:

<u>Section</u>	<u>Location</u>	<u>Years of Refert.</u>	<u>Total no. Years</u>
1	upper 1/4	1977-1979	3
2	mid-upper 1/4	1977-1980	4
3	mid-lower 1/4	1977-1981	5
4	lower 1/4	1977-1982	6

Thus, the seeded portion of the Demonstration Area received repeated refertilization treatments extending from 3 to 6 consecutive years.

Beginning in 1988, active mineral exploration was reinitiated in the New World District by Crown Butte Mines, Inc., a new company at that time. Some inadvertent errors by the company led to some exploration drilling activities within the Demonstration Area in several locations, and resulted in some damage to the vegetation and soils within the study area. Attempts to repair these re-disturbances were partially successful, but the scars are still evident.

RESEARCH RESULTS AND DATA INTERPRETATION

Assessment of data on plant biomass productivity and percent cover from the four refertilization sections between 1978 and 1983 have been summarized elsewhere (Brown et al. 1984). The data were thoroughly disappointing because they failed to illustrate any direct or indirect effects of continued refertilization beyond three consecutive years. Expectations suggested that longer periods of refertilization should yield significant effects on plant biomass and cover, but statistical analyses suggested that no beneficial effects were observed. As a result, future assessments based on the refertilization partitions was abandoned, and will not be considered in detail here. Consequently, all quantitative assessments after 1983 were conducted by lumping all the data from the entire seeded portion of the Demonstration Area.

Plant Invasion and Species Richness

The invasion and colonization by other plant species into the Demonstration Area over time is considered a valid measure of the effectiveness of the cultural treatments used to ameliorate limiting spoil conditions to initiate secondary succession. Prior to treating the spoils on this site in 1976, the spoil material had remained essentially free of all invasion and colonization by plants from surrounding communities over the 25 years since the mine had been abandoned. It is assumed that succession was unable to become initiated due to the limiting nature of the exposed spoil materials. Unpublished, yet instructive data had been gathered between 1972-1976 that illustrated the extent of seed rain occurring on the McLaren Mine. Spoil samples 1 m^2 and 2.5 cm deep had been collected from 100 locations across the mine, and were then spread over a layer of washed sand in horticultural flats in the greenhouse. These were then watered and carefully studied for seedling emergence. Although the total number of seeds and their viability were not determined, total plant emergence was recorded until all apparent germination ceased. This study showed that an average of 265 seedlings m^{-2} were potentially present on McLaren Mine spoils, but were apparently unable to germinate and emerge on-site due to limiting spoil properties. It is believed that these seeds originated in adjacent plant communities and were transported onto the mine site via wind, water, or by other vectors. Thus, it was clear that viable seeds were present on (and in) the mine spoils prior to treatment, but succession was not evident due to restrictive environmental conditions.

Figure 1 summarizes observations of the total number of vascular plant species observed on the McLaren Mine Demonstration Area by year. These data clearly illustrate an aggressive increase in plant species richness through natural colonization on the site over time, beginning with the original 6 species seeded on the area in 1976. It is noted that during the years of active refertilization, between 1977-1982, apparent species invasion was suppressed and rates of increase in total numbers of species were sluggish. It is suspected that repeated pulses of high nutrient rates tended to favor the establishment and occupation of the site by grasses, which tend to be "luxury consumers" of available nutrients. Grasses also tend to be highly competitive and hence may have effectively slowed the rate of succession on the Demonstration Area until refertilization was discontinued (Figure 1). The number of observed plant species on the area after 1982 increases dramatically until about 1989, when nearly 40 species were recorded on the site. Since then (1995) the total number of species observed has reached as many as 43.

In addition to the total number of vascular species observed, we compared the number of species by lifeform encountered during sampling for plant frequency on the Demonstration Area with those encountered in three nearby native reference communities (Figure 2). The total numbers of species shown in Figure 2 were observed in quadrats laid out in restricted random patterns over the four areas, and hence those represented in Figure 2A (Demonstration Area) do necessarily coincide with the number of species shown in Figure 1 which are recorded totals observed over the entire Demonstration Area. The three reference areas (Figures 2B, C, and D) were selected as representative of major successional stages of plant communities in the New World District. The seral stage of development of each selected plant community was assigned

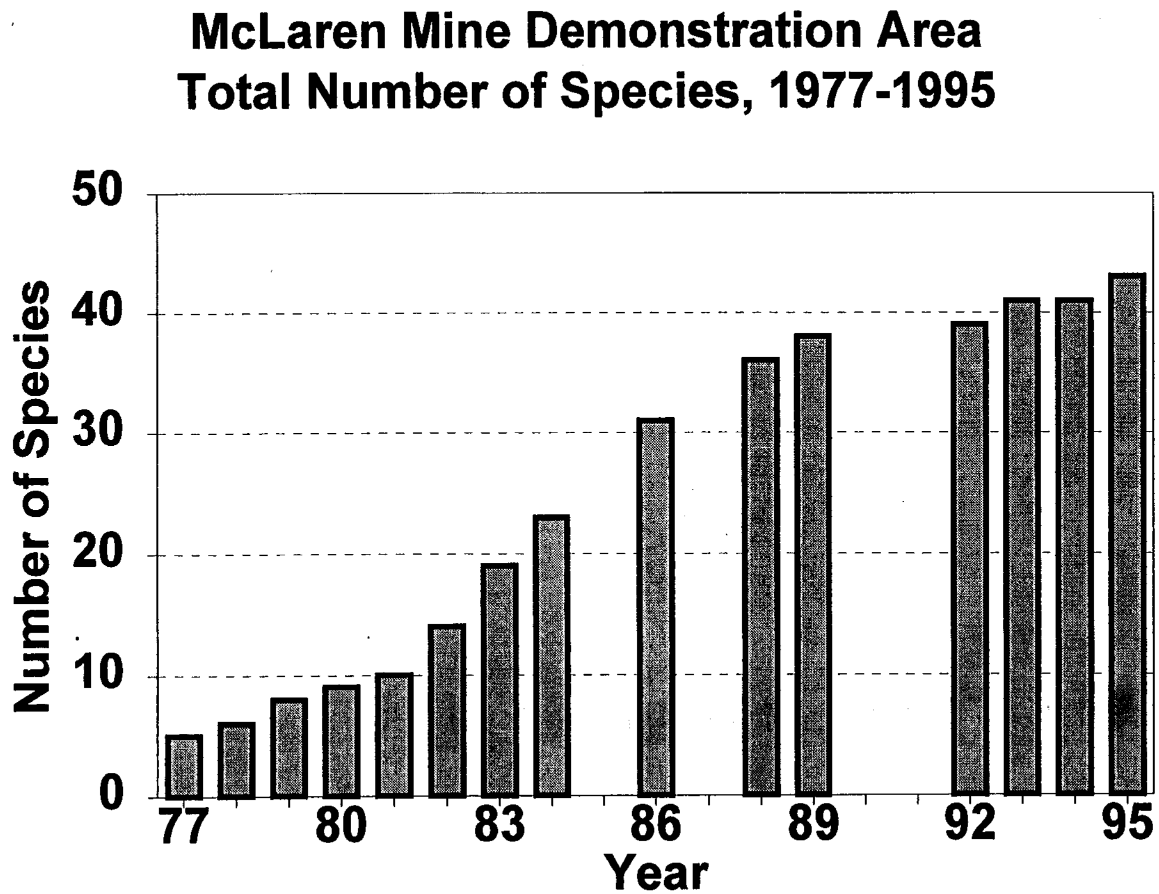

Figure 1. The total number of vascular plant species observed within the McLaren Mine Demonstration Area, 1977-1995. No data were collected in 1985, 1987, or 1990-91.

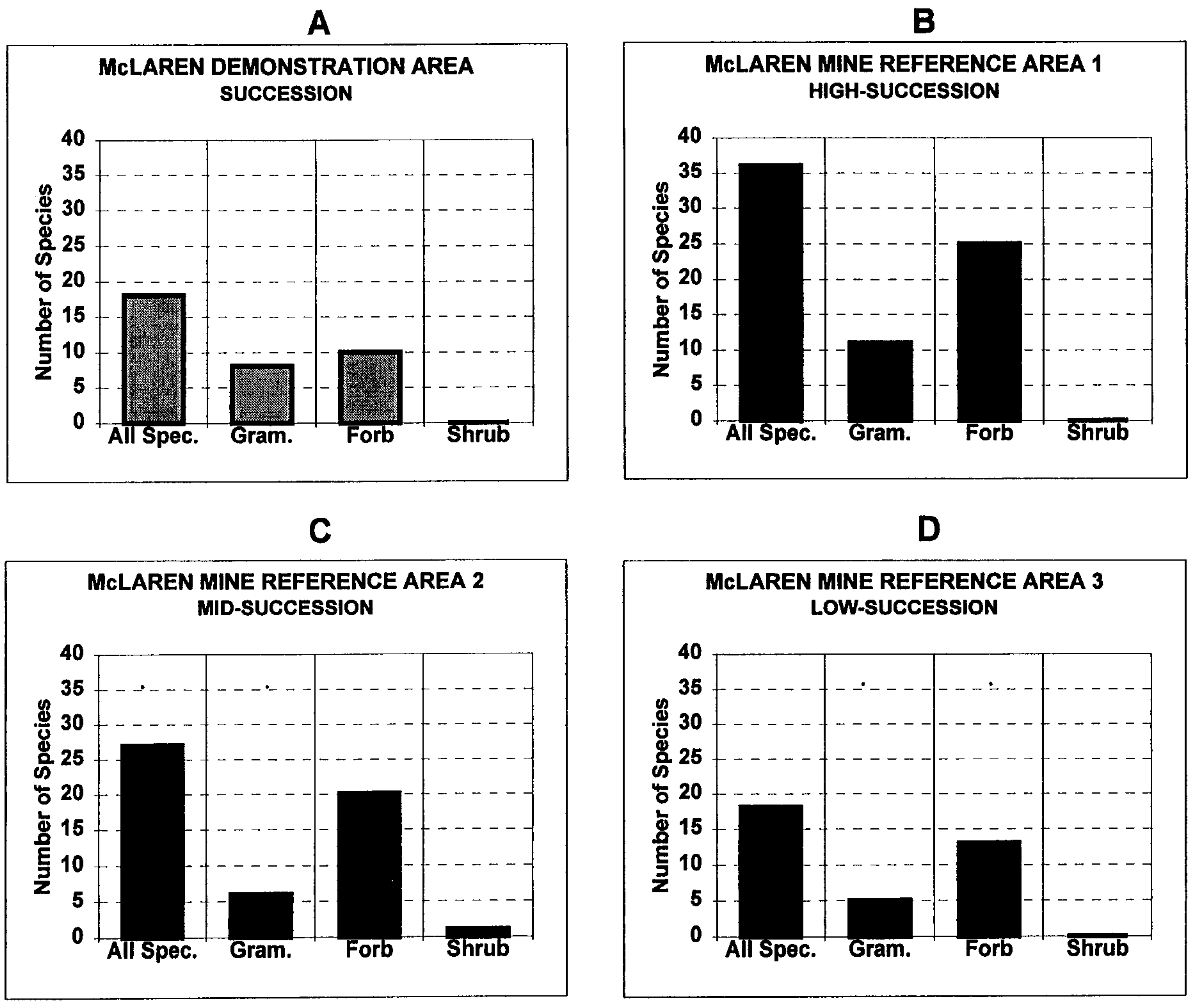

Figure 2. Comparison of the number of vascular plant species by major lifeform (e.g., graminoids, forbs, shrubs, and all species) on the McLaren Mine Demonstration Area (graph A) with those in three representative native reference plant communities. Reference area 1 (graph B) represents the highest level of observed succession, reference area 2 (graph C) represents the mid-level of successional development, and reference area 3 (D) represents the lowest level of successional development in the New World District.

arbitrarily based on experience, and ranges from "high-succession" (reference area 1, representative of the most advanced stages of community development, B in Figure 2), "mid-succession" (reference area 2, representative of intermediate stages of development, C in Figure 2), to "low-succession" (reference area 3, representative of the lowest stages of development on natural soil, D in Figure 2). Our intent was to use these areas as reference sites to compare relative attributes of developing plant communities, including soil physical and chemical properties, with those observed on the Demonstration Area (A in Figure 2) over time. The data illustrated in Figure 2 summarize the relative numbers of species encountered in each area by lifeform (all species vs. graminoids vs. forbs vs. shrubs), and show that the Demonstration Area is beginning to achieve a lifeform composition similar to that observed in lower to middle-level successional native plant communities. Indeed, the proportion of graminoids (grasses and sedges) in the Demonstration Area to the total number of all species remains higher than that observed in native plant communities, but these data illustrate that significant invasion and colonization by lifeforms other than graminoids has occurred since initial revegetation. It is interesting that the relative proportion of forbs to the total number of species increases in the reference areas with the arbitrary ranking in seral stage, and appears to reflect the general structure expected in subalpine-alpine herb-field communities (e.g., Billings 1974; Johnson and Billings 1962).

Plant Biomass Productivity

Biomass, or total plant productivity per unit area per unit time, is one of the most useful measures of plant performance in an environment. Figure 3 compares the biomass of all vascular species in the Demonstration Area with those in adjacent reference areas. These data clearly illustrate the effects of refertilization during the first several years following revegetation; total plant biomass in the Demonstration Area was as much as 3 to 4 times that measured in native reference communities. However, over time as the residual effects of repeated refertilization began to subside, the difference in biomass between the two sites diminished, and in more recent years the Demonstration Area appears to be tracking similar biomass observed in native communities (after 1984 in Figure 3). Annual variability in plant biomass is evident in Figure 3 as reflected in the oscillations in the totals for both areas, and is suspected to be caused by both annual climatic variability and experimental error.

A more rigorous test of the performance and rate of development of the vegetation in the Demonstration Area is illustrated by the data in Figure 4. These data represent computations of the 95% confidence intervals of total plant biomass in the Demonstration Area compared with that in adjacent native reference areas. In this case, the vertical bars represent data computed from the equation:

$$\pm 95\%\ CI = 2[(se_1)^2 + (se_2)^2]^{0.5} \quad (1)$$

where $\pm$95% CI is the 95% confidence interval, se_1 is the standard error of the mean of biomass in the Demonstration Area, and se_2 is that of the native reference areas. The center point of each vertical bar represents the mean difference in biomass between the two areas, and the + and - extremities represent the limits of the 95% confidence interval. Statistical theory suggests that wherever these vertical bars cross below the 0 biomass on the Y axis, there is a 95% chance that the two areas do not differ significantly. From the data in Figure 4, it can probably be assumed

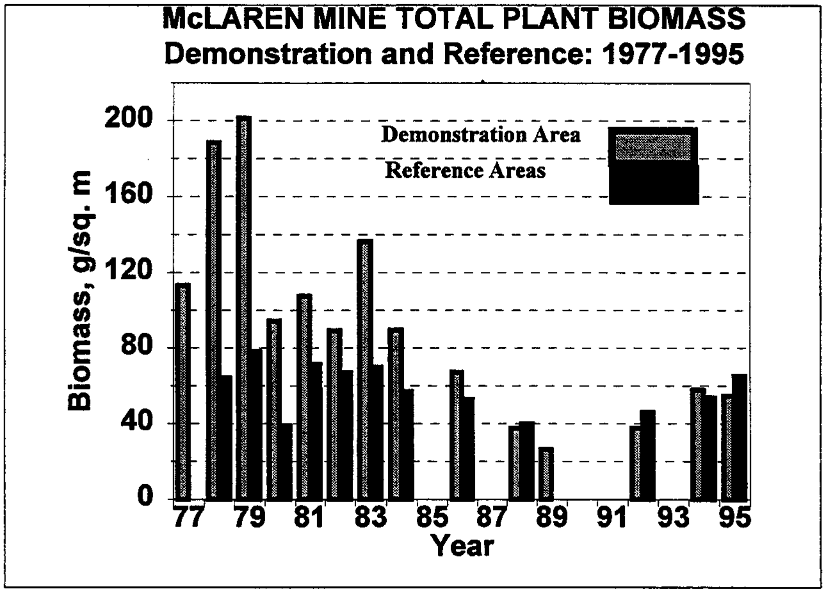

Figure 3. Comparison of total plant biomass (g/m^2) within the McLaren Mine Demonstration Area and adjacent native reference areas, 1977-1995.

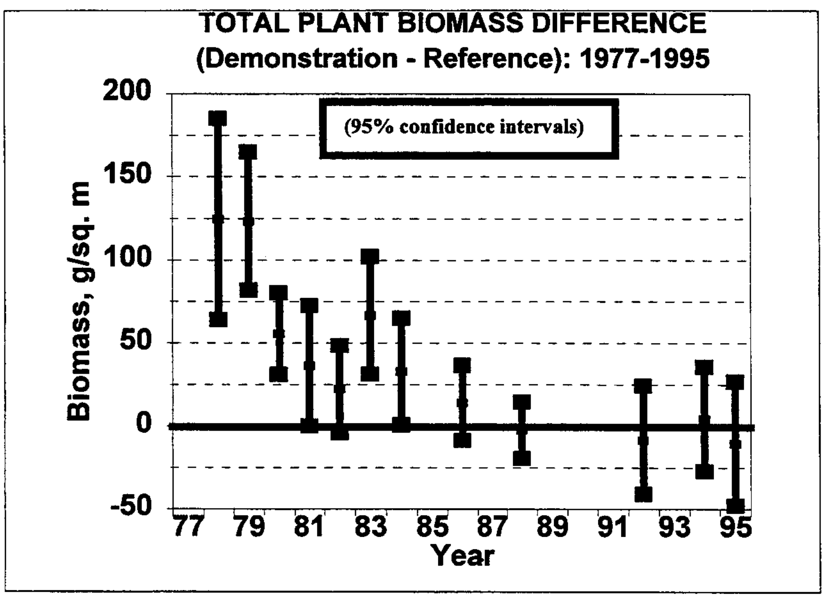

Figure 4. Differences in biomass between the McLaren Mine Demonstration Area and native reference areas, 1977-1995. Vertical bars represent the 95% confidence interval.

that the Demonstration Area began approaching consistent statistical similarity with adjacent reference areas in terms of total biomass after about 1985, or about 9 years following installation. It can be argued that biomass may not always be the best or only comparative trait by which similarities between revegetated and reference sites should be judged, but these data do support the supposition that the two areas share common ecological characteristics and trends over time. In view of the vast differences that existed on these two areas less than 20 years ago, and also in view of the harshness of the local environment, we suggest that these data offer significant promise that reclamation and revegetation treatments can be used to initiate long term restoration.

Cover Characteristics

Cover is a measure of the amount of soil/spoil surface area potentially protected from the various forces of erosion by the diverse structural elements of a plant community. These elements,or components of total cover often include the live individual crowns and other architectural features of vascular plants (leaves, stems, flowers, etc.), litter or detritus, rocks and stones, and other items. Figure 5 summarize a comparison of only live vegetation cover between the plants in the Demonstration Area with those in adjacent native reference communities. Surprisingly, the Demonstration Area has compared closely with total plant cover in reference areas throughout the period of vegetation development, 1977-1995. In some years (e.g., 1982 and 1984), cover data were collected on the Demonstration Area, but not for reference areas. However, the data taken together illustrate that following the initial period of repeated refertilization, the two areas have maintained similar total live cover throughout, and appear to be tracking each other over time. The plants within the Demonstration Area have undergone major structural changes during the first 3-5 years after site installation. During the first few years after seeding the Demonstration Area the vegetation was composed of numerous small immature seedlings and small plants, whereas in more recent years the vegetation is primarily composed of lower density, but structurally larger individuals similar to the condition observed in native plant communities. Variations in plant response to changes in climatic events, together with sampling error, are suspected of being responsible for most of the oscillations in the data from year to year.

Total cover is considered the sum of live vegetation, litter, and rocks as measured from 100-point grids over vertical photographs of each quadrat frame. These components all provide some degree of protection against erosion by both water and wind, and when summed together provide a measure of total cover. In Figure 6 total cover of the Demonstration Area and other reference communities is compared over the period 1978-1995. Even more striking than for live cover (Figure 5), the data in Figure 6 illustrate that the total cover within the Demonstration Area has been very similar to that in reference areas since site installation. Although there have been periods of variability in total cover over the last 19 years, these appear to be normal oscillations due to climatic irregularities from year to year.

Comparison of Soil Properties

Soil properties are perhaps among the strongest indicators of successional-convergence between severe disturbances and native communities. Evidence of soil genesis in McLaren Mine spoil material on the Demonstration Area has been observed for several years as illustrated by

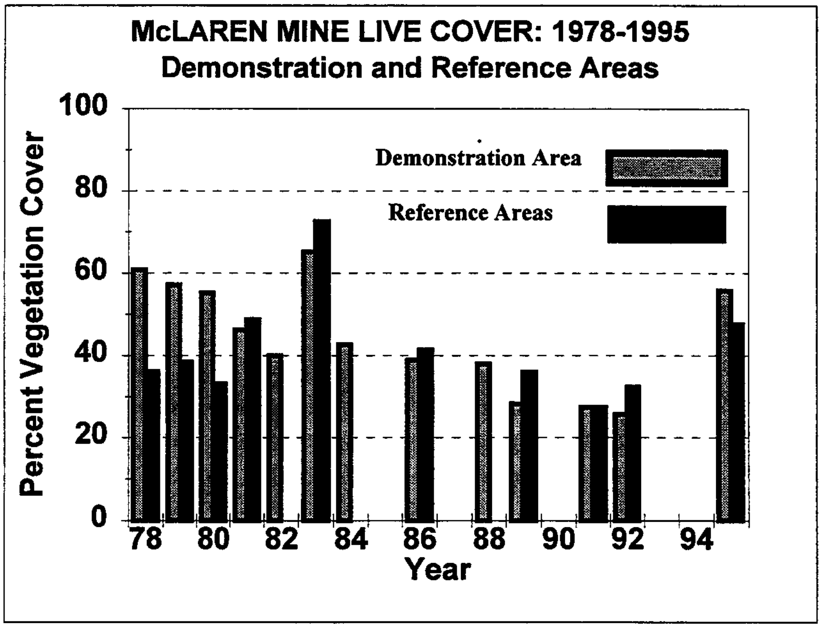

Figure 5. Comparison of total live plant cover (%) of the McLaren Mine Demonstration Area with that of native reference plant communities, 1978-1995.

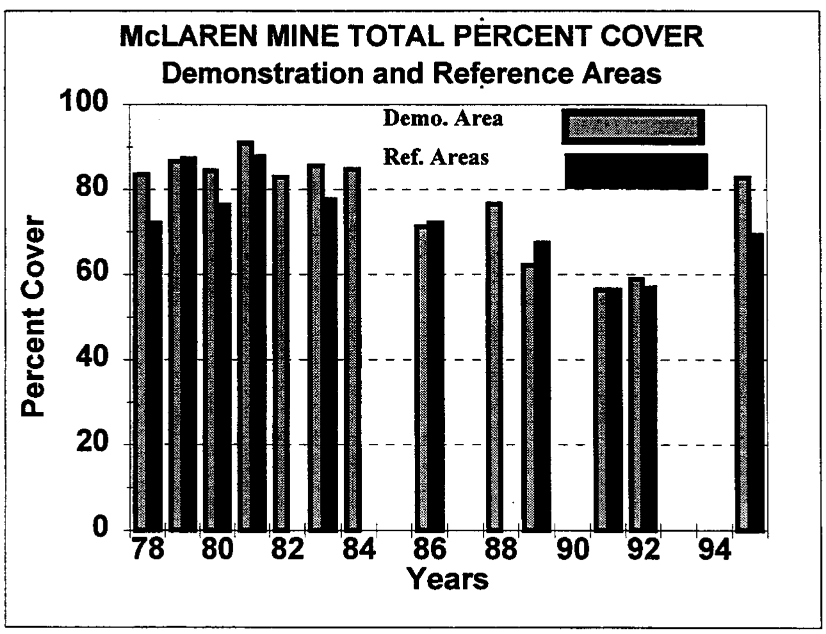

Figure 6. Comparison of total cover (%), including live plant, litter, and rocks (>2mm) for the Demonstration Area and native reference areas, 1978-1995.

obvious organic matter staining in the upper layer of mine spoil within the most dense zones of plant rooting. Plant rooting activity has increased substantially within 20-30 cm of the surface in the last 10 years.. Rooting depths now exceed the depth to which cultural treatments were applied (15 cm), and in some locations roots have been observed below 40 cm. However, the most dense rooting activity is confined to the upper 15 cm throughout the Demonstration Area. The coarse fragment (> 2mm) composition in the spoil materials and native soils are highly variable, ranging from 30% to 70% by weight depending on location. Rigorous soil sampling was undertaken in 1995 to compare the properties of raw mine spoil with that of developing soil in the Demonstration Area and that of natural undisturbed soils in native reference areas, and these data are summarized in figures 7, 8, and 9.

Figure 7 is a summary of soil/spoil pH data observed in mine spoil, and in apparent A and C horizons of developing soil within the Demonstration Area compared with that within reference areas. The A-C horizon designation of developing soils within the Demonstration Area is based on visible properties of soil color due to organic matter staining and apparent textural and structural properties. Within reference areas this horizination is strongly developed and easily recognized. The data illustrate the long-term effect that liming has had on the mine soils of the Demonstration Area; in 1976 the pH of these spoil materials was similar to that shown for raw spoil, whereas 19 years after liming the pH is more similar to that of natural soil, or perhaps slightly higher.

Figure 8 summarizes concentrations (mg/kg) of some of the various metals observed in the soils and spoils of the McLaren Mine. The soil samples were analyzed by the Soil, Plant, and Water Analysis Laboratory at Utah State University (Logan, Utah 84322) using pH 7.3, 0.005 M DTPA (Lindsay and Norvell 1978). Differences in copper (Figure 8A) between untreated mine spoil and the developing soil within the Demonstration Area may not be significantly different (note $\pm$ 1 standard error bars), but the greater concentrations observed in the Demonstration Area may reflect more extraction of Cu by DTPA because of the higher pH of the treated mine spoil. Copper concentrations in natural soils are significantly lower than those observed in treated or untreated mine spoil.

The stability of metal-DTPA complexes, and hence the relative amounts of metals extracted by DTPA are influenced by soil pH. The stability of the Fe-DTPA complex increases with decreasing pH (Lindsay and Norvell 1978). Thus, more Fe is extracted by DTPA relative to other metals from the high-Fe, low pH, untreated minespoil than from the treated minespoil or native soil (Figure 8B). As pH increases, the stability of the Fe-DTPA decreases and thus more Cu (Figure 8A) and Zn (Figure 8D) are extracted by DTPA relative to Fe (Figure 8B). Although Cu, Mn, and Zn concentrations are generally higher in Demonstration Area developing soils than they are in raw spoil or native soils, there are no apparent indications that these concentrations are limiting to plant growth and development. Although Cu can be toxic to some plant species at the concentrations observed in the Demonstration Area, based on the aggressive nature of colonization on the site since 1976 (Figure 1) there are no apparent adverse effects of Cu on these plant species. The concentrations of the four metals illustrated in Figure 8 show no significant adverse link to successional development of the Demonstration Area plant community.

Soil nutrient concentrations are summarized in Figure 9 for percent total N (Figure 9 A), percent total organic C (Figure 9 B), and P and K concentrations (mg/kg by $NaHCO_3$ extraction). The levels of N, P, and K within the Demonstration Area reflect residual effects of fertilizer applications, and compare similarly with levels observed in natural reference area soils. Total N

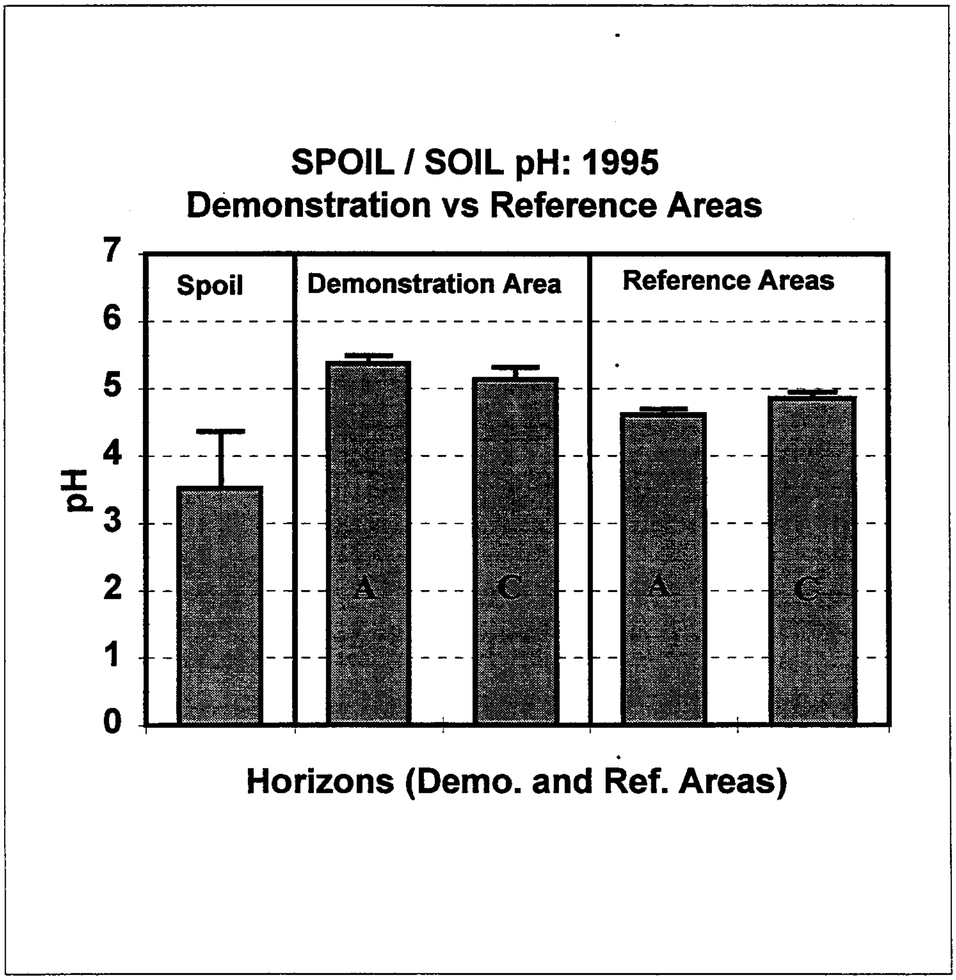

Figure 7. Comparisons of soil/spoil pH of untreated McLaren mine spoil (left), the Demonstration Area, (middle), and native reference areas (right). The letters A and C refer to soil horizons. Mine spoil has no developed horizons.

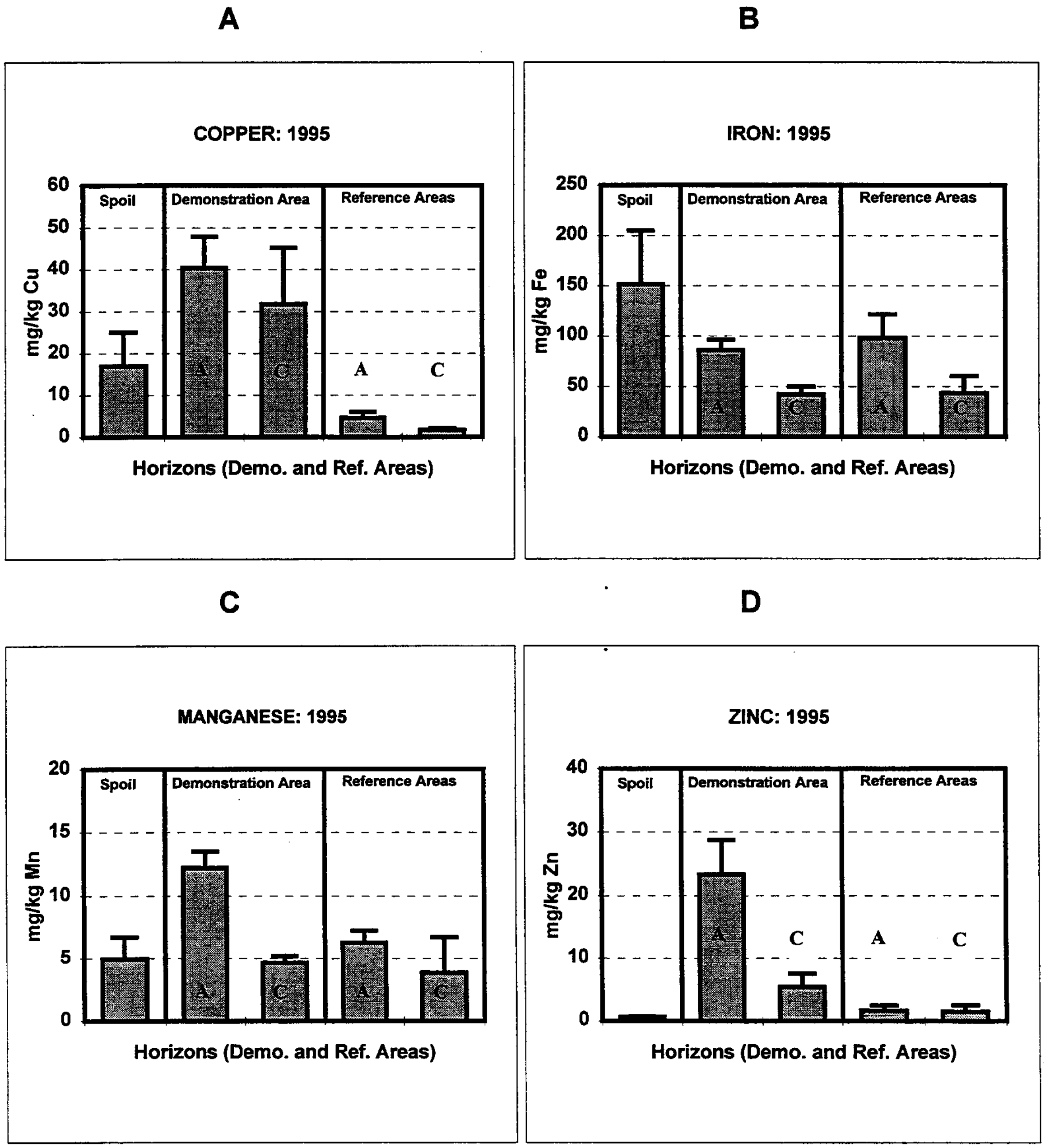

Figure 8. Comparison of soil/spoil concentrations of metals; copper A, iron B, manganese C, and zinc D. Untreated McLaren mine spoil (left), Demonstration Area (middle), and native reference areas (right). Letters A and C denote soil horizons. Raw mine spoil has no developed horizons.

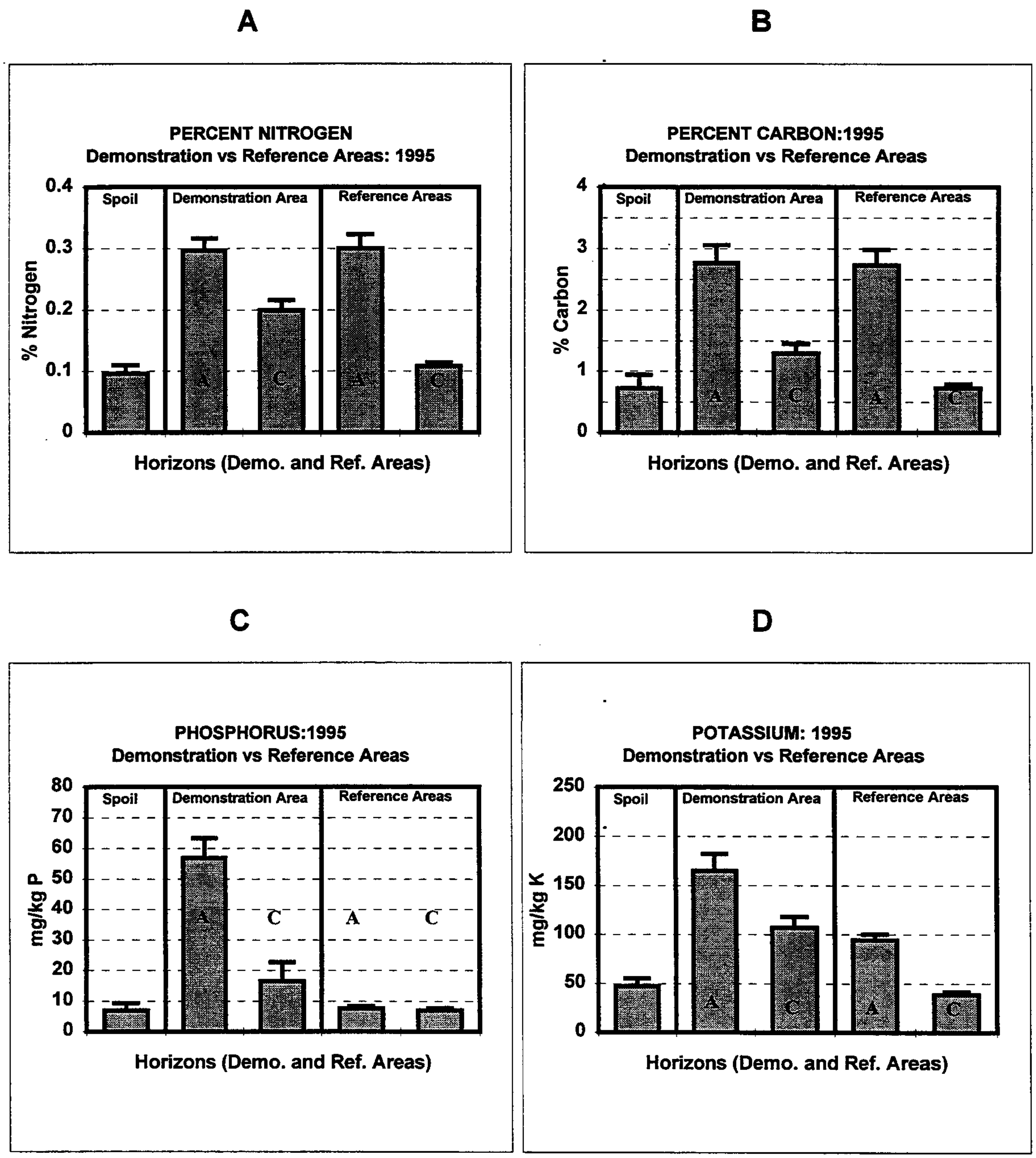

Figure 9. Comparison of soil/spoil nutrients; % nitrogen A, % carbon B, mg/kg phosphorus C, and mg/kg potassium D. Untreated McLaren mine spoil (left), Demonstration Area (middle), and native reference areas (right). Letters A and C denote soil horizons. Raw mine spoil has no developed horizons.

(Figure 9A) levels are impressive in the developing soils of the Demonstration Area, and suggest that nutrient cycling is active at least within the developing A horizon. Also of considerable interest are the levels of observed total organic C (Figure 9B) in the Demonstration Area, indicating a response to organic matter accumulation from plant litter turn-over. There are no statistical differences between total organic C amounts in the Demonstration Area developing soils and those observed in natural reference area soils. Phosphorus and K levels (Figure 9 C and D) in the Demonstration Area are particularly high, reflecting high rates of P and K fertilization between 1976-1982. Phosphorus is immobile, and the high concentrations observed in the developing A horizon of the Demonstration Area are due to the surface applications during the period of repeated refertilization. Available P and K concentrations in the untreated minespoil are below levels (for $NaHCO_3$ extractions) at which a biomass response to P and K fertilizer are expected. However, it is not known if the large biomass responses (Figure 3) to fertilizer additions during and following establishment of the Demonstration Area are from N or P and K, or all three nutrients. At present, N is the most limiting nutrient in the Demonstration Area because biomass production has declined to levels indistinguishable from the native reference areas (Figure 4) even though soil P and K levels remain high. Biomass production in the Demonstration and native reference areas now occurs at levels that can solely be supported by nutrient cycling.

CONCLUSIONS AND RECOMMENDATIONS

In this paper two hypotheses were addressed: 1) active revegetation and reclamation practices can be used to initiate succession on severe disturbances where natural succession has been suspended or deflected due to the severity of environmental conditions created by the disturbance; and 2) succession can be enhanced and accelerated beyond rates of development normally observed through the use of adapted and ecologically compatible species, and such cultural treatments as refertilization or other appropriate methods. Based on the research studies conducted on the McLaren Mine between 1976 and 1995, the conditions of these two hypotheses are accepted.

It is evident that severe disturbances, particularly that occur in harsh climatic zones such as at high elevations or in arid to semiarid regions, often result in limiting conditions that virtually prohibit natural processes such as succession from becoming initiated. We define "severe" disturbances as those that result in the loss of natural vegetation and soils, that expose geologic materials that may contain limiting chemical or physical properties, and that may destroy of interfere with surface and subsurface hydrologic pathways. When disturbances are so severe that natural succession is suspended or interrupted, thus impeding the processes of natural ecological restoration, a state of instability may persist that exacerbates annual cycles of accelerated erosion and sediment transport. These processes further deflect succession and delay ultimate ecosystem recovery. If the assumption is accepted that the objective of natural western wildland management should be to ameliorate disturbances in order to achieve a stable self-sustaining condition requiring little or no continued active intervention, then it is apparent that active restoration programs must be adopted by public land management agencies. Under these conditions, severe disturbances are expected to be managed so that natural processes of succession ultimately guide ecosystem recovery, development, structure, and function. Thus, an active or "operative" approach of intentional intervention to ecological restoration using intensive and rigorous revegetation and reclamation as primary tools, is required instead of more passive ones based on latent management options alone.

In classical ecology, succession is variously described as the universal and natural process of community and ecosystem formation and development (e.g., Clements 1916; MacMahon 1983; Weaver and Clements 1938). This definition infers a broader concept that includes the processes of soil genesis, the development of nutrient cycling, and the re-establishment of hydrologic pathways during community and ecosystem formation as additional vital products of succession. Thus, succession is considered to include all the chemical, physical, and biological forces responsible for ecosystem formation. Further, we define this ecological process as the primary force that leads to ecological restoration following disturbance. Succession is the process that land managers must rely upon most for "nature to take its course" following revegetation, reclamation, or any other management action taken on disturbed wildlands.

Successful ecosystem restoration involves the recognition of the principles of succession, and the role that this phenomenon plays in developing all the components of ecosystems including biological, chemical, and physical elements. An operative approach to ecosystem restoration as advocated here, especially on relatively small or "patch" disturbances within larger ecosystems, provides an essential means of re-integrating the disturbance back into the original ecosystem and minimizing the potential for catastrophic expansion of the effects of contaminated soils and waters and other long-term negative environmental impacts.

The research results discussed here suggest a number of conclusions and recommendations regarding the implementation of ecosystem management and the policies and practices appropriate for managing disturbances on western wildlands. Although practices of revegetation and reclamation are certainly not new, elements of them appear to be misapplied and misinterpreted too often when implemented on disturbances of western public wildlands. These conclusions and recommendations include:

1. Despite the severity of environmental conditions on disturbed sites, intensive ameliorative reclamation treatments, combined with revegetation should be aggressively implemented to initiate active natural succession.

2. Natural succession is an event-driven process (e.g., episodic) and can occur largely independent of time. Obviously, time is always a factor, but it is probably misleading to associate successional development of natural communities as only a long-term, slow, process. Thus, the impacts of limiting environmental factors such as low nutrient availability, inaccessible seeds of adapted ecologically compatible (suited for local forces of succession and ecosystem development) species, limiting soil or spoil pH and the availability of toxic chemicals, aridity, extreme temperature fluctuations, and other conditions are manipulatable elements on most disturbances. Aggressive and active inputs of ameliorative treatments can modify or alter limiting conditions sufficiently to initiate succession.

3. Revegetating with appropriate plant species is perhaps one of the most significant steps toward active ecological restoration, and yet is one of the steps most frequently misapplied. It is recommended that concerns about physiological adaptation alone are insufficient; an element of local ecological compatibility with the forces of succession and ecosystem development are equally essential. The species used in revegetation

largely determine the direction that site recovery will assume, at least in the short-term. Use of adapted, yet ecologically incompatible species, may likely deflect successional direction, or in extreme cases, suspend or redirect it altogether, leading to undesirable communities.

4. It is strongly recommended that land management agencies become more familiar and knowledgeable about successional pathways in their area of responsibility. Simple observation of succession on various old disturbances in a range of ecological zones, noting the most aggressive plant species involved in seral community development in each area, can be highly useful for selecting species for use in revegetation.

5. Agencies should adopt a policy of collecting, or otherwise acquiring through commercial sources, seeds of native successional species to be available when revegetation is required. Seeds of appropriate species are not necessarily available every growing season, nor do commercial sources always maintain adequate stores to meet unusual requirements. Agencies like the U.S. Forest Service, Bureau of Land Management, National Park Service, various state agencies and others should inaugurate a common-garden program of growing selected stock of key native successional species for seed production. Simple agronomic and horticultural practices could be implemented to "push" plant production toward high seed yields, and these could be harvested and stored for eventual revegetation application needs in appropriate areas.

6. Adopt an aggressive, short-term (3 to 5 years) policy for active seasonal or yearly refertilization as required on severe disturbances that "pushes" plant development. Although refertilization no doubt favors highly competitive luxury consumer plants such as grasses (and perhaps less desirable weeds), on sites that are particularly nutrient deficient refertilization favors organic matter accumulation and leads to nutrient cycling capabilities. Grasses are particularly capable of utilizing high nutrient inputs, and may tend to depress the development of biodiversity when high rates of nutrients are readily available. However, following the termination of repeated refertilization schedules, a decline in production can be anticipated eventually leading to open sites available for colonization of other lifeforms and species. Refertilization schedules and durations vary with environmental conditions, and may need to be determined by simple experimentation. Similar policies for reapplications of lime or other cultural treatments may need to be adopted as site conditions warrant.

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SYMBIOTIC NITROGEN FIXATION BY LEGUMINOUS AND NON-LEGUMINOUS SYSTEMS OCCUPYING DISTURBED SOILS

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ABSTRACT

Nitrogen fixation by symbiotic bacteria occupying nodules of certain vascular plants is viewed as an important avenue of nitrogen from the abiotic pool (atmosphere) into the biotic pool. Legumes have from antiquity been known to enhance especially intensively managed (plowed at least annually) ecosystems. In extensively managed (not plowed) ecosystems such as rangelands and forests, leguminous systems are apparent, but increasing evidence suggests that some if not many of these systems fix negligible levels of nitrogen, especially in arid and semi-arid environments. None-the-less, it is common practice to include legumes in seed mixtures for revegetation of disturbed soils. Levels of nitrogen fixed by legumes in disturbed, semi-arid environments may be low, but the deep rooted habit of many legumes provides other benefits including access to deep nutrients and water. The propensity of some leguminous plant to accumulate and convert toxic materials as well as production of alkaloids, are clear disadvantages. Alternatives to using legumes in revegetation include the use of non-leguminous nitrogen fixing plants (actinomycete nodulated or actinorhizal plants) for revegetation of semi-arid sites. These plants include such plants as bitterbrush, mountain mahogany, alder, buffalo berry, mountain dryad and others. Use of both leguminous and non-leguminous nitrogen-fixing plants in reclamation presents special problems regarding seed availability and germination as well as acquisition of infective and effective symbiotic bacteria.

INTRODUCTION

Symbiotic nitrogen fixation through the association of particular vascular plants and certain bacteria is a major source of nitrogen for a variety of ecosystems including intensively managed systems as well as extensively managed systems. Of the associations capable of this kind of activity, the most widely known is the mutualistic association between members of the plant family Fabaceae (formerly Leguminosae) and the genus of bacteria

(Eubacteriales) Rhizobium (now split between two genera: Rhizobium and Bradyrhizobium). These nitrogen fixing leguminous systems are widely dispersed from hot to cold and wet to dry climates, from low elevation to high elevation and from low latitudes to high latitudes.

In intensively managed environments (farmed environments), these systems are known to fix large amounts of nitrogen. Soybean (Glycine max L.), for example, is known to fix much nitrogen when planted in monoculture. Certainly rates of 300 Kg/ha (267 lbs/acre) of nitrogen fixed annually is not unusual for this crop. Other crop plants: Alfalfa (Medicago sativa), clovers (genera Trifolium and Melilotus) also fix much nitrogen. One farmed leguminous genus which does not fix much nitrogen is Phaseolus (the beans). None-the-less, the concept that legumes add much nitrogen to an ecosystem, is a prevalent concept. It is a concept that pervades also the reclamation industry, even where areas to be reclaimed are arid to semi-arid and the soils are of poor quality or are essentially nonexistent.

This paper will address some of the broad general characteristics of the family Fabaceae (Leguminosae) and the capacity of its members to fix nitrogen. Several case studies of legumes in arid to semi-arid environments will be used to emphasize the attributes of this group of plants. These studies focus on the nitrogen fixed in these systems as well as other attributes of the leguminous system. Attributes of non-leguminous nitrogen fixing systems will also be presented as alternatives to leguminous systems.

THE FAMILY FABACEAE

In unfertilized, rain-fed rangelands, grasslands and forests, most of the N for plant growth can be traced to biological N fixation. Although there is nitrogen fixed by asymbiotic nitrogen fixation (e.g. via blue-green bacteria) and by symbiotic systems such as lichens, in many systems, Rhizobium-nodulated plants and Frankia-nodulated plants (see below) are very important contributors or are thought to be very important contributors to the nitrogen inputs of a site.

It seems possible that large quantities of N may be fixed biologically in arid and semi-arid environments by Rhizobium-legume symbioses (Pepper and Upchurch, 1991). Most of the plants that are nodulated by Rhizobium are in the Fabaceae (Leguminosae, although there is at least one known exception (Trinick, 1973; Trinick, 1982a)). Of the approximately 15,000 species in this family, only about 1200 have been examined for nodulation (Trinick, 1982b), and approximately 80% of these were found to be nodulated and consequently have the potential to fix nitrogen (Table 1). Numerous leguminous species inhabit even very arid environments (Table 1). Rhizobia that infect these plants are less well studied (Pepper and Upchurch, 1991).

The bacteria that are responsible for the nodulation of legumes are in the family Rhizobiaceae. Until 1984, all bacteria that nodulated legumes were placed in the genus Rhizobium. Starting with the 1984 edition of Bergey's Manual of Determinative Bacteriology (Jordan), the bacteria that nodulate legumes are divided into two genera: Rhizobium and Bradyrhizobium (Pepper and Upchurch, 1991) based on whether the infective bacteria are fast or slow growing (Greek adjective bradus, slow).

It is difficult to ascertain how much N is actually fixed by legumes in arid and semi-arid environments. Often, growing season length as well as precipitation and degree-days determines the legumes active at a particular site and how much N they fix. Further, soil characteristics determine the quantity of N fixed. Certainly, it is well recognized that high levels of N in soils inhibit nitrogen fixation as well as nodule formation. In addition, some legumes root deeply and only nodulate deeply in soils. For example, Virginia et al. (1986) found evidence that mesquite (genus Prosobis) in the Jornada del Muerto of south central New Mexico nodulated very deeply in the alluvial of that environment. Beadle and Tchan (1955) also strongly suggest that conditions of temperature, moisture, or lack of endophyte often prevent nodulation in arid environments.

Cicer Milkvetch (Astragalus cicer).

Cicer Milkvetch has been studied for some years by a number of individuals, but much work has been done especially by Townsend et al. (e.g. 1978 and 1990). One of the contentions of these researchers (and indirectly by others, see Johnson and Rumbaugh, 1981) is that A. Cicer does not fix much nitrogen and, further, is not well nodulated. In 1993 Zhao initiated a study of a 17 year old stand of A. cicer in the Shirley Basin of Southeast Central Wyoming (Zhao, 1996). This stand covered several hectares (four to five acres) and had a stand density of about 3700 plants per ha (1500 plants per acre), and was mixed with grasses (e.g. Bromus sp., Agropyron sp., etc.) shrubs (Atriplex species) and other forbes (e.g. Melilotus officinalis). The site was a disturbed site, being previously mined for Uranium and revegetated in the late 1970s. A. cicer was not a part of the original reclamation mixture at the site, but seed was probably brought in from a SCS planting in the general vicinity by grazing animal (probably antelope) that frequented both areas.

Initial observations and excavations of Cicer Milkvetch on this site showed plants to be very well nodulated even to some considerable depth (at least 60 cm). Further investigations of this plant, however, revealed that this plant does not fix high rates of N. Using the acetylene reduction assay and the ^{15}N dilution technique, the total nitrogen fixed annually by A. cicer at the Shirley Basin site was 0.21 kg N/ha (approximately 0.19 lbs per acer).

The low level of nitrogen fixation, the frequent occurrence of pseudo-nodules being caused by isolated Rhizobium in renodulation experiments, and the incapacity of Rhizobium isolated from A. cicer to renodulate the parent host plant (A. cicer) suggests that the nitrogen fixation apparatus of this plant is defective.

Asian Pea Shrubs (Genus Caragana)

The grasslands (MGA) of Inner Mongolia (a province of China) and the fledgling Republic of Mongolia (all in Asia) and the Northern Mixed Prairie (NXP) of North America have some striking similarities as well as some dramatic differences (Williams et al, 1993). The two regions have major similarities regarding altitude, annual precipitation and latitude. The two regions differ in significant manners: (1) the annual precipitation in the MGA is such that the majority of the precipitation occurs during the growing season, (2) the MGA is almost devoid of sedimentary rocks and as a consequence the textures of soils are very sandy when compared to the NXP, and (3) the leguminous genus Caragana is very common on the MGA from the arid regions to those that are more humid. There is not a comparable legume system in the NXP. These differences have implications regarding management of these two grassland areas from the perspective of plant water usage, management of organic matter in the soil and control of erosion. There is some evidence that as a grassland, the MGA is more productive than the NXP, but is likely more susceptible to disturbance.

The plant communities which occupy the MGA are similar to those in the NXP. Some species are identical (e.g. Artemisia frigida) and many are similar. Perhaps most significant regarding the fertility of soils in the MGA is that a single genus of legumes occupies most sites throughout the area. This genus, Caragana, is composed of hardy, drought resistant species. The fact that this genus is leguminous and known to nodulate, would suggest that the nitrogen fixation associated with this shrub probably has had an influence on the nitrogen balance of these ecosystems. Indeed, observations of the MGA from near Hohhot (the provincial capital of Inner Mongolia) to Ulaanbaatar (the national capital of Mongolia) almost always include data suggesting that the Caragana species are green, robust and prominent in these grassland environments. This circumstantial evidence plus the knowledge that legumes are nitrogen fixers results in the easy hypothesis that nitrogen fixation plays a key role in the appearance, and abundance of this genus, even on disturbed sites.

Observations by Chinese scientists (Chen, 1986) as well as those of the senior author of this document (S.E.W.) suggest that that at least in relatively arid conditions in the MGA, that members of the genus Caragana are not well nodulated. Chen, 1986, has been excavating roots systems of Caragana on the Mongolian Steppe for much of his career. His drawings of Caragana root systems seldom show nodules, although he has done excavations to great depths (Figure 1). Nodules can sometimes be observed on Caragana that border riparian zones (observations by S.E.W.), but the sense is that this is the exception rather than the rule. If there is nitrogen fixation by the genus Caragana in the MGA, it seems more likely that the rates of fixation are very small, particularly in arid and semi-arid zones.

Toxic Properties Associated with Legumes

One of the most widely discussed aspects of rangeland legumes has to do with the accumulation and conversion of the element Selenium (Se). Several members of the genus Astragalus (A. pectinatus and A. bisulcatus) are noted for their capacity take up Se from deeply situated locations in the soil, convert this into highly soluble forms and accumulate the element to sometimes very high levels in the plant tissue (Beath, 1982). Other legumes (e.g some species in the genus Lupinus) are known to produce alkaloids which are also sometimes deleterious to animals that may consume them (Beath et al., 1939). Duke (1981) lists more than 100 toxic substances found in leguminous genera.

Other Legumes

Numerous legumes occupy ecosystems through out the world. In the central and northern Rocky Mountains, legumes are often observed in rangeland, in alpine environments and, to a lesser degree under forest canopy. Although in some habitats, nodules can be found readily on these plants, for many, nodules are rare even when the soil is moist and when observations are made prior to on-set of flowering. Johnson and Rumbaugh (1981) investigated the nodulating habit of range legumes in Utah. Although these researchers did find nodules on some legumes (e.g. Medicago sativa), many of the plants they examined in native conditions were not nodulated (e.g. A. cicer, Astragalus falcatus, Hedysarum boreale and Lupinus sericeus). They commented that nitrogen fixation rates of legumes was low (done via acetylene reduction methodology), but they did not calculate annual rates of

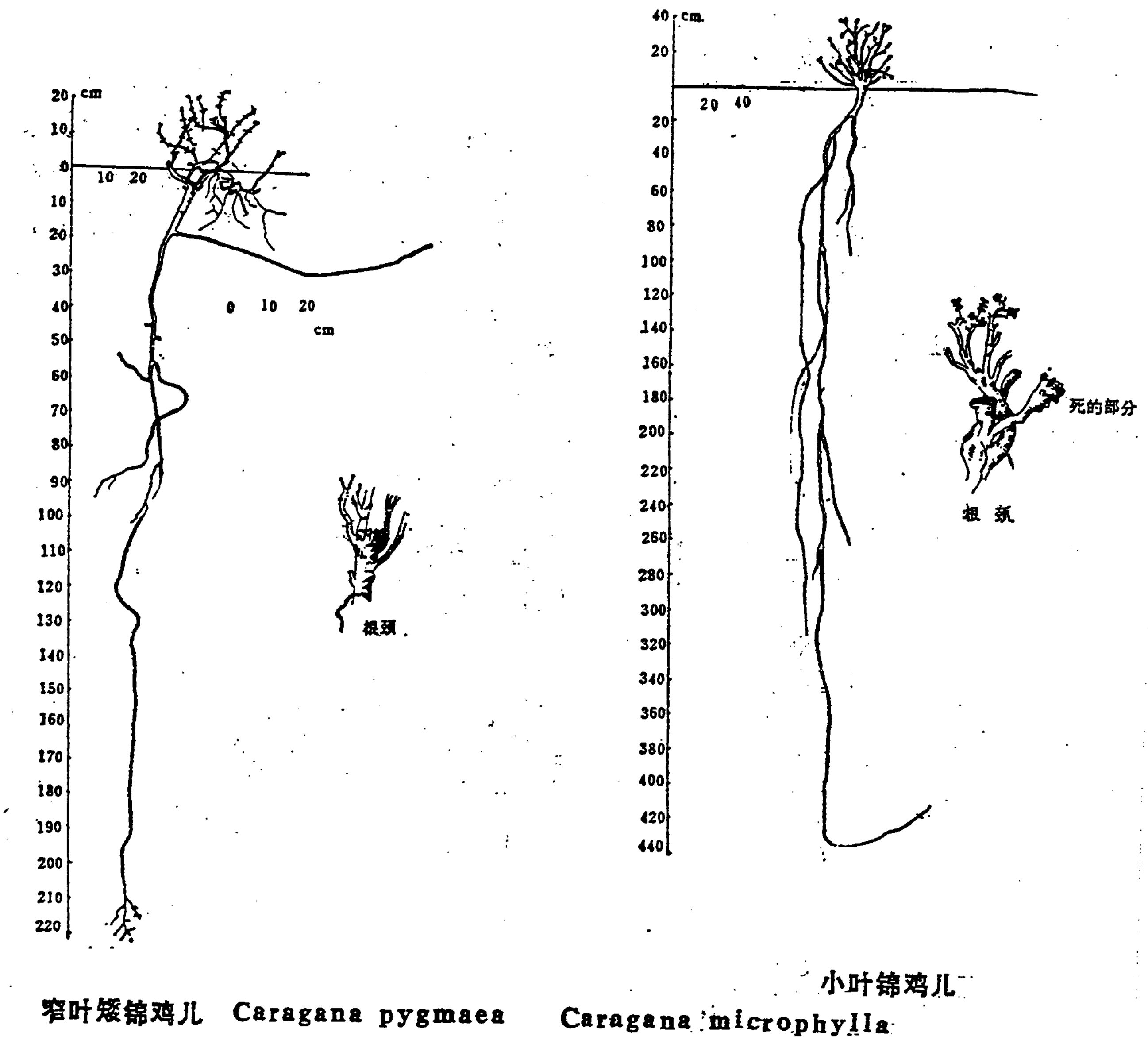

Figure 1. Root system profiles of Caragana pygmae and Caragana microphylla from Chen (1986). Chen notes the deep rooting habit of these shrubs, but sledom notes presence of nodules.

nitrogen fixation.

Many legumes are, however, deeply rooted. But the discovery of nodules is dependent on the preserverance of the nodule digger. The nature of the substrate (e.g. clayey or cobble copious) also may result in determination that a plant is not nodulated very commonly, when indeed it is otherwise. Legumes in the genus Lupinus provide a example of this. Lupines in arid environments often put down a considerable tap root. Nodules usually appear as several prominent protuberances on the tap root, usually after the root leaves the surface soil and enters sub-surface soil. Nodules, as a consequence, may exist very close to the surface in some undeveloped soils, but usually exist deeply in developed soils (unpublished data, S. E. Williams).

ACTINOMYCETE NODULATED PLANTS

Actinomycete or Frankia-nodulated plants have the potential to be important contributors of nitrogen to especially rangeland and some forest ecosystems. Table 2 tabulates the plants that are known to fix nitrogen through formation of nodules with actinomycetes.

Nitrogen fixation by actinomycete nodulated plants can be extremely important in rangeland, particularly shrub land, environments. Nitrogen fixation by Alnus spp.(alder) has been reported to be as much as 300 Kg per Ha (267 lbs per acre) annually, averaged over 25 years (Newton et al., 1978); however, these high rates have been measured under the rather mesic conditions of the Pacific Northwest. Estimates made by Binkley et al., 1994, range from 50 to 200 kg N fixed per ha (44 to 178 lbs per acre) are probably more realistic for this genus. Ceanothus, a genus peculiar to North America, inhabits a wide variety of environments from understory in coniferous forests to Chaparral and open environments. Youngberg and Wollum (1976) established a nitrogen fixation for Ceanothus velutinus of 108 Kg per Ha (96 lbs per acre) annually averaged over 10 years. However, Kummerow (1978) established a nitrogen fixation rate of 0.1 Kg per Ha (0.09 lbs per acre) annually for Ceanothus greggii. Other nitrogen fixing plants (Table 2) which are actinomycete nodulated, have been shown to fix variable amounts of nitrogen, but in arid environments, the quantities are undoubtedly low, although this nitrogen is likely crucial for the functioning of these ecosystems. Dalton and Zobel (1977) indicated that annual nitrogen fixation by Purshia tridentata (bitterbrush) was probably less than 1 kg N per ha (less than 0.9 lbs per acre) in Oregon. Shepherdia canadensis (buffaloberry)in clearcut sites of British Columbia was calculated to fix about 1 kg N per ha annually (Hendrickson and Burgess, 1989). Cercocarpus ledifolius (curl leaf

Table 2. Currently known actinomycete-nodulated plants (also known as Frankia-nodulated plants or Actinorhizal plants): taxonomic identity, geographic distribution and nature of sites occupied.

Family	Genera	No. Species[a]	Geographic distribution	Sites
Betulaceae	Alnus	47	N. America,Japan,S.Am. (Andes),Europe,Sibera,N. China.	Poor soils, sand hills/dunes glacial till, wet bogs, mine dumps, gravel, wastelands, volcanic ash.
Casuarinaceae	Allocasuarina[b]	54	Australia,central to western.	Hot and dry areas, low nutrient soils.
	Ceuthostoma[c]	2	Melanesian Is., Pacific.	
	Casuarina[b]	16	Australia.	Costal and fresh water. Warm to hot, subhumid to humid.
	Gymnostoma[b]	18	Papua New Guinea	Hot and humid.
Coriariaceae	Coriaria	16	Japan, New Zealand, Chile to Mexico.	Mediterranean to lowlands and subalpine, sandy or gravelly soils or clay.
Datiscaceae	Datisca[d]	1	California, western Nevada,and Baja California.	Dry stream beds or washes.

Elaeagnaceae	Elaeagnus	38	N. America,Asia,Europe.	Disturbed areas, sand dunes poor soils, riparian sites.
	Hippophae	3	Asia, Europe, from Himalayas to Arctic Cir.	Sand dunes,coastal areas.
	Shepherdia	3	North America	Sand soils, disturbed areas, riparian, under Pinus forests.
Myricaceae	Comptonia[e]	1	Northeastern N. America.	Dry, often barren, sandy soils.
	Myrica	28	Tropical, subtropical, and temperate regions extending to Arctic Cir.	Acid bogs, sand dunes, mine wastes.
Rhamnaceae	Adolphia[f]	2	California and Mexico.	Coastal, chaparral.
	Ceanothus	31	North America, espec. Western U. S.	Dry forest and chaparral, subalpine zones.
	Colletia	4	South America	
	Discaria	10	Andes, Brazil, Oceania.	Gravelly soils, arid zones.
	Kentrothamnus[g]	1	Argentina and Bolivia.	Matorral shrublands
	Retanilla[g]	2	Peru and Chile.	Matorral shrublands
	Talguenea[g]	1	Chile.	Matorral shrublands
	Trevoa[g]	6	Andes,especially Chile.	Matorral shrublands

Rosaceae	Cercocarpus	20	Western United States to Mexico.	Foothills, disturbed soils, rocky arid areas.
	Chamaebatia[h]	2	California	Chaparral
	Cowania	4	Utah,Arizona,New Mexico, Mexico (S. Colo.).	Foothills, high arid plateaus.
	Dryas	3	Alaska to Colorado in N. Am., Europe, Circumpolar.	High altitude and latitude, variable soils.
	Purshia	2	Western North America.	Disturbed soils on upland plains, foothills, and under Pinus forests, also deserts.
	Rubus[i]	250	Indonesia and No. Am.	Sand, rock sites, bogs.

a. Number of species, most are probably nodulated with the exception of Rubus.
b. Based on taxonomic separation of Casuarina to include Allocasuarina and Gymnostoma (Torrey and Berg, 1988; Wilson and Johnson, 1989).
c. Johnson, 1988, separated this genus from the other Casuarinaceae.
d. Taxonomy of plant described by Stone, 1993. Reported nodulated in Benson, 1988.
e. Habitate according to Gleason and Cronquist, 1991.
f. Habitate described by Sawyer, 1993.
g. Habitate referenced by Mabberley, 1981.
h. See Heisey et al., 1980.
i. The only observation of nodulated Rubus comes from Indonesia (Becking, 1979 and 1984), where at most two species have been reported to be nodulated. More recently discounted as a truely nodulated genus (Stowers, 1985).

mountain mahogany)in California was reported to fix 7 kg N per ha annually (Lepper and Fleschner, 1977).

White and Williams (1985) report that the actinomycete-nodulated plants Purshia tridentata and Cercocarpus montanus (ture mountain mahogany) do not nodulate in relatively high nitrate and organic matter soils (also see Peterson et al., 1991). It is tempting to extrapolate these findings to other actinomycetes nodulated plants; however, Alnus spp very frequently are actinomycete nodulated in very high organic matter riparian soils. It is, however, quite likely that such environments are quite low in mineral nitrogen.

Ceanothus

Aside from Alnus, the other genus of nitrogen fixing plants on forested sites in the Western United States is Ceanothus (Conard et al., 1985). Alnus is restricted to mostly riparian or mesic sites whereas Ceanothus occupies drier sites often at higher elevations or under Mediterranean climatic regimes (hot dry summers, cool wet winters). Ceanothus is a key and often dominant component of chaparral in Southern California. It serves to retard erosion on steep slopes (DeBano and Conrad, 1978) as well as impaction vegetation dynamics, nutrient cycling and wildlife habitat. Ceanothus also provides fuel for chaparral conflagrations which periodically burn in the mountains of Southern California.

Of the 31 species of Ceanothus, all probably nodulate and presumably fix nitrogen (Conard et al., 1985). Rates of nitrogen fixation have been worked out for only a few species on a hand-full of sites. Most of the work has been done with C. velutinus in the Cascade Range. It is apparent that this species is capable of fixing considerable nitrogen, annually up to 108 kg per ha (96 lbs per acre)(Youngberg and Wollum, 1976). Several researchers in independent studies, using variety of techniques tend to agree that C. velutinus is capable of considerable nitrogen fixation (Conard et al., 1985).

Published rates of nitrogen fixation by southerly species of Ceanothus, as well as those species occupying high sites in drier sites for example in the Rocky Mountains, are lacking. Work by Kummerow et al., 1978 indicated very low nodulation and nitrogen fixation by Ceanothus greggii. This is a desert Ceanothus species. An attempt to quantify N-fixation by C. crassifolius was made by Zinke (1969) who showed that soil accretion of N implied aa annual fixation rate of 28 kg N per ha (25 lbs per acre) and ecosystem accretion (soil plus litter plus biomass) implied an annual fixation rate of 76 kg N per ha (68 lbs per acre).

In unpublished work by one of the authors (SEW), distribution of nodules on *C. crassifolius* seemed dependent on age of plants and on soil characteristics. Plant age may very well correlate with depth to nodules. In mature plants, nodules appear often quite deeply in soil (Table 3). The zones of maximum nodulation seem to occur well below the soil surface in these sites. Nodules were observed to depths of 160 cm in 26 yr old sites with maximum nodulation occurring at approximately 80 to 120 cm. Although nitrogen fixation by this species varied greatly from one age class of plants to another, calculations showed that this plant fixed 332 kg N per ha (295 lbs per acre) over 26 years. This averages to 12.8 kg N per ha (11.4 lbs per acre) annually over the 26 year period.

Table 3. Root and nodule distribution with depth in a 26 year old *Ceanothus crassifolius* stand in the San Gabriel Mountains of Southern California.

Depth cm	Root dry weight	Nodule dry weight
	---------------grams per m^2----------	
0-20	40	0
21-40	647	3.55
41-60	126	6.86
61-80	56	25.72
81-100	76	4.75
101-120	279	18.33
121-140	31	0
141-160	85	0
161-180	39	0
181-200	19	0
201-220	16	0
221-240	21	0
241-260	6	0

Actinorhizal Shrubs in the Central Rocky Mountains

Of the actinorhizal shrubs known world wide,there are several which ma be very important in certain environments in the Central Rocky Mountains. These plants have high potential for use on disturbed lands. Members of the genus *Alnus* (common river alder) can be used in riparian areas, particularly in upland locations. Elaeagnus species (e.g. Russian olive) can be used for reclamation of riparian areas i lower elevations sites, although this plant is noted as a pest in some irrigated environments. Shepherdia species (buffaloberry) is common in clear-cuts and often is a member of the understory of conifers (especially Pinus species). Although Ceanothus species seem adapted to Mediterranean climates, there are several species that occupy uplant sites in the Central Rocky Mountains (e.g. Ceanothus velutinus).

Probably the most noteworthy group of actinorhizal plants in the Central Rocky Mountains are members of the Family Rosaceae. Species in the genus Cercocarpus (mountain mahogany) are wide spread, usually in foothills environments and usually on coarse, limestone substrates. Cowania species (cliff rose) occupies semi-arid plains, foothills and mountain slopes in Arizona, New Mexico, Utah and Mexico (Righetti, et al., 1986). Dryas species (mountain dryad) occupy slpine tundra sites, but it is not known if these plants bear nodules in zone south of Central Canada. Purshia species (bitterbrush) ocupy a diversity of sites from near desert to understory of pine forests. This plant genus has high potential for long-term reclamation (Righetti et al., 1986).

GERMINATION AND INOCULUM

Successful germination of many native legumes as well as nodulating non-legumes is the result of special treatment often in the way of cold stratification, treatment with hot water or with chemicals (e.g. thiourea). Even with such treatment, germination may be low, erratic or both.

Availability of nodulating organisms ranges from easily available to unavailable. Rhizobia strains for inoculation of legumes are available commercially. It is also fairly easy to isolate rhizobia from root nodules, although selection of the best strains may require considerable effort (Date and Halliday, 1987). Isolation of Frankia species from roots is much more difficult than isolation of Rhizobia. Frankia are relatively slow growing and do not compete well with other common microbial saprotrophs. Nodulating organisms have not been isolated from many of the actinomycete-nodulated plants. Numerous methods for isolation and cultivation Frankia are available. Lechevalier and Lechevalier (1988) summarize these methods and provide references for others.

CONCLUSIONS

It is apparent that nitrogen fixing associations between higher plants and certain bacteria, are capable of fixing considerable nitrogen under some conditions. Climatic, parent material, topographic and/or other biological conditions may limit nitrogen fixation under extensively managed systems and may result in very small amounts of nitrogen being fixed. None-the-less, nitrogen fixing plants even in very harsh conditions are often apparent because they remain active longer than surrounding plants. The nitrogen fixing habit of these plants may impact this enhanced activity. However, many legumes and nodulated non-legumes that occupy forest and range sites are very deep rooted. It is possible and probable that some of these plants nodulate only very deeply in soil, but their deep root systems may also access nutrients and water that are unavailable to shallow rooted plants. This deep rooted habit is important because it permits these plants to transcend surface phenomenon, reaching subsurface resources important to their long-term survival.

The low nitrogen fixation rates of some native legumes as well as actinomycete nodulated plants should not deter land managers from planting these important species. Although some nitrogen fixation rates may be very small, many of these systems are not nitrogen limited, but rather limited often by availability of water. Nitrogen fixation rates are perhaps only small when viewed annually, or when compared with rates of fixation under intensively managed systems. When viewed over centuries or longer, rates of nitrogen fixed may be very significant for meeting the nitrogen requirements of these often low productivity systems. Further, the nitrogen fixed by these systems, unless harvested by domesticated grazers, goes into the organic matter pool as organic nitrogen. The enhancement of nitrogen in the organic pool of these systems is more important to the long term stability and sustainability of these systems than providing above ground, nitrogen enhanced forage for domesticated grazers. Improvement of soil organic matter provides improved structure of the soil which has long-term benefits of enhancing water movement into soils as well as retarding wind and water erosion. Nitrogen associated with this organic matter component provides a slowly available nutrient for other plants. As such, protection of the nitrogen fixing plant and its nitrogen fixing apparatus from heavy grazing by ungulates may enhance longer term stability of a grassland or shrubland ecosystem. Some plant systems may provide a physical basis for their own protection (e.g. thorns on Caragana species partially protect these plants from grazing), whereas other may be unpalatable to grazers. Such plants may provide longer-term benefits to an ecosystem than plants not armed with thorns or unpalatability, but providing easily accessible and nutritious forage to ungulate grazers.

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COLLECTION AND PRODUCTION OF INDIGENOUS SEED FOR NATIONAL PARK RESTORATION PROJECTS

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ABSTRACT

With the passage of the National Transportation Act of 1982, the National Park Service receives Federal Highway Administration money to rehabilitate and upgrade deteriorating road systems within national parks. A decision was made to reseed disturbed roadsides with native indigenous plant materials to minimize erosion, compete with invading weeds, and restore native plant communities. To maintain the genetic integrity of the natural ecosystems, only indigenous plant material originating in close proximity of each road project was utilized.

Since 1986 the Bridger Plant Materials Center has worked with Yellowstone and Glacier National Parks to identify native species that can be readily collected, propagated on a large scale, and successfully reestablished on disturbed roadsides. Records are kept on collection date, collection time (grams/person hour), cleaning time, seeds/ kilogram, seed viability, and seed and plant production.

Given the commitment to use only native indigenous plant material, the National Park Service must determine what species would be native to open disturbances in a forest community, define the limits of a genotype, set allowance limits on natural selection and genetic drift of material produced remote to the park, and define what type of restored plant community is an acceptable end product.

INTRODUCTION

Revegetation, reclamation, and restoration--all imply the re-establishment of plant cover on a disturbed site, but if taken literally may imply three levels or intensities of mitigation. 'Revegetation' is simply the re-establishment of a plant cover, often a monoculture of an introduced cultivar. Although relatively inexpensive, revegetation may not offer permanence or ecological stability. 'Reclamation' often involves an attempt to restructure the soil profile and utilize native or well adapted cultivars. 'Restoration' not only requires the use of adapted native plant material, but also considers the genetic similarity and compatibility with adjacent undisturbed plant communities.

With the passage of the National Surface Transportation Act of 1982, Congress recognized a nation-wide need for rehabilitating and upgrading deteriorating road systems in national parks. In the past, most restoration within park boundaries was accomplished by natural means, i.e., plant propagules originating in salvaged topsoil or dispersed from adjacent, undisturbed plant communities. The National Park Service has established a policy of reseeding or replanting park disturbances with native indigenous species in an attempt to maintain the genetic integrity of the existing native plants. Restoration by seeding and planting, rather than by natural succession, is being used to establish a plant cover on disturbed sites to protect against surface water and wind erosion, and compete with invading weeds and exotic plant species.

A nation-wide cooperative agreement between the U.S. Department of Interior--National Park Service (NPS) and the U.S. Department of Agriculture-Natural Resources Conservation Service--Plant Materials Centers (PMCs) was established in 1986 to determine which native species could be collected, increased, and reestablished on disturbed road sites. The decision by the NPS to take the restoration approach has generated many unanswered questions and much controversy concerning the protection and preservation of the indigenous gene pools.

Some of these questions include the following:

1. Because a roadway creates an artificially exposed site within a forest community, what species can be considered indigenous to the sites?
2. What constitutes the limits of a genotype? How far from the project area can plant propagules be collected and still be within these limits?
3. What species can be readily collected and produced using standard cultural techniques?
4. By taking seed outside the park to a dissimilar environment to increase seed or plants, is genetic drift or natural selection going to impact the genetic integrity of the plant material?
5. Will the planting of collected and produced material significantly affect the development of plants from naturally occurring seed sources?
6. What type of plant community is an acceptable end product?
7. Is restoration worth the additional time and expense?

SPECIES SELECTION

Once the NPS made the decision to utilize native indigenous plant material in their restoration efforts, they first had to determine what species would naturally colonize on open disturbances within forest communities. In Yellowstone National Park the first road project (Old Faithful to West Thumb) was through lodgepole pine (*Pinus contorta*) habitat types, whereas in Glacier National Park the first project was along Lake McDonald through a cedar-hemlock (*Thuja plicata/Tsuga heterophylla*) forest. The open road corridor would not support the understory species of the forest communities. By examining abandoned roads, burns, old disturbances (both man-made and natural) and open parks and meadows in and adjacent to Yellowstone and Glacier Parks, it was possible to identify early colonizing species. These species consisted primarily of short-lived self-pollinating perennial grasses and a few perennial forbs (table 1).

Table 1. Native plant species found to reestablish naturally on disturbed sites in Yellowstone and Glacier National Parks .

COLONIZERS			
Short-lived Perennial Grasses		Perennial Forbs	
Elymus trachycaulus	slender wheatgrass	*Achillea millefolium*	western yarrow
Bromus marginatus	mountain brome	*Anaphalis margaritacea*	pearlyeverlasting
Elymus elymoides	bottlebrush squirreltail	*Phacelia hastata*	silverleaf phacelia
Elymus glaucus	blue wildrye	*Aster integrifolius*	thickstem aster
		Solidago canadensis	goldenrod
		Viguiera multiflora	showy goldeneye
LATE SERAL DOMINANTS			
Long-lived Perennial Grasses		Perennial Forbs	
Poa ampla	big bluegrass	*Lupinus argenteus*	silvery lupine
Deschampsia cespitosa	tufted hairgrass	*Eriogonum umbellatum*	sulphur eriogonum
Pseudoroegneria spicata	bluebunch wheatg.	*Penstemon confertus*	yellow penstemon
Festuca idahoensis	Idaho fescue	*Geranium viscosissimum*	sticky geranium
Poa alpina	alpine bluegrass	*Potentilla gracilis*	cinquefoil
Phleum alpina	alpine timothy		
Agrostis scabra	rough bentgrass		

Chambers et al. (1984), working in the alpine zone of the Beartooth Mountains of south-central Montana, found early colonizing species to have characteristics most desirable for reclamation of alpine disturbances. These species exhibited obvious ability to establish and grow on harsh phytotoxic sites, they frequently have larger ecological amplitudes, and they are distributed over wide geographic areas. Harper (1977) stated that early colonizing species usually had abundant and consistent seed production, effective seed dissemination, higher germination percentages, and broad tolerances for establishing on disturbed sites. Late seral dominants, on the other hand, as defined by Johnson and Billings (1962), are found on older and less severe disturbed sites. They are included in seed mixtures to speed up succession, but may not be totally successful because of competition from colonizers, or they may not be suited to the edaphic conditions of the disturbed site.

An examination of the existing seed bank in salvaged topsoil samples from the Craig Pass road project (YNP) revealed a limited number of species and quantities available. The only species that emerged in a greenhouse study were lodgepole pine, lupine, Ross's sedge (*Carex rosii*), elk sedge (*Carex geyeri*), and two short-lived forbs pussypaws (*Spraguea umbellata*) and groundsmoke (*Gayophytum diffusum*). The low level of seed and vegetative propagules that existed in the salvaged topsoil further supported the need for seeding road related disturbances, particularly in Yellowstone. There was a higher level of seed bank material in the salvaged topsoil in Glacier but it also had a higher level of exotics, which included timothy (*Phleum pratense*) and smooth brome (*Bromus inermis*).

GENOTYPE DETERMINATION

Presently all Yellowstone collections are made within park boundaries and usually within 8 to 10 km of the project site. In Glacier, seed is not only collected from within the park, but also from adjacent Forest Service land within the drainage and within the same habitat types. The genetic variability within and among plant populations vary by species, based on geographic range, reproduction mode, mating system, seed dispersal mechanism, and stage of succession (Hamrick 1983). Whether a species is self-pollinating or outcrossing makes a difference in genetic variability. The selfing mode of reproduction limits the movement of alleles from one population to another, so these species are found in small disjunct populations with little variation within populations, but distinct variation among populations. Outbreeding plants have widely dispersed pollen and seed and tend to have a lot of variation among individuals but less variation among populations. Species with winged or plumose seeds have the greatest potential for gene movement and subsequently have less variability among populations. Both Yellowstone and Glacier have high numbers of animals which increases the opportunity for gene movement via ingested or clinging seed.

To capture the genetic diversity of early successional stage (primarily selfed) plants, seed would have to be sampled from several populations within a project area. However, with late seral dominants (primarily outcrossed) the number of populations that would need to be harvested would be significantly less. Glacier Park contracted with Dr. Thomas Mitchell-Olds of the University of Montana to examine phenotypic and genotypic variation among different populations of strawberry (*Fragaria virginiana*) and among different populations and different generations of mountain brome. Based on electrophoretic banding patterns and differences in morphological characteristics (leaf size/number and stolon numbers), it was determined that east side (east of the Continental Divide) and west side populations of strawberry are significantly different. The genetic diversity of strawberry along environmental and geographic gradients on either side of the Divide was not significant.

When a disturbed site is planted with seed from an adjacent or close proximity site there is a possibility that a distinct, new genotype may develop. Jain and Bradshaw (1966) found that those species that evolve on a disturbed site may actually be genetically different than the plants of the same species on adjacent undisturbed sites. Antonovics (1968) found that on harsh sites affected by low pH and heavy metals, that grass species had the capability of changing from outcrossing to self-fertilization to prevent dilution of the gene pool by adjacent unadapted populations. This only raises the question of the need to harvest from many sites if a new distinct genotype will evolve on disturbed sites as influenced by the harshness and edaphic conditions of the site.

At this point, what actually constitutes a genotype is more theory than fact. Presently some national parks have self-imposed collection restrictions of 5 km for short-lived, selfing species, 8 km on short-lived outcrossing species, and up to 16 km on long-lived outcrossing species. These distances may be smaller if there are major changes in geography and plant communities within the project area.

SEED COLLECTION

Seed collection within national park boundaries can only be done by hand or using backpack vacuums. Collection outside of the park is also done by hand because of the rough terrain and/or small plant communities that are harvested. Hand collection consists of hand stripping or cutting off seedheads--a time-consuming task however it is performed. The National Park Service (NPS) utilize a variety of permanent, seasonal and volunteer employees to collect most of the seed, and after drying, send the harvested material to the Bridger PMC for cleaning. The amount of seed that can be harvested per person hour varies with species, density of the plant population, the yearly climate, degree of seed set, and the individuals collecting the seed (table 2).

Table 2. Seed collection rates of the primary plant species being used for restoration projects in Yellowstone National Park.

Common Name	Scientific Name	Number Collections	Time Ratio Range	Time Ratio Average
			grams/person-hour	
GRASSES				
mountain brome	*Bromus marginatus*	41	30/1008	269
slender wheatgrass	*Elymus trachycaulus*	68	35/976	235
bluegrasses	*Poa spp.*	17	8/514	149
blue wildrye	*Elymus glaucus*	39	23/465	147
bluebunch wheatgrass	*Pseudoroegneria spicata*	21	10/433	122
rough bentgrass	*Agrostis scabra*	11	29/197	94
tufted hairgrass	*Deschampsia cespitosa*	23	3/318	89
bottlebrush squirreltail	*Elymus elymoides*	15	12/195	77
Richardson needlegrass	*Stipa richardsonii*	6	23/118	67
Idaho fescue	*Festuca idahoensis*	25	13/162	63
subalpine needlegrass	*Stipa nelsonii*	22	9/96	43
FORBS				
showy goldeneye	*Viguiera multiflora*	5	28/332	126
penstemons	*Penstemon spp.*	32	14/454	105
helianthella	*Helianthella uniflora*	11	20/214	101
wild buckwheat	*Eriogonum umbellatum*	56	9/263	78
western yarrow	*Achillea millefolium*	63	3/188	53
thickstem aster	*Aster integrifolius*	20	3/136	52
lupines	*Lupinus spp.*	32	5/222	49
silverleaf phacelia	*Phacelia hastata*	23	4/300	46
pearlyeverlasting	*Anaphalis margaritacea*	18	3/149	41
goldenrod	*Solidago canadensis*	13	2/78	41
cinquefoils	*Potentilla gracilis/arguta*	31	9/110	39
hairy goldenaster	*Heterotheca villosa*	11	4/57	29
sticky geranium	*Geranium viscosissimum*	9	5/62	16

Some of the easiest species to collect are the short-lived pioneer species such as mountain brome and slender wheatgrass. Collection of seed from some forbs such as pussytoes (*Antennaria* sp.) and broadleaf arnica (*Arnica latifolia*) is very time consuming and probably not worth the effort. Seeds of a majority of the composites (Asteraceae Family) are difficult to collect because there is usually poor seed fill, the plumose seed has a very short time period between maturity and shattering, and there is significant insect predation on the seedheads. Those species that are easiest to collect are generally the easiest to produce because of their seed production potential and general high level of seed viability.

Since 1985, seed of 45 species of grasses and sedges, 66 species of forbs, and 30 species of trees and shrubs have been collected from 130 different sites in Yellowstone National Park. During the same time period seed of 35 species of grass, sedge and rush, 73 species of forbs, and 30 species of trees and shrubs were collected for 98 sites in and around Glacier National Park.

The cost of collection varies from about $40/kg for large-seeded grasses to well over $200/kg for some of the forbs. Cleaning and processing the seed can add another $10 to $20/kg to the overall cost. Compared to the cost of seed of introduced cultivars ($1 to $4/kg) or native cultivars ($5 to $40/kg), there is a definite added expense when using native indigenous plant materials.

SEED AND PLANT PRODUCTION

The Bridger PMC is located approximately 160 km northeast of YNP and 560 kilometers southeast of GNP. The elevation at Bridger is 1,128 m and the average growing season is 130 days. Seed is collected from sites at 1,800 m to 2,400 m in YNP and from elevations of 970m to 2,050 m in GNP--most sites having less than 100-day growing seasons. The biggest short-coming at Bridger, for seed production of mountainous species, has been the hot dry spring weather. Species that mature and set seed in August and September in the mountains will mature as early as late June or July in Bridger. Hot weather during anthesis will significantly reduce pollination and subsequent seed set.

Seed production fields are established by seeding 1-meter spaced rows at a rate of 90 pure-live-seed per linear meter of row. Fields are furrow irrigated, fall fertilized (60 kg nitrogen and 40 kg phosphorus/ha), and cultivated/sprayed following standard procedures used by most commercial seed growers. Extensive hand roguing is required to minimize weed and off-type invasion. Depending on the size of the seed increase field, seed is harvested by hand, head-harvested with a swather equipped with a canvas catch basin, or with one of two small plot combines. All harvesting equipment is thoroughly cleaned between harvesting of each individual ecotype.

There is some question as to how much natural selection and genetic drift will occur when seed is grown at a site remote from the source. Merrell (1981) stated that individuals developing at the same time, but under different environmental regimes, may have different phenotypes develop, even though their genotypes are essentially the same. Seed production at a site remote from and dissimilar to the original collection site has the potential for natural selection and genetic drift. There is a potential for a decrease in genetic diversity at several stages of production: the sizing nature of the cleaning process may exclude the largest and smallest seeds; harsh conditions at the time of germination and emergence may limit the survival to only the most viable seeds; as individual plants compete for space and nutrients in the seed production field some individuals may succumb to others; and during the harvesting process only those seeds that are mature at the time of harvest will be represented--early and late maturing individuals will be lost. Samples of three generations of mountain brome were evaluated both phenotypically and genotypically by Dr. Thomas Mitchell-Olds and Diane Pavek at the University of Montana-Missoula. The original collection (G_1) was collected in the Dickie Creek drainage adjacent to GNP (1987), the second generation (G_2) was produced at the Bridger PMC (1990) in a field established with G_1 seed, and the third generation (G_3) was produced at the Bridger PMC (1992) from a stand established with G_2 seed. Mithcell-Olds (1993) found that phenotypic variation (comparing morphological characteristics at three common garden sites in GNP) and genotypic variation (isozyme electrophoretic analysis utilizing 25 scorable bands) was non-significant among the three generations of mountain brome. The distance coefficients (after Johnson and Wischern 1982) and the similarity coefficients (after Gottlieb 1977) indicated that there was very little difference among the original mountain brome collection and the two subsequent generations grown at the Bridger PMC. Although this data is for one species only, it does support the potential of producing native indigenous plant materials at a site remote from their source. If electrophoretic techniques are to be used to define genotypic variation and divergence, the National Park Service must establish tolerance limits on all material produced remote to their respective parks.

If increased seed is to be used on restoration sites, the planning process must allow at least 3 years: the first to collect seed, the second to plant and establish a seed production field, and the third to make the first harvest. Three to four harvests can be taken from a field before production drops to an uneconomical level. The cost of producing seed under commercial conditions varies greatly with species, size of field, yearly environmental conditions, and the timing of harvest. However, seed production under cultivated conditions produces a more reliable quality and quantity of seed than under natural conditions.

To date, there are only a few private growers that are attempting to grow native indigenous ecotypes under contract with the National Park Service and U.S. Forest Service (table 3). Contracts with private growers should include some guarantee of genetic purity, usually a predetermined fixed price and an agreement to purchase all seed produced or allow surplus to be sold on the open market.

Table 3. Estimated cost of production of native ecotypes by commercial growers.

Scientific Name	Asking Price	
	$/pound	$/kilogram
Bromus marginatus	$3-$10	$6-$22
Deschampsia elongata	$10-$30	$22-66
Elymus glaucus	$8-$28	$18-62
Agrostis idahoensis	$9	$20
Glyceria elata	$8	$18
Elymus elymoides	$17	$37
Stipa comata	$75	$165
Stipa columbiana	$46	$101

Source: Contracts between U.S. Forest Service and private seed producers in Oregon.

RESTORATION TRIALS AND MONITORING

Test plots (YNP) and monitoring transects (GNP) have been established to monitor restoration success and successional progress. Plots in YNP compare seeded with natural regeneration, mulched with non-mulched, fertilization with non-fertilization, and north-facing slopes with south-facing slopes. These plots have shown the advantage of seeding with a mixture of native species. Natural regeneration in disturbed areas within a lodgepole pine /grouse whortleberry (*Vaccinium scoparium*) habitat-type was limited to Ross's sedge, elk sedge and lodgepole pine. The seeded plots quickly developed a dense cover of grasses and forbs while also allowing natural regeneration of the sedges and some forbs. However, lodgepole pine regeneration was inhibited by the seeded material and the sedges were not as robust as in the unseeded plots because of plant competition. Although the same seed mixture of six grasses and two forbs were used on both north-facing and south-facing slopes, the plant communities that developed after seven years were quite different. The more protected north-facing slope developed a more diverse plant community, consisting of a uniform amount of five grasses and good forb and tree regeneration. On the harsher south-facing slope the plant community is dominated by two grasses (slender wheatgrass and rough bentgrass) with virtually no forb or tree survival (table 4). At both sites the seeded plots were not invaded by a short lived perennial forb (groundsmoke - *Gayophytum diffusum*) during the second through fourth years as were the unseeded plots. The seeding process bypassed that successional stage altogether.

Mulching was done with a bark mulch (one-third cedar and two-third fir) at an average depth of 2.5 cm. Mulching did not have a significant affect on plant establishment and survival except in a few places where the mulch was applied too deep. In this situation, mulching actually inhibited plant establishment. However, based on the apparent results on other portions of the road project, mulching should not be ruled out because of the protection mulch provides against catastrophic weather events and unseasonable warm, dry spring weather at the time of germination and emergence. Mulching, like seeding, did restrict the establishment of annual and short-lived forbs--essentially skipping a successional stage.

The fertilization rate of 10 kg nitrogen per metric ton of bark mulch had no significant impact on plant establishment and survival or any influence on plant succession.

Table 4. Average percent plant composition of seeded and nonseeded species over all seeded treatments at two sites along the Craig Pass Road Project, YNP.

	Scaup Lake (north-facing)		Kepler Cascades (south-facing)	
Plant Species	1989	1995	1989	1995
	%	%	%	%
Seeded:				
Elymus trachycaulus	4	10	15	27
Bromus marginatus	19	2	21	11
Agrostis scabra	18	12	30	32
Elymus glaucus	10	20	5	7
Phleum alpinum	9	18	7	tr
Elymus elymoides	5	19	8	10
Lupinus argentea	3	tr	2	--
Potentilla gracilis	7	3	4	--
Nonseeded:				
Carex spp.	13	13	8	13
Pinus contorta	2	3	1	--
Lupinus spp.	tr	tr	tr	--

GNP monitoring of restoration projects has utilized the ECODATA ecological classification system developed by Region One of the U.S. Forest Service. Extensive monitoring has documented the success of their restoration efforts and aides in the determination of species use in subsequent restoration projects.

Both YNP and GNP have used container-produced forbs to supplement seeding in heavy use areas and for special aesthetic needs. On large projects the establishment of forbs with containerized material is cost and time prohibitive. Plots were established along the Craig Pass road project (Little Thumb Cr.) to evaluate the establishment and longevity of 12 species of forbs (table 5). Replicated plots of the forbs were fall dormant seeded along with 70 seeds/m^2 each of mountain brome and slender wheatgrass. Plots were evaluated three times per year to monitor the extent of mortality and delayed germination.

Table 5. Stand density of seeded forbs at the little thumb Creek test plots in YNP.

Forb Species	Plant Density (plants /m^2)					
	1990	1991	1992	1993	1994	1995
Achillea millefolium	411	156	133	158	158	123
Eriogonum umbellatum	179	176	117	101	88	115
Phacelia hastata	305	148	133	88	81	73
Aster integrifolius	190	86	68	66	63	69
Solidago sp.	203	38	37	45	43	46
Anaphalis margaritacea	215	35	28	45	42	44
Penstemon sp.	50	58	68	55	47	41
Lupinus argentea	122	51	46	38	20	19
Chaenactis douglasii	115	82	49	32	12	7
Arnica latifolia	22	11	4	4	5	7
Heterotheca villosa	30	7	5	6	1	4
Antennaria umbrinella	29	2	3	6	4	4

Through the interpretation of test plots, monitoring and basic trial and error the National Park Service has been able to narrow down the number of species they are working with and develop successful seed mixtures for each different project area (table 6). They have been able to custom fit seed mixtures for specific climatic and edaphic conditions.

Table 6. Basic seed mixtures developed for different vegetation types in Glacier and Yellowstone National Parks (other species are used as available).

GNP--Alpine	GNP--Fescue Grasslands	GNP--Cedar/Hemlock
*Poa alpina**	*Bromus marginatus**	*Bromus marginatus**
*Phleum alpinum**	*Pseudoroegneria spicata**	*Elymus glaucus**
*Poa gracillima**	*Festuca idahoensis**	*Deschampsia cespitosa**
Deschampsia atropurpurea	*Festuca compestris**	*Calamagrostis rubescens*
Carex hayeniana	*Koeleria macrantha**	
	*Elymus trachycaulus**	*Achillea millefolium**
Aster laevis		*Penstemon confertus*
Sibbaldia procumbens	*Gaillardia aristata**	*Penstemon albertinus*
Senecio triangularis	*Hedysarum boreale**	*Rosa woodsii**
Erythromium grandiflorum	*Geranium viscosissimum*	*Symphoricarpos albus**
	Solidago canadensis	
	*Potentilla gracilis**	
YNP--Lodgepole Pine Forest	**YNP--Northern Grasslands**	**YNP--Wetlands**
*Bromus marginatus**	*Stipa comata**	*Deschampsia cespitosa**
*Elymus trachycaulus**	*Pascopyrum smithii**	*Agrostis scabra**
*Elymus elymoides**	*Leymus cinereus**	*Elymus trachycaulus**
*Agrostis scabra**	*Stipa viridula**	
*Poa ampla**	*Bromus anomalus**	*Pedicularis goenlandica*
		Gentiana detonsa
*Achillea millefolium**	*Achillea millefolium**	
*Lupinus sericeus**	*Linum lewisii**	
*Phacelia hastata**	*Potentilla fruticosa*	
*Potentilla gracilis**		
Eriogonum umbellatum		
*Viguiera multiflora**		

* Species of which seed or plants have successfully been produced at the Bridger Plant Materials Center.

To maximize species diversity and productivity, plants should be chosen to minimize competitive interactions in mixtures. The goal of the restoration effort is to produce a plant community that is as stable as the adjacent undisturbed area. The nature of the disturbance may place constraints on both the ability to reclaim a site and the subsequent succession processes that occur on that site (Chambers et al. 1990). To minimize competition seed mixtures should not be too complex. With linear disturbances, in particular, seed rain from adjacent areas will provide added species diversity to a seeded plant community.

SUMMARY

The National Park Service has made a commitment to restore all disturbances within their boundaries by salvaging and restoring topsoil and identifying, collecting, producing, and replanting native indigenous plant material. With this commitment comes the task of defining the limits of a genotype, setting allowance limits on natural selection and genetic drift of material produced remote to the parks, and defining what type of plant community is a stable, acceptable end product.

Maintaining the genetic integrity of native plant populations is one of the National Park Service's top priorities in restoration of their road projects and although it may be expensive, this approach is one of the few ways to ensure that the gene pool is kept pure (or nearly so).

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RESTORATION OF DREDGE TAILINGS FOR THE BLUE RIVER WALK IN BRECKENRIDGE, COLORADO

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ABSTRACT

Hundreds of acres of dredge tailing spoil piles have covered the Blue River valley floor from just south of Dillon Reservoir to the center of Breckenridge since the gold boom in the late 19th and early 20th centuries. Over the last 90 years few plants have colonized these areas due to the loss of most soil and fine materials in the dredging process.

Since 1992 the Town of Breckenridge has been converting a tailings area along a half mile of river in the heart of town into a restored montane landscape setting for the new Blue River Events Center and Blue River Walk trail system. This complex includes 5 acres of restored aspen woodland, lodgepole pine and blue spruce woodland, montane meadow, big sagebrush shrubland, and riparian meadow and wetland along a newly restored Blue River stream channel.

The restoration project has focused on the use of salvaged local fresh topsoils and indigenous plant materials. Seeds and cuttings of local vegetation have been contract grown in a nursery and re-introduced to the site along with salvaged transplant materials from development sites in the valley.

INTRODUCTION

About one hundreds years ago, in an area the Ute Indians prized for hunting and trapping, a devastating type of mining disturbed hundreds of acres of the Blue River Valley to depths of up to ninety feet. While other forms of gold mining had preceded it for almost 40 years, dredge mining was to be one of the most destructive. It turned thousands of years of valley floor development upside down. The soil and organic matter that wasn't washed downstream was mixed into the remaining glacial till and alluvial deposits, leaving a hummocky landscape of dredge tailings barren of most vegetation.

In this century some of the dredge tailing piles have been mined for aggregate or leveled for parking lots and development. In 1988 Breckenridge purchased an eleven acre parcel of leveled dredge spoil material in the center of town previously used as overflow ski parking. What was left of the Blue River flowed down a steep sided channel through the length of the property. No longer meandering through beaver meadows thick with willows, alders, and sedges, this stretch of the river had very little vegetation to shade the channel which usually ran dry from late August until spring thaw.

PROJECT DESCRIPTION

In 1991, the Town of Breckenridge decided to daylight the stream and build a park-like setting with a year-round waterway. A landscape architect (Wenk and Associates, Denver, Colorado) was hired to design the park to include an event center and lawn, vehicular and pedestrian roads, paths and bridges, parking lots, vegetated areas and a restored river channel. Originally the vegetation was specified to be simply "*native*" vegetation. It sounded good on paper, but years of experience growing "*native*" and "*adapted*" plants for the other city gardens had required intense maintenance to replace dead and struggling *non-adapted* native and introduced species.

Breckenridge lies at 9600 feet elevation and proves a stressful environment for vegetation with an average of only 30 frost-free days per summer growing season. In order to reduce the effort required to keep this park setting attractive, it was decided to focus the revegetation on a restoration of the historic Blue River valley plant communities and actual local native species. The goal became the restoration of an aesthetically enhanced version of the valley prior to dredging. To accomplish this a goal a restoration consultant (Keammerer Ecological Consultants, Inc., Boulder, Colorado) and soils consultant (Walsh and Associates, Inc., Boulder, Colorado) were brought onto the team.

Channel Reconstruction

In spring of 1993 the River Walk Center was constructed and the river channel widened and regraded, removing 90,000 tons of dredge tailings. About half of the tailings were screened to recapture the fine materials which were returned to cover the cobble in the river channel. A 15,000 square yard, 40 mil PVC liner was sandwiched between two layers of Mirafi-140, a 1/2 inch felt like fabric, for protection. These were placed in the channel to create a water proof carrier for the river. The liner was covered with four to five feet of cobble in the center and less at the edges. The banks were graded at a 2:1 slope a distance of 50 to 75 feet on each side of the channel to accommodate the liner extension, soil placement and future landscaping. Rounded boulders were placed in the channel to armor the shores and create a natural stream configuration. Massive dry stack sandstone walls were constructed along the corridor to reduce the side slope gradients and retain the foundations of pre-existing structures.

Plant Community Restoration

Once the structural features began to take shape, the restoration of native plant communities. was initiated. Relatively undisturbed portions of the upper Blue River Valley area were evaluated to determine what the pre-mining landscape might have contained. It was determined that the riparian areas probably consisted of a complex of sedges, alders and willows. The surrounding drier valley floor was most likely a patchwork of Lodgepole Pine (*Pinus contorta*) and Aspen (*Populus tremuloides*) woodlands in a matrix of low sagebrush (*Seriphidium canum* and *S. vaseyanum*) shrublands and grassy meadows. Occasional spruce (*Picea pungens*) and Narrowleaf Cottonwoods (*Populus angustifolia*) probably anchored the streamsides. These plant communities were identified as the target restoration vegetation. The newly created land forms were evaluated for suitability to support the targeted plant communities.

To replace the soil layer lost in the dredging process three sources of replacement soils were identified. These were: excess cut materials from a road construction site, old sagebrush shrubland topsoil stockpiled at a gravel pit located ten miles downstream, and fresh topsoil salvaged from a construction site called the "bench" in lodgepole pine forest and sagebrush shrubland on the valley slope above the project area. The soil characteristics of each of these borrow soils were studied and compared with those of the targeted plant communities. The gravel pit and road cut materials were determined to be better used in a subsoil position, while the fresh soil from the "bench" development site was used to topdress most of the sites. One restored sagebrush slope used mostly the older stockpiled gravel pit soils, but was topdressed with fresh pocket gopher diggings from a local sagebrush shrubland in order to inoculate the restored area with viable soil microorganisms.

Seed collection began as soon as the target plant communities were selected. Local genotype seeds were collected at these sites throughout the growing season for three years of construction in order to obtain the greatest community diversity possible. Each year some of the seed was sent to a grower (Pleasant Avenue Nursery, Buena Vista, Colorado) to produce the planting stock. These larger nursery grown plants assured a floral display in this highly visible area years sooner than could be expected from direct seeding. After testing the seed for germination in the fall, seeds were pre-treated and sown. The seedlings were transplanted into 4 by 4 inch pots with a 4 3/4 inch depth to assure space for the development of a heavy root system prior to transplanting into the site. This size was found to be superior to the more common one gallon container because the root mass could fill the soil volume sooner and permit earlier planting on the site. The nursery potting soil consisted of a relatively heavy mix of 25% native topsoil, 15% sand, 10% pearlite, 25% soil-less potting mixture, and 25% sphagnum peat. This combination was heavy enough to reduce the danger of plant loss from frost heave, promote easy absorption of moisture into the potting mix, and encourage root growth into the surrounding soil after planting. Cuttings of local woody species were also grown at the nursery and returned to the project rooted and ready to plant. In all, over twelve thousand shrubs and herbaceous plants were purchased from nurseries, many of these were contract grown from local genotype seed or cuttings.

Collected seed was air dried and processed in a chipper shredder for direct seeding. Seeds mixtures were designed for different slopes, aspects, moisture or shade levels in each plant community. Many species were planted singly in order to avoid large homogenous "wildflower meadow in a can" type results. This required over seeding the same area many times to apply all the desired species for each plant community.

When the local seed was unavailable, difficult to obtain or larger plants were needed, materials from outside the Breckenridge area were imported. This was particularly true for the larger shrubs and trees purchased from nurseries and collectors in the region.

One of the most valuable sources of restoration materials for the project came from the same development site used as a fresh topsoil source. Prior to the removal of topsoil from the proposed road right of way on the "bench" site, the restoration crew salvaged eight thousand of 1 to 5 gallon containers of local native plants. These potted plants were actually small plugs of the targeted communities complete with soil, microorganisms, seeds, and a mixture of species. The survivorship of these transplanted materials was very high for several reasons. Only species lacking deep taproots were collected. Smaller specimens of shrub species were selected over larger individuals, care was taken to fill the voids in the pots with soil to assure uniform moisture for the root systems. Collected pots were moved into a wooded site where the pots could be mulched with pine needle duff, and watered regularly.

Once a site was prepared and topsoiled the nursery or transplant stock appropriate to the targeted plant community was installed. An effort was made to locate plants in micro-environments favorable for their survival. The dry stacked sandstone 'cliffs' presented some of the most interesting challenges and opportunities. Much effort went into placing rich organic soil into the cracks and planting the appropriate species in locations where water would drain down the crack system and water the plants. With the short summers in Breckenridge, the planting season could continue through the cool high elevation summer until snow fall.

Problems

At this time the project is entering the third growing season. As with most restoration projects there are weeds. The high visibility of the project requires consistent weed management to maintain an acceptable appearance. All areas are being irrigated throughout the establishment phase. The need for watering and weeding should diminish over time. Some areas may require additional hard surfaced trails and stairs to reduce the soil compaction and plant damage from informal 'cut off' paths.

The project was comparable in cost to a detailed landscape installation. Four factors contributed significantly to the expense: the project's location in the mountains, necessity for extensive regrading, the need to import all soils, and the desire for an early floral display necessitating the use of nursery grown native stock.

Opportunities

The Breckenridge River Walk is an unusual project for a mountain town. The degree of effort to restore native vegetation to this section of highly disturbed mined land is closer to the detail applied to the landscape surrounding a national park visitors center. This is not too surprising since the goals and problems facing Breckenridge are similar to those facing a high volume national park. In both areas the goal is to restore functional, attractive, native vegetation as a setting for a heavily trafficked tourist focal point. In these park sites the diversity and natural beauty of the nearby ecosystems is echoed in a concentrated display. These restored landscapes serve to create continuity with the local ecosystems and provide an opportunity to educate visitors regarding the key features, processes and sensitivities of these surrounding natural areas. This may result in a greater understanding and enjoyment of the environment as well as more responsible use of local natural resources. Parks support this public usage through development of interpretive programs. At this time an interpretive program is under consideration for the River Walk area. This program would consist of explanatory signs, a brochure, and periodic guided tour program.

Signs: Sturdy metal signs are relatively vandal proof and can be printed with line drawings, text, and photographs in black on white or in color. Subjects could include geologic crossections of the valley, mining impacts, historic photos, river restoration, pre-mining valley ecosystems, existing valley ecosystems, local wildlife and wildflowers. Smaller signs could describe individual areas in the restoration and identify some of the common or colorful plant species present in the area.

Tours: The members of the River Walk Crew could lead guided tours through the restoration area. Visitors could discuss the techniques used to create the Blue River Walk. These tours could be scheduled for Monday or Friday afternoons, as requested. The crew has learned from their labor many of the steps required for a successful restoration. Some additional training could deepen their knowledge and add to the ownership and pride they feel for their work on this unique project.

Brochure: An interpretive brochure could be available at the Events Center. This would be keyed to a series of numbered signs in the River Walk or simply follow a map through the area. Individual descriptions would focus on the different restored ecosystems (aspen woodland, lodgepole pine forest, sagebrush shrubland, montane meadow, scree slope, and streamside wetland) as well as historic details (dredge pond, historic buildings, etc.). The brochure could describe the restoration process, which is a new concept in landscape design. This would support deeper understanding of the River Walk design when tours are unavailable. Participation in the careful treatment of the area would be requested as the visitor is informed of the uniqueness of the area.

CONCLUSION

The Breckenridge Blue River Walk is an important demonstration restoration project for Summit County. Well positioned for visibility, many people will see this area and be could be encouraged to undertake similar projects, expanding the reintroduction of native ecosystems to other weedy, disturbed properties within the Blue River valley. The result could be a more natural, attractive, and enduring landscape. Innovative public projects such as the River Walk can contribute to the appearance and ecosystem health of the whole region.

CAMOUFLAGED CHANNELS CORRAL RUNOFF AT THE HORSE RANCH

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ABSTRACT

An exclusive housing development constructed upstream of a world renowned trout fishery in the heart of the Rocky Mountains of Colorado demanded superior and efficient erosion protection. Soft green landscape was desired but with the project located in a mountain valley with a 325 hectare (800 acre) drainage basin subject to heavy annual snowfall and high runoff velocities, the designer was forced to consider hard armor systems such as rock riprap and concrete paving. Aesthetic concerns ruled out hard armor systems and a three-dimensional permanent geosynthetic erosion mat which extends the performance limits of vegetation was installed in approximately 5 kilometers (3.1 miles) of camouflaged surface water drainage channels. The main channels are 3 meters (10 feet) wide with lateral channels 1.5 meters (5 feet) in width. Installation details and on-site assistance were supplied by the manufacturer of the geosynthetic erosion mat and the performance has been monitored for two years.

This paper presents a detailed overview of this challenging project, including design calculations, cross-sections, installation challenges, a cost analysis and long-term performance. Using this information, a detailed positive conclusion is drawn on the cost effectiveness of geosynthetic erosion mats as lining materials in surface water drainage channels.

CHANNEL STABILIZATION

Stabilization against waterway erosion, bed scour, and undermining of slopes is typically accomplished with either rigid or flexible lining systems. The primary difference between the two categories is their response to changing channel shape. Flexible linings can conform to a wide variety of contours, obstacles and geometries while rigid linings may not. Although rigid linings may generally withstand higher discharges, flow velocities and shear stresses, they may fail entirely if a portion of the lining is damaged. Rigid linings are susceptible to subsidence and frost heave, prohibit infiltration, are unable to capture sediment, accelerate runoff velocities and discharges, exhibit an unnatural appearance, provide no wildlife habitat, and are costly to construct. Flexible vegetated linings, on the other hand, are significantly less expensive, feature a natural appearance, are easier to install, permit infiltration and exfiltration, capture sediment and thus provide better habitat opportunities for local flora and fauna (Chen and Cotton, 1988).

BIOTECHNICAL COMPOSITES™ are a family of geosynthetic materials comprised of non-degradable components that furnish temporary erosion protection, accelerate vegetative growth, and ultimately become synergistically entangled with living plant tissue to permanently extend the performance limits of natural vegetation used in channel stabilization. Exhaustive field and laboratory studies have verified that flexible, three-dimensional geosynthetic erosion mats can create a "soft armor" channel lining system capable of providing twice the performance of unreinforced vegetation (Theisen, 1991). Proven performance has allowed geosynthetic mattings to occupy one of the fastest growing niches in the erosion and sediment control industry (Austin and Theisen, 1994).

CHANNEL LINING MATERIAL SELECTION

Designing storm water runoff channels for the exclusive Horse Ranch community near Aspen, Colorado situated at 2440 meters (8000 feet) above sea level in the heart of the Rocky Mountains was a formidable task. The civil engineers faced several challenges including: heavy annual snowfall; slopes as steep as 20% erodible; low fertility soils composed of silty to sandy clays and shale; relatively high channel velocities; soil-drying southern exposures; a three to four-month growing season; and saturated soil conditions (Northcutt, 1994). Local water quality concerns due to the development's location upstream of Brush Creek which empties into the world renowned Roaring Fork River trout stream, combined with the residents' strong sentiments for aesthetically pleasing natural landscaping techniques positioned the owner, Snowmass Land Company, between a "rock and a hard place", literally! (Figure 1).

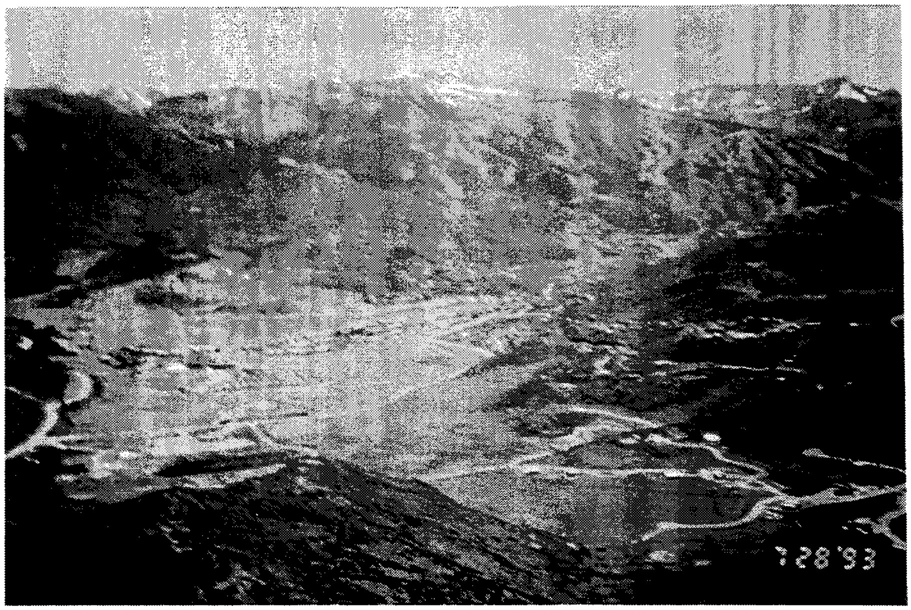

Figure 1. Aerial View of Horse Ranch Housing Community and Drainage Basin

Reducing runoff velocities, as well as controlling erosion and subsequent sedimentation during storm water collection of the mountainous 325 hectare (800 acre) drainage basin compelled the project engineers, Drexel Barrell of Boulder, Colorado, to consider both rigid and flexible lining materials for the channels. Water quality, freeze-thaw, aesthetic and cost concerns quickly ruled out concrete lined channels as an option for the 5 kilometers (3.1 miles) of main and lateral storm water channels. Riprap was also considered an expensive overkill and "environmentally unfriendly" while unreinforced natural vegetation could not accommodate the anticipated velocities of 1.7 to 3.3 m/sec (5.6 to 10.8 ft/sec). Research has confirmed the velocity limit for unreinforced, strongly rhizomatous, sod-forming grasses under ideal growth conditions (approaching 100 percent cover) in non-erosive soils is, at best, 1.8 m/sec (6 ft/sec) while less closely-knit vegetation persisting under sub-optimal conditions in more highly erosive soils may fail at velocities of less than 1 m/sec (2 to 3 ft/sec)(Carroll et al, 1991; Chen and Cotton, 1988; Hewlett et al, 1987; Theisen, 1992; Western Canada Hydraulic Laboratories, 1979).

Several degradable products have been designed to facilitate establishment of vegetation and offer short-term erosion protection. Although "high velocity" straw, coconut, and excelsior blankets as well as fiber roving systems may temporarily resist the expected velocities, these products do not augment long-term erosion protection due to the desired degradation of their components. Their primary function is to establish vegetation; not to reinforce it. As these materials undergo degradation, only unreinforced vegetation will remain to protect the channel. In addition, the performance of many natural fiber blankets under sustained flow events (> 1 hour) has yet to be documented. Due to their temporary nature, these materials were inappropriate for the long-term channel stabilization required on this project.

Focusing on long-term erosion protection as well as establishing vegetation in the channels, Drexel Barrell then reviewed permanent geosynthetic "soft armor" alternatives and learned of the long and successful performance of turf reinforcement mats (TRMs). Turf reinforcement is a method or system by which the natural ability of plants to protect soil from erosion is enhanced through the use of geosynthetic materials. A flexible three-dimensional matrix retains seeds and soil, stimulates seed germination, accelerates seedling development and most importantly, synergistically meshes with developing plant roots and shoots (International Erosion Control Association, 1992). In laboratory and field analyses, biotechnically-reinforced systems have resisted flow rates in excess of 4.3 m/sec (14 ft/sec) for durations of over two days (50 hours), providing twice the erosion protection of unreinforced vegetation (Carroll et al, 1991; Hewlett et al, 1987; Theisen, 1991; Theisen,1992). Such performance has resulted in the widespread practice of TRMs as alternatives to concrete, rock riprap, and other armor systems in the protection of open channels, drainage ditches, detention basins and steepened slopes. An overview of the performance of various channel lining techniques is presented in Figure 2. This data provides both short-term and long-term performance guidelines.

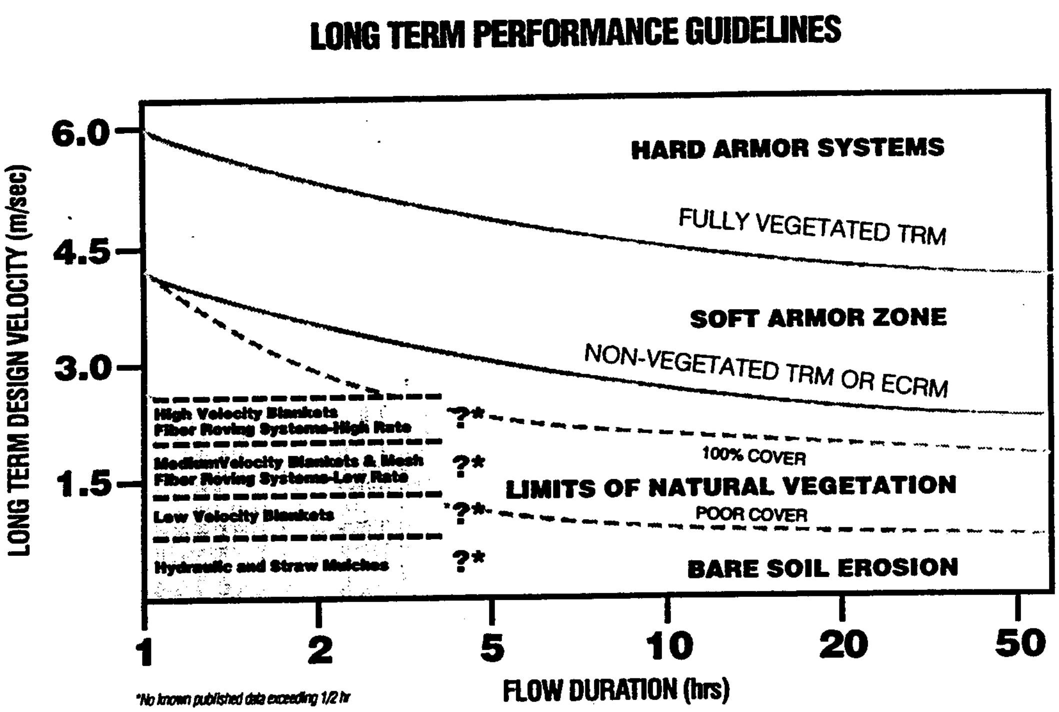

Figure 2. Performance Guidelines of Various Channel Lining Materials.
(Adopted from IECA, 1992)

Permanent geosynthetic mattings are composed of durable synthetic materials, stabilized against ultraviolet degradation and inert to chemicals normally encountered in a natural soil environment. These mattings consist of a lofty web of mechanically or melt-bonded polymer nettings, monofilaments or fibers which are entangled to form a strong and dimensionally stable matrix. Polymers include polypropylene, polyethylene, nylon, and polyvinyl chloride (Theisen, 1991).

Geosynthetic mattings generally fall into two categories: Turf Reinforcements Mats (TRMs) or Erosion Control Revegetation Mats (ECRMs). Schematics of these two product categories are shown in Figure 3. Higher strength TRMs provide sufficient thickness and void space to permit soil filling/retention and the development of vegetation within the matrix. TRMs are installed first, then seeded and filled with soil. Seeded prior to installation, ECRMs are denser, lower profile mats designed to provide long-term ground cover and erosion protection. ECRMs rely upon sediment capture for increased long-term stability. By their nature of installation TRMs can be expected to provide more vegetative entanglement and better long term performance than ECRMs. However, denser ECRMs may provide superior temporary erosion protection (Theisen, 1991).

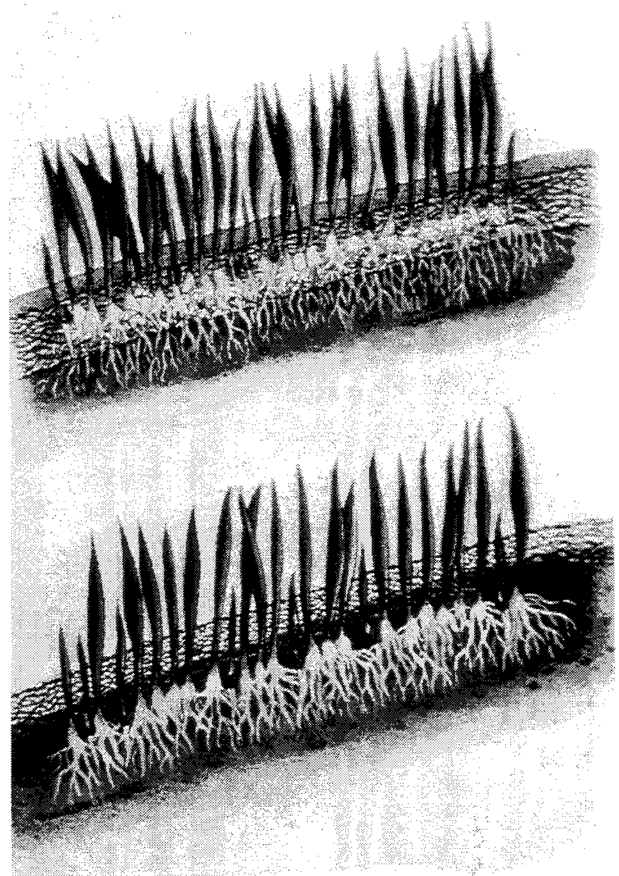

Figure 3. Schematics of TRM and ECRM

DESIGN PROCEDURES

After assessing the aggressive hydraulic conditions at the Horse Ranch, Drexel Barrell considered a TRM to line the trapezoidal main and lateral channels. Assigning an average Manning's roughness coefficient of 0.032, the engineers proceeded with the hydraulic design. Initial calculations indicated an average design velocity of 3.3 m/sec (11 ft/sec) with maximum short duration velocities approaching 4.6 m/sec (15 ft/sec). These calculations further supported the consideration of a TRM.

The channel side slopes were initially set at 4H:1V to maintain velocities and depths of flow within the performance limits of the TRM. A review of Synthetic Industries' published technical reports on the results of a 2-year study at a western U.S. water research laboratory provided maximum permissible design velocity and shear stress values for LANDLOK® TRM 1060. Unvegetated, this material will resist velocities of 6.1 m/sec (20 ft/sec) under short-term flow conditions (30 minutes) and up to 4.3 m/sec (14 ft/sec) under long-term events (50 hours). Furthermore, the maximum shear stress values reported are 39.1 kg/m^2 (8 lbs/ft^2) for short-term and 24.4 kg/m^2 (5 lbs/ft^2) for long-term storm events (Theisen, 1992)

The engineers' approach was a series of grass-lined, TRM-reinforced channels designed to handle a 100-year storm. A 1.6 km (1 mile) long main channel was to run through the subdivision with 11 smaller laterals entering or feeding into the main system. After selecting a proposed location and alignment, Drexel Barrell used a volumetric approach to estimate the watershed flow in the storm water diversion channel (Soil Conservation Society, 1986). The design discharge in the channel was then converted into average velocity using the Continuity Equation (French, 1985). This is expressed as:

$$Q\text{-}AV_{ave}$$

Where:	Q	=	design discharge in the channel, m^3/sec (ft^3/sec)
	A	=	flow area in the channel, m^2 (ft^2)
	V_{ave}	=	average velocity in the cross-section, m/sec (ft/sec)

An initial cross-section was selected and based upon a permissible velocity approach, actual flow conditions and the normal depth of flow were calculated using Manning's Equation. The flow conditions are a function of channel geometry, design discharge, channel roughness (unique to the selected channel lining material), and channel slope (French, 1985). The velocity was then computed as:

$$V_{ave}\text{-}\frac{\theta}{n}R^{2/3}S_f^{1/2}$$

Where:	V_{ave}	=	average velocity in the cross-section, m/sec (ft/sec)
	ϕ	=	factor correcting system of units used (ϕ = 1.49 for English units and ϕ = 1.0 for Metric units)
	n	=	Manning's roughness coefficient
	R	=	hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter, P
	S_f	=	friction slope of the channel approximated by the average bed slope (for uniform flow conditions)

Eleven (11) different design "points" were taken from within the storm water channel system and maximum conditions were calculated from the 100-year storm. Initial results of the hydraulic analyses are shown in Table 1.

Analyzing the worst case scenario for the turf reinforcement mat (long-term, unvegetated conditions), the highest expected design velocity (located a design point B), V_{ave}, was compared to the maximum permissible design velocity of the TRM, V_{max}, to determine the factor of safety against failure of the lining material:

$$FS=\frac{V_{max}}{V_{ave}}=\frac{4.3 m/sec}{3.3 m/sec}=1.3 \qquad \underline{\underline{OK}}$$

Based upon these results, the engineers concluded that the TRM would be stable when subjected to the velocities associated with long-term, unvegetated conditions of the 100-year storm. Drexel Barrell was prepared to specify a TRM for velocities above 1.8 m/sec (6.0 ft/sec) contingent upon one final analysis.

Table 1. Initial Maximum Permissible Velocity Design Parameters

Channel Design Point	Approx. Slope (%)	Bottom Width (m)	Max Flow (m^3/sec)	Max Velocity (m/sec)
A	13.5	3	2.0	2.9
B	20	3	1.9	3.3
C	20	0*	0.6	2.9
D	10	3	2.8	2.9
E	8	0*	0.3	1.7
F	11	1.5	1.8	2.9
G	20	0*	0.5	2.5
H	5	0*	0.7	2.7
I	13	0*	0.5	1.8
J	10	0*	0.3	2.4
K	5	1.2	12.2	2.9

* Indicates V-shaped channels were initially selected due to spatial limitations. All design points represent trapezoidal-shaped channels.

The hydraulic tractive force, or shear stress, developed in the channel cannot exceed the permissible shear stress of the TRM. As an additional safety check, an analysis was performed that manipulated the Tractive Force Equation with the channel geometry, flow conditions, and the UWRL test results for the design storm (Chen and Cotton, 1988). The maximum shear stress was then computed:

$$T_{ave} \text{-} WRS_f \qquad (3)$$

Where

T_{ave}	=	average shear stress in cross-section, kg/m^2 (lbs/ft^2)
W	=	unit weight of water, 9.8 kN/m^3 (62.4 lbs/ft^3)
R	=	hydraulic radius, equal to the cross-sectional area, A, divided by the wetted perimeter, P
S_f	=	friction slope of the channel approximated by the average bed slope (for uniform flow conditions)

By substituting the maximum depth of flow, D, in the equation for hydraulic radius, R, a more conservative approach was evaluated. A summary of calculated shear stress at each channel design point is shown in Table 2.

Table 2. Initial Maximum Permissible Shear Stress Design Parameters

Channel Design Point	Approx. Slope (%)	Depth (cm)	Max. Shear Stress (kg/m²)
A	13.5	18	24.7
B	20	15	30.5
C	**20**	***24***	***48.8***
D	10	24	24.4
E	8	21	21.3
F	11	24	33.5
G	**20**	***21***	***42.7***
H	5	30	15.2
I	13	24	31.7
J	10	18	18.
K	**5**	***82***	***41.2***

This check resulted in a maximum calculated shear stress of 48.8 kg/m^2 (9.9 lbs/ft^2) occurring at point C. Therefore, comparing the maximum permissible shear stress of the TRM, T_{max} = 39.1 kg/m^2 (8 lb/ft^2), to the expected hydraulic conditions associated with short-term, unvegetated conditions of the 100-year storm, T_{ave}, a potential for failure was identified:

$$FS_f = \frac{T_{max}}{T_{ave}} = \frac{39.1 kg/m^2}{48.8 kg/m^2} = 0.8$$ **NO**

Once it was discovered the channel lining material was potentially subject to shear stress failure during a short-term storm event, the channel sections that exceeded the maximum permissible shear stress of the TRM were widened to 3 meters (10 feet). This lowered the depth of flow and created the maximum shear stress condition at design point F. The final factor of safety, FS_f, at design point F for the short-term storm event was then determined:

$$FS_f = \frac{T_{max}}{T_{ave}} = \frac{39.1 kg/m^2}{33.5 kg/m^2} = 1.2$$ **OK**

Employing flexibility and creativity with the channel geometry, the engineers demonstrated the TRM-lined channels were now also protected against shear stress failure. The hydraulic design was considered complete and approved for construction. A generic specification for the TRM selected for the Horse Ranch project is listed in Table 3.

Table 3. Turf Reinforcement Specification

The Turf Reinforcement Matrix (TRM) shall consist of a lofty web of black polyolefin fibers positioned between two high strength, biaxially oriented nets and mechanically bound together by parallel stitching with polyolefin thread. The matrix shall possess strength and elongation properties to limit stretching in a saturated condition. Every component of the matrix shall be stabilized against ultraviolet degradation and inert chemicals normally encountered in a natural soil environment. The turf reinforcement matrix shall also conform to the following minimum average roll values (MARV) after a 24 hour saturation period:

PROPERTY	TEST METHOD	MARV
Thickness (in)	ASTM D-1777	0.5
Tensile Strength (lb/ft)	ASTM D-5035	220 x 165
Tensile Elongation (%)	ASTM D-5035	10 (min) 40 (max)
Tensile Strength at 10% Elongation (lb/ft)	ASTM D-5035	145 x 110 (typical)
Moisture Absorption	ASTM D-570	0.01 (max)
Weight (oz/sy)	ASTM D-3776	14
Ground Cover Factor (%)	Light Projection Analysis	60
Ultraviolet Stability (%)	ASTM D-4355	80

CONSTRUCTION

The general contractor, Gould Construction, Inc. of Glenwood Springs, Colorado, installed the permanent erosion control mats in the main and lateral trapezoidal-shaped channels. Specially fabricated 1, 2, 3, and 4-meter wide rolls were supplied to the contractor to facilitate installation. All but 500 m^2 (600 yds^2) of the 19,230 m^2 (23,000 yd^2) of mats were custom sewn at the factory to conform to the project's channel geometries. Factory sewing of adjacent rolls minimized overlapping and potential weak spots, reduced waste, and accelerated installation. Since discharges would be greatest at the lowest points of the drainage basin, Gould Construction began installation of the TRM in these areas in May 1992. Check slots and anchor trenches were excavated using a track hoe and hand tools. The TRM was rolled upstream and firmly anchored in place using the anchor trenches and 20 cm x 2.5 cm x 20 cm (8" x 1" x 8"), 4.3 mm (8 gauge) U-shaped wire staples, placed in the channel bottoms and side slopes at a rate of 2 staples per square meter (2-1/2 per yd^2) (Figures 4 and 5). The manufacturer provided installation assistance during the early stages of construction.

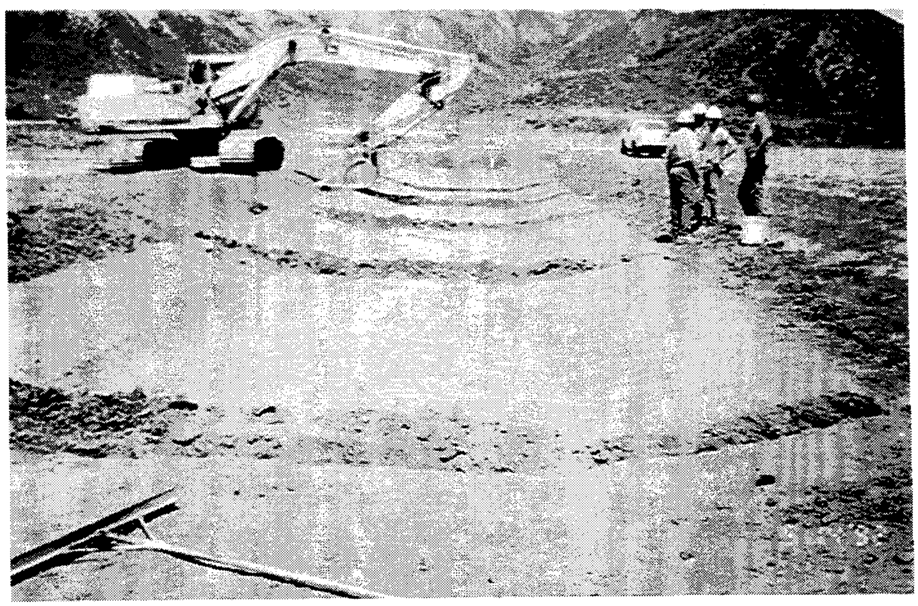

Figure 4. Construction of Check Slots and Anchor Trenches

Figure 5. Upstream View of TRM Installation in Main Drainage Channel

During excavation of the lower reaches of the main channel, springs emanating from a perched water table created a virtual quagmire which halted construction. After consultations between the owner, designer, contractor and manufacturer, it was decided to construct subsurface nonwoven geotextile-wrapped trench drains in the flow line to accommodate this constant flow of mountain spring water (Figure 6). The trench drains lowered the water table nearly 1.3 meters (4.2 feet) and after 30 days the soils dried enough to allow the contractor to continue grading the channel and install the TRM.

Once a portion of the channel was installed, the TRM was then hydraulically seeded by Landforms, Inc. of Aspen with a dryland pasture mix of locally adapted cool season grasses at the rate of 14.7 kg per 1,000 m^2 (3 lbs. per 1,000 ft^2). The heavy seeding rate was well fertilized and irrigated to ensure a dense stand of vegetation. Species included smooth bromegrass, perennial ryegrass, three varieties of crested wheatgrass, intermediate wheatgrass and Ruebens Canada bluegrass. In the saturated lower channel reaches, the TRM was soil-filled by raking approximately 2.5 cm (1 inch) of topsoil into the mat and lightly hydroseeding/mulching above the soil. Small rock riprap energy dissipators were constructed near large culvert inlets and outlets. A nonwoven geotextile was used beneath the rock to serve as a filter and separator to prevent subsurface erosion.

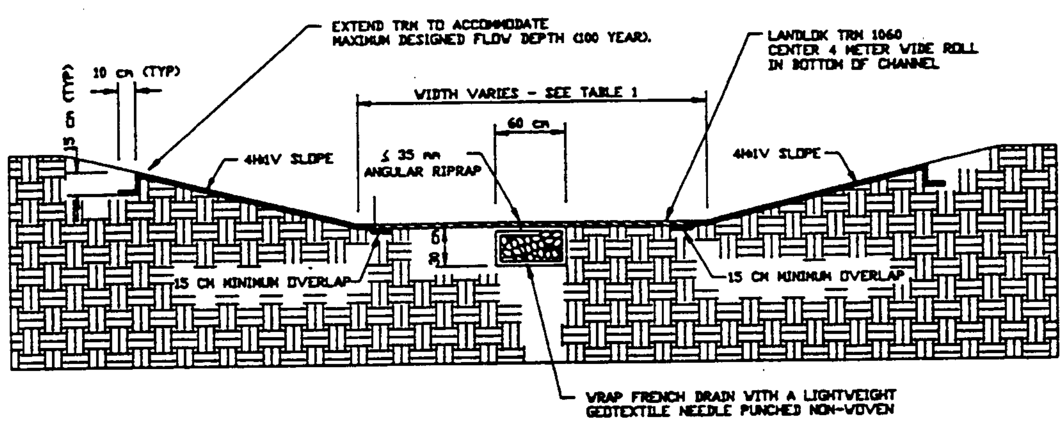

Figure 6. Cross-section of Geotextile-wrapped Trench Drain to Control Perched Water Table

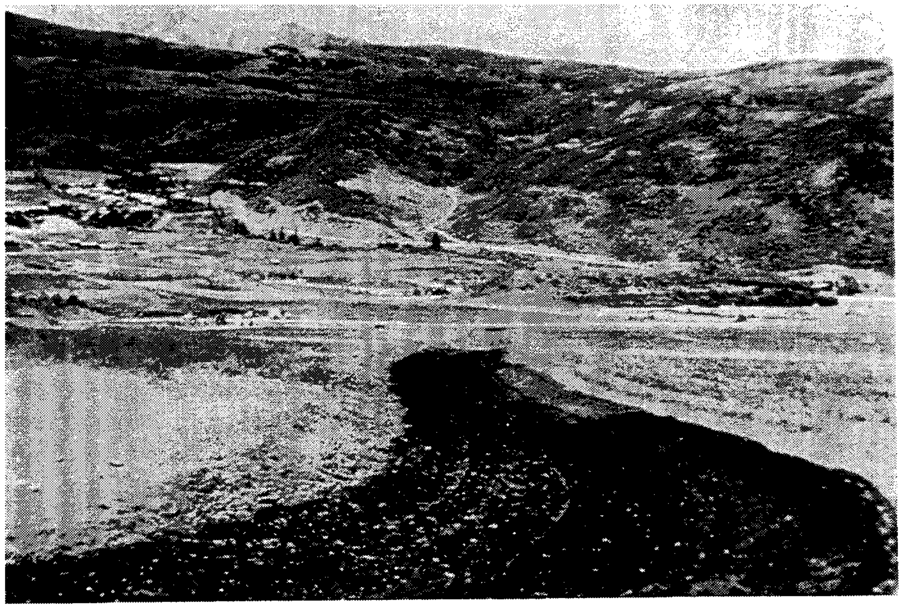

Figure 7. Main Drainage Channel After Installation (May 1992)

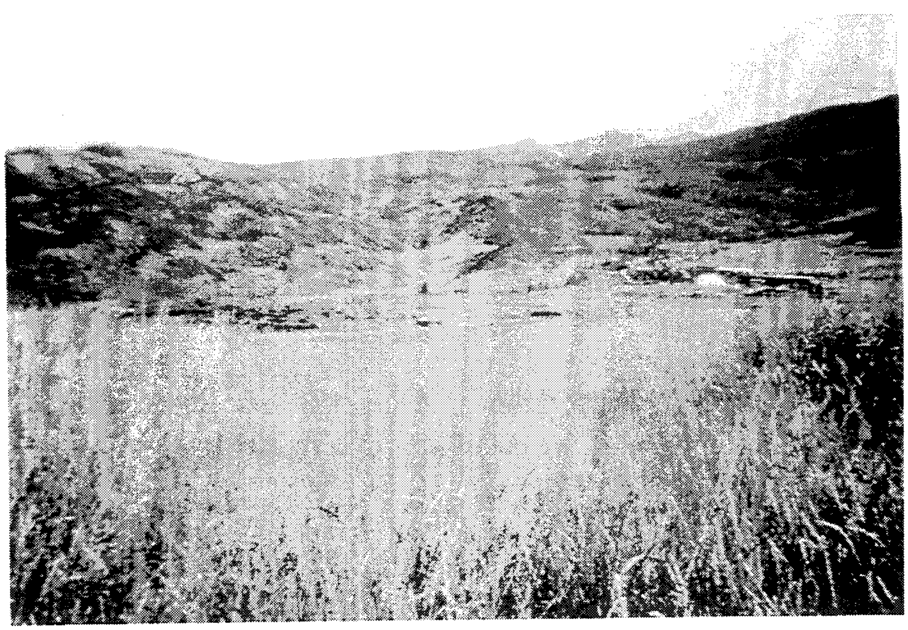

Figure 8. Main Drainage Channel (July 1993)

RESULTS

More than 19,228 m^2 (23,000 yd^2) of turf reinforcement mats (TRMs) were installed in various phases of the Horse Ranch project at a cost of $9.90/$m^2$ ($8.25/$yd^2$), as compared to rock riprap, which normally costs about $24/$m^2$ ($20/$yd^2$) to install in this region of the United States. Riprap installation costs may be double this amount in other areas of the United States. Factored over the entire Horse Ranch project, the owner has realized a total savings of over $270,000 by utilizing TRMs over less appealing rock riprap systems.

The site has now weathered two winters of abundant snowfall and subsequent runoff, as well as an extraordinarily wet summer and an extremely dry summer with virtually no erosion. The vegetation has become firmly established within the TRM and the channels have blended very nicely with the landscape (Figure 7 and 8). It should also be noted that in the channel where the TRM was soil filled vegetation was established much faster than the non-soil filled channels. The hydraulic stresses associated with the first two years of monitoring have definitely challenged the TRM and all reports have been extremely positive. "In terms of aesthetics, I'm happy with the project...the channels have performed well.", reports Jim Wells, construction manager for the Snowmass Land Company (Northcutt, 1994).

Residents of the Brush Creek Valley are hard pressed to identify the camouflaged TRM-reinforced drainage channels from afar. Aerial photographs of the site only identify small areas of the rock riprap energy dissipators near large culvert inlets and outlets that disrupt the gentle meander of the verdant channels. Further downstream in the cold, crystal clear waters of the Roaring Fork River, the trout fishing is as good as ever.

CONCLUSIONS

Utilizing an innovative geosynthetic turf reinforcement mat (TRM) as the flexible channel lining material on the Horse Ranch project proved to be an effective, economical, and technically-sound permanent erosion control solution for the following reasons:

1) The TRM was installed at approximately 41% of the cost of conventional rock riprap and resulted in a total saving of over $250,000.

2) After two years of aggressive hydraulic conditions and monitoring, the TRM is demonstrating excellent performance and blending nicely with the surrounding terrain.

3) Standard and well-accepted hydraulic engineering design procedures were used to analyze and technically justify the incorporation of a TRM into the project.

4) The environmental benefits of the TRM were realized (natural appearance, infiltration and exfiltration features, promotion of sediment

capture and enhancement of wildlife habitiat) in a very environmentally-sensitive area of the United States.

ACKNOWLEDGEMENTS

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THE ROTOCLEAR: A UNIQUE AND PROMISING TOOL FOR VEGETATION MANAGEMENT

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ABSTRACT

The Rotoclear is essentially an industrial sized rototiller pulled by either a tractor or bulldozer. It is capable of chipping and incorporating above ground vegetation to a selected soil depth, usually in one pass. The machine's effectiveness with woody species depends principally upon hardness, diameter and stand density. Rotoclearing has been used for managing vegetation in such diverse uses as habitat improvement on forest and rangelands; brushing for power line corridors, oil and gas pipelines; preparing croplands; and resource salvage and reclamation at mining operations. The Rotoclear's distinct advantage lies in those vegetation communities where their incorporation into the soil results in addition of mulch, retention of plant nutrients, soil structure improvement, increased resistance to soil erosion and the regrowth of retained plant materials. Livehandled, rotocleared reconstructed mine soils have met SMCRA revegetation standards for bond release without additional mulching or seeding. Given The Rotoclear's impressive capabilities, it is hard to understand why it has not received greater usage. Lack of utilization may in part stem from the fact that rotoclearing is fairly costly when compared singly with other management tools. However, rotoclearing's multiple benefits normally result in it being the preferred tool when a holistic economic and environmental benefit assessment is performed.

INTRODUCTION

The Madge Rotoclear has been used for managing vegetation for a number of purposes, including habitat improvement, preparation of fire lines and disposal of slash in forest lands, clearing powerline and pipeline corridors, clearing and preparing seedbeds for agricultural purposes, and for clearing and revegetating mined lands. Although the machine has been around for over 20 years, it has received limited usage in the USA. Lack of usage may be in part attributed to the fact that the rotoclearing process is a fairly expensive one. None-the-less, rotoclearing results are superior to those of most traditional revegetation practices. Also, when all rotoclearing benefits are economically compared to the cost of separate operations necessary to achieve similar results, it usually is a superior, cost effective performer. This paper presents a description of the machine and the rotoclearing process, a review of rotoclearing benefits, rotoclearing limitations, and a review of economics and benefits between rotoclearing, traditional and three "comparable" methods.

ROTOCLEARING: THE MACHINE AND PROCESS

The madge Rotoclear is essentially a giant rototiller mounted on a two-wheeled, rubber tired trailer. Physical dimensions are 22'6" long, 9'8" wide, and 9 feet high. It weighs 22,000 lbs. The cutting rotor is driven by a General Motors diesel (8V-92T). The rotor cuts a swath about 7'6" wide. Standard drum diameter is 31 inches, with other custom diameters being available. Depending upon the drum size used, depth of cut is adjustable between 0 and 18 inches. The rotor is equipped with 56 self-sharpening, knock-out replacement teeth. The rotor spins at 360 rpm. Motive power is provided by either a four-wheel drive tractor or a bulldozer. Topography and vegetation community within the area to be treated normally dictate choice of motive equipment. Motive equipment should be equipped with a blade for pushing over woody stems so that they may be rotocleared.

The rotoclearing process is accomplished by slowly pulling the machine over the area to be treated. Production rates vary from 0.5 to 3.0 acres per hour depending upon topography, characteristics of the vegetation community being treated and degree of incorporation desired. The motive equipment pushes woody vegetation over, and the Rotoclear chips it up and incorporates it into the soil. An important aspect of rotoclearing is that not only above ground biomass is treated, but organic materials below ground may also be treated. One-pass treatment is usually possible in most vegetation types. Larger and harder woody species may require two or more passes, depending upon desired results. Aspen stands with average Diameter at Breast Height ("DBH") of 7.5 inches have been treated with one-pass operations. On the other hand, large DBH pinon pine requires a minimum of two or more passes for effective incorporation. The machine is capable of running through sedimentary and softer types of metamorphic rock. Abrasion factors raise treatment costs when the percentage of rock becomes significant, especially in the form of consolidated outcrops.

For safety purposes the rotor is completely enclosed within plate steel, thus eliminating the major safety hazard associated with most mulching/chipping machines. The steel case prevents materials being processed from being thrown out and becoming hazards. A hydraulically lifted door provides access to the rotor from the back of the rotor case. Although not recommended, it is possible to walk 30' behind the machine during operation on even ground without fear of being hit by woody missiles.

Rotoclearing is best performed on soils with normal moisture contents. Soil structure may be damaged if undertaken on excessively wet or certain dry soils (nominal loss of litter structure). Also, best volunteer vegetation response is obtained when soil moisture conditions are not extreme. From an operational standpoint, excessively dry conditions result in more frequent maintenance, while excessively wet conditions may clog the rotor, especially in silty or clayey soils. Vegetation seasonality and treatment objectives also influence the best time of the year to perform rotoclearing.

ROTOCLEARING BENEFITS

Rotoclearing may provide a number of benefits with properly planned usage. Significant benefits include:

Brush Disposal

Woody vegetation is chipped and incorporated into the soil. This avoids windrowing operations and disposal problems associated with traditional brushing methods. Besides obvious usage in land clearing operations, the establishment and maintenance of fire control lines is possible.

Mulching

Rotocleared vegetation is fragmented and incorporated uniformly throughout the rotor's cutting depth, substituting for other forms of mulch commonly used for revegetation purposes. The incorporated material serves as an organic mulch which aids in soil reconstruction and revegetation efforts. Use of rotocleared plant materials normally replaces the need for additional mulching in subsequent revegetation operations.

Studies conducted at Energy Fuels Mine, Northwestern Colorado (Crofts 1981) determined that rotoclearing big sagebrush communities incorporated a minimum of 2.5 tons per acre of plant matter. In areas where aspen was the dominant species with a understory consisting predominately of snowberry, Rotoclear incorporated above ground biomass was in excess of 77.3 tons per acre (air dry weight). In Pinyon/Juniper vegetation communities at the McKinley Mine near Gallup, New Mexico over 13 tons of above ground biomass was incorporated into the soil as mulch through rotoclearing (Erickson, 1983).

Volunteer Vegetation

Plant materials incorporated into the soil are capable of various forms of reproduction. In many instances volunteer growth from these plant materials is adequate to revegetate disturbed lands without the planting of augmentive seedings. Critical to obtaining maximum regrowth is the minimization of additional mechanical or vehicular disturbance. If augmentive seeding is undertaken on rotocleared soils, broadcasting methods have less impact of regrowth of volunteer vegetation than drilling seed.

Augmentive seedings or plantings are necessary when: 1) Desirable plant material sources are inadequate and supplemental materials are needed, or 2) Desirable plant species are absent and must be provided to achieve specific post-disturbance revegetation goals. Using volunteer vegetation to meet revegetation goals has an advantage in that local native plant materials are utilized. Rotoclearing avoids the introduction of weedy, undesirable or introduced species which may be contained in either mulch or seed mixes and which may be unacceptable to the regulator.

Woody Stems

Reconstructing or revitalizing woody components in vegetation communities is an expensive, often labor intensive operation. Minimum woody stem stocking densities may be required by government agencies to provide post-disturbance habitat needs. For example, postmining wildlife habitat land uses routinely incorporate revegetation criteria specifying a minimum number of woody stems be living in place for minimum time periods (typically densities from 450 to 2,000 living woody stems in place for a minimum of three years have been specified).

Rotoclearing woody plant communities and livehandling the soil has resulted in the establishment of an average of 3,000 woody stems per acre after three growing seasons on revegetated mined lands. Typically woody stem density is high (5,000 stems per acre) after the first growing season on revegetated mined land, tapering off somewhat during the second and third years. This reduction may be caused by: 1) The ecological nature of reconstructed mine soils which favor the establishment and growth of grassland communities; 2) Management practices used to develop and maintain the revegetated area (fertilization practices and grazing or harvesting methods play important roles in encouraging the growth of either the herbaceous or woody habit component on rangeland reclamation); and 3) Ungulate grazing pressure (At The Energy Fuels Mine Elk grazing reduced woody species density on rotocleared soil reclaimed areas (Carlson, 1996)).

In many cases over 2,000 big sage stems per acre have been established on rotocleared mine soils after a two or three growing seasons. At the Edna Mine, Oak Creek, Colorado, big sagebrush plants after two growing seasons were up to 18 inches tall and had produced viable seed. Root sprouting species (snowberry, serviceberry, and chokecherry) have volunteered equally well from rotocleared topsoil at Edna. Gambel's oak does not respond favorably to rotoclearing, with volunteer growth being nominal. Table 1 contains woody stem density transect data taken from Edna Mine rotocleared topsoil treatments in 1993 and 1995. Clearly, rotoclearing is capable of reducing or even eliminating the need for inclusion of expensive woody species seed in revegetation mixes and can preclude the need to conduct extremely expensive bare root or containerized woody species transplanting programs.

Nutrient Retention/Release

Incorporating plant materials rather than brushing them and disposing of them results in the retention of macro and micro nutrients critical and essential to plant growth. These nutrients are released over time by decomposition making them available for plant uptake.

Seedbed Preparation

Rotoclearing prepares seedbeds that are optimum for planting and seeding operations. Clods are broken up and soil physical conditions are optimized for seed germination and plant establishment. If seeding rotocleared soil is undertaken, it is important to minimize to the extent possible the time period between Rotoclear treatment and seeding. The shorter this time lapse, the less impact on volunteer vegetation regrowth. Broadcast seeding is preferred over drill seeding, since soil compaction and disturbance impacts are less. It is also

Table 1
Seeded and Non-Seeded Rotocleared Shrublands: Edna Mine, Northwestern Colorado

	PRE-ROTOCLEAR VEGETATION TYPE		ROTOCLEARED - DIRECT HAUL NO SEED - 1993 DATA		ROTOCLEARED - DIRECT HAUL NO SEED - 1995 DATA	
	SAGEBRUSH/ SNOWBERRY	MOUNTAIN SHRUB	1991 Spring Application	1991 Summer Application	1991 Spring Application	1991 Summer Application
% TOTAL COVER	**87**	**98**	**75.5**	**52.7**	**93.8**	**88.3**
% HERBACEOUS COVER	**45.4**	**48.7**	**52.6**	**32.0**	**77.9**	**70.4**
Perennial Cover	43.6	47.9	37.6	8.7	66.2	25.2
Annual Cover	1.8	0.8	15	23.3	11.7	45.2
% SHRUB COVER	**42**	**41**	**<1**	**0**	**1**	**<1**
% Snowberry	27	21				
% Sagebrush	13					
% Gambel's oak		8				
% Serviceberry	1	7				
% Chokecherry		4				
STEM DENSITY/ACRE	**21,616**	**28,657**	**2,099**	**895**	**1,608**	**577**
Snowberry	12,083	12,328	1,698	648	1,214	401
Big sagebrush	4,950		70	22	106	71
Gambel's oak		8,300	13	27	0	0
Serviceberry		4,071	228	38	199	11
Chokecherry		2,614	35	110	26	38

Habitat Enhancement and Diversity

Properly planned, rotoclearing can result in rejuvenation of plant communities. Taking advantage of this, timed spatial use within large management areas may be planned to provide significantly improved wildlife habitat with optimized carrying capacity. To accomplish this rotoclearing is performed on management units at specified intervals. This ensures that vegetation communities are in various stages of seral succession within the managed area. These practices are designed to avoid extreme fluctuations in availability of habitat and its inherent carrying capacity. This capability is particularly useful for wildlife management, which may include listed or potentially listed threatened and endangered species.

Habitat may be further diversified through the modification of soil chemistry. An example occurred at the McKinley Mine in New Mexico where rotocleared soil from Pinon/Juniper plant communities experienced a change in pH from alkaline to slightly acidic. The more acidic soils maintain plant communities which have species compositions significantly different than their alkaline counterparts (Borders, 1996).

Air Quality

Rotoclearing generated fugitive dust depends upon the soil type and moisture conditions. Operating in extremely dry, fine textured soils results in its greatest generation. Usually the dust remains at relatively low levels in close proximity to the machine. In comparison with the air quality issues associated with the use of fire as a management tool, rotoclearing air quality issues are insignificant.

Treatment Control

The area where the Rotoclear is used can be carefully chosen, treatment boundaries specifically marked and the machine operated within that area. This is not the case with chemical or fire treatments where drift or jumping firelines may occur. Avoiding such potential liabilities, especially in more densely populated areas, is a definite advantage of rotoclearing.

Benefits are derived from being able to control the size and shape of the areas where habitat improvement is desired. Treatment can be performed in mosaics within larger areas which effectively maintain various successional stages which optimize habitat for a greater number of species. Treatment area layout can be adjusted to minimize adverse hydrologic impacts (i.e., minimize slope lengths) and avoid unnecessary erosion. The Rotoclear may be operated any time of the year which increases its effectiveness as a habitat management tool (obviously certain ground conditions may impact the desirability of operation, while meteorologic conditions are relatively unimportant). Land may be rotocleared at time to take advantage of moisture and vegetation growth periods. With regard to wildlife habitat management, rotoclearing can be performed during low or non-use periods to minimize vegetation management operation impacts.

ROTOCLEARING LIMITATIONS

Rotoclearing is not the perfect vegetation management tool, but it is one of the best ones available. The following items represent some of the more significant limitations and considerations that affect Rotoclear usage.

Topography

Rotoclearing operations are governed by the same laws of physics that dictate the safe boundaries for all heavy equipment operation. Slopes 3h:1v or flatter represent no particular problems. Slopes between 3h:1v and 2h:1v may slow productivity rates and require implementation of additional safety precautions. On slopes steeper than 2h:1v operations may be prohibited or require special adjustments which make operations cost prohibitive.

Climatic Conditions

Like the U.S. mail, meteorologic conditions have little effect on Rotoclear operation. As long as motive equipment has an enclosed climate controlled operator cab, the weather outside can be frightful. Obviously reduced visibility, significant snow cover, floods and other acts of God may necessitate prudent suspension of operation.

Soil Moisture

Soil moisture is an important factor which should be considered in scheduling rotoclearing. Regrowth of vegetation depends heavily upon adequate soil moisture content, especially when soils are salvaged and redistributed. This is particularly true if soil is stockpiled before redistribution. Length of stockpiling definitely reduces plant material viability, although species adapted to semi-arid and arid lands may retain viability through several years of stockpiling. If regrowth of inherent plant materials is a primary project goal, soil moisture will limit suitable periods for operation.

From a physical process standpoint, excessively dry or extremely wet soil conditions should also be avoided. Rotoclearing during these soil moisture conditions will result in soil structure damage. Additionally, dry condition operation has the potential to generate larger amounts of dust which increase machine maintenance requirements. Extremely wet conditions will decrease machine effectiveness, make incorporation more difficult and may cause mud to clog the rotor.

Timing of Operations

Timing of usage is controlled by a project's floral or faunal goals. Seasonality of plant species determines when the optimum periods for operations will occur. Acceptable operation periods will either encourage regrowth or reduction of vegetation. Likewise, the presence or absence of wildlife species, and associated seasonal habitat usage, may dictate when to and when not to Rotoclear. This is particularly true if habitat is being enhanced or maintained for wildlife management, which may include listed or potentially listed threatened and endangered species.

Allelopathogens

Certain plants may contain concentrations of species specific allelopathogens. It has been speculated that rotoclearing might release inordinately high levels of these substances through the weathering of fragmented plant materials. To date there has been no documentation that elevated allelopathogen levels have significantly impacted the growth of other plant species in rotocleared soils.

Decomposition Induced Nitrogen Deficiency

Another concern is that the incorporation of large amounts of organic material might tie up soil nitrogen in the decomposition process, resulting in shortages for vascular plant growth. Research has shown that such a tie up does not occur and is not a concern (Quelle, 1980).

ROTOCLEARING ECONOMICS

Rotoclearing results in a number of operational and environmental benefits which are not achieved through the solitary usage of other vegetation management tools. Determining which vegetation management tools are to be used for a given project is simply a matter of evaluating economics associated with specific project goals. Clearly defining project goals and timelines will determine which operation(s) to select. Appendix A contains a listing of commonly used construction and equipment methods and practices employed in western land development projects. A typical range of costs associated with these methods, and their respective biological and operating considerations and benefits are described. While not all inclusive, the appendix contains a reasonably comprehensive summary of methods and practices currently available to land disturbance and habitat managers.

The remainder of this section evaluates the current economics of rotoclearing with three "comparable" vegetation management tools, fire, brush hogging and roller chopping. Cost comparisons are based on averages for performing the various operations in the western United States. Current rates for these operations may vary according to local economic conditions and availability. A brief description of these methods is presented below outlining product and considerations. This is followed by cost comparisons.

Fire

Burning has been used for many years and the benefits derived from its use speak for themselves. It is a time tested practice that produces good results, albeit highly variable. It appears that this variability in results stems principally from the lack of control over the burn rate and heat level. Major problems with burning are: 1) It is somewhat antiquated and is not particularly well suited for use in the increasingly suburbanized counties in the intermountain west, 2) Nutrients, notably carbon, are lost to the atmosphere, and 3) Effective applications are limited primarily to summer and fall periods when fires burn hot enough to maximize their effectiveness (Frary, 1996). From air quality, aesthetic and liability standpoints, the use of fire has serious acceptance and permitting problems.

Brush Hogging

Mowing with a brush hog works well in shrub communities that are three feet in height or less. Medium and larger diameter materials are more difficult to cut. Usage has concentrated on areas where reduction in unwanted shrubs, forbs or grasses is sought. The principal benefit is that brush hogging is relatively inexpensive and may be used for long-term maintenance of some vegetation communities. In some cases it may be used to construct fire breaks for burning. Use of the brush hog does not significantly alter vegetation habit composition unless used frequently for a number of years. Perennial species which reproduce from ground level or underground plant materials are favored by its usage. In areas with high levels of above ground biomass, brush hogging may create excessively thick layers of chopped vegetation that interfere with plant regrowth. In semi-arid and arid climates, decomposition takes an inordinately long time, which results in such surface debris being an even greater nuisance.

Roller Chopping

This method has been used for many years with varying degrees of success. Like brush hogging, roller chopping affects only plant materials above the ground surface. Therefore its benefits and drawbacks from a vegetation management standpoint are similar to those of brush hogging. A significant difference is that it is capable of processing larger diameter woody materials than the brush hog. This results in larger pieces of woody material being left on the ground's surface that can interfere with subsequent plant establishment.

Rotoclearing Comparisons

Rotoclearing challenges fire as a vegetation management tool from many standpoints. Rotoclearing typically produces more diverse vegetation faster than burning, particularly woody species. It is believed that this occurs because heat has a greater negative impact on plant materials than physical disturbance. The Rotoclear's fragmentation of plant materials appears to stimulate their regrowth. The retention of viable plant materials (root stocks, seed stocks, fungi, algae and soil microorganisms) and nutrients in the form of mulch is a big positive for rotoclearing. Properly timed rotoclearing results in a vegetative response that vastly exceeds that of controlled burning. The soil erosion control provided through incorporation of vegetation mulch by the Rotoclear is far superior to the accelerated erosion rates experienced on soils exposed to the elements after a burn.

The principal advantages of rotoclearing over brush hogging are the ability to process larger diameter woody materials, to incorporate this mulch into the soil to a specified depth and to disturb or leave intact subsurface plant materials as desired. If long-term vegetation community management is a concern, the Rotoclear normally out performs brush hogging based on frequency of treatment. The economic benefits of rotoclearing become obvious when managing critical habitats over extended time periods (i.e. through climatic stages of seral succession).
These same advantages hold true for rotoclearing over roller chopping, albeit roller chopping can process medium diameter woody materials. The problem with roller chopping is that the chopped material size is large enough that it often interferes with subsequent vegetation establishment operations. The Rotoclear out performs all of these methods in preparation of optimum seedbeds.

Costs

Based upon multiple benefit performance and success of vegetation, especially shrub establishment costs, the Rotoclear is one of the best methods available for habitat improvement and revegetation of disturbed areas. Operational savings of $450 per acre are expected in performing standard mined land reclamation operations. For mined lands which require the establishment of a minimum of 1,000 woody stems per acre, plant material and transplanting cost savings may easily amount to $2,127 per acre. Table 2 contains cost comparisons between rotoclearing and traditional mine reclamation operations.

CONCLUSION

Numerous reclamation and revegetation methods and practices have been tried over the years. They have produced a wide variety of products with a wide range of results, both between and within themselves. A number of the methods and practices utilized in mined land reclamation and agricultural applications may be potentially used in habitat management. These methods and practices range greatly in cost, examples being the relatively inexpensive broadcasting of seed to the transplanting of shrub clumps with large front-end loaders.

TABLE 2

ROTOCLEARING COSTS VS. TRADITIONAL MINE RECLAMATION OPERATIONS

ITEM	ROTOCLEARING ($/ACRE)	TRADITIONAL OPERATIONS ($/ACRE)
Brushing	200	60
Mulching		365
Seeding		90
Fertilizing		60
Crimping		40
SUBTOTAL	**200**	**615**
DIFFERENCE		**415**
Woody Stem Transplanting		2,130
TOTAL	**200**	**2,745**
DIFFERENCE		**2,545**

Notes:

•To calculate rotoclearing's optimum economic benefits it was assumed that all topsoil was livehandled. No economic benefit was included for improved loading characteristics of rotocleared topsoil during salvage operations.

•Mulching assumed an application rate of 2 tons per acre of native grass hay.

•Shrub and tree transplanting costs vary widely. For this example it was assumed that 2,506 native species tublings would be transplanted @ $0.85 each. A 25 percent survival rate was used to determine this initial stem number, which would result in meeting exactly a final stem stocking density of 1,000 per acre. Most reclaimed mined land woody materials plantings have dismal survival rates significantly less than 25 percent.

Realistically, there is no single panacea operation that meets the diversified goals and solves the complex problems faced by managers involved with environmental development, reclamation, rehabilitation or enhancement projects. Site specific conditions and project goals must be evaluated and defined to determine what combination of management methods and practices should be utilized to best meet the chosen objectives. Rotoclearing, with its multiple environmental benefit capabilities, is a valuable tool requiring serious consideration by the environmental project manager.

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APPENDIX A: VEGETATION MANAGEMENT METHODS/PRACTICES SUMMARY

MANAGEMENT PRACTICE	COST PER ACRE	ADVANTAGES	LIMITATIONS-BIOLOGICAL (BIO), OPERATIONAL (OPS)
Rotoclearing			
Rate-1 to 3 acres per hour	$206	1) Incorporates organics into soil and prepares soil for salvage/ repacement, 2) Removes decadent vegetation above and below ground surface 3) Reduced interplant competition stimulates growth of species which reproduce using underground methods (root sprouting, tubers, rhizomes, etc.), 4) Optimum for seedbed preparation, 5) Alleviates compacted soils, 6) Improves moisture retention and holding capabilities, 7) Decreases erodibility through incorporation of organic materials and improved infiltration rates, 8) May mechanically reduce or remove undesireable species, 9) Fragments established root mass which increases plants that are asexual vegetative propogators, 10) New undesireable species are not introduced into the plant community	BIO: 1) Severely limits or prevents regrowth of species that do not propogate using underground methods or that are not prolific seeders, 2) Non-selective in removal of vegetation, 3) Completely disrupts established root mass, 4) Soil moisture conditions directly impact vegetation propogation effectiveness, OPS: 1) Operations are limited to slopes flatter than 2h:1v, 2) Slopes steeper than 3h:1v affect productivity since machinery is essentially limited to working downhill and deadheading back on flatter slopes for next pass, 4) Higher density rock outcrops reduce performance and increase maintenance costs
Brush Hogging			
Rate-3 to 10 acres per hour	$45	1) Utilizes above ground plant materials for mulch, 2) Temporarily removes woody vegetation, 3) Stimulates growth and increase of herbaceous species until woody canopy reestablishes itself after removal, 4) Improves soil moisture regime through reduced transpiration and evaporation, 5) Height that vegetation is removed to can be adjusted, 6) New undesireable species are not introduced into the plant community	BIO: Severely limits or prevents growth of species that do not sprout from underground methods, 2) Non-selective in removal of above ground vegetation, 3) May limit regrowth of species that do not sprout using underground propogation methods or that do not respond well to severe pruning OPS: Limited to slopes flatter than 2h:1v. Slopes steeper than 3h:1v affect productivity since machinery is essentially limited to working downhill and deadheading back on flatter slopes for next pass.

APPENDIX A (cont.)

MANAGEMENT PRACTICE	COST PER ACRE	ADVANTAGES	LIMITATIONS-BIOLOGICAL (BIO), OPERATIONAL (OPS)
Burning			
Rate-variable	$9 to $15	*Both Burn Rates* 1) Stimulate establishment and regrowth of species adapted to fire, 2) Return some nutrients to soil, 3) No topographic limitations to application, although steeper slopes require greater attention and caution, *Dry Conditions with fast, cool fire* 1) May reduce herbaceous component through seed destruction, paticularly annuals, 2) Easier to extinguish, but uncontrolled wildfire is more likely *Moist Conditions with slow, hot fire* 1) Will reduce or remove both woody and herbaceous species, 2) Easier to control, wildfires are less likely to occur.	BIO: 1) Difficult to control burn rate which may affect desired species, 2) Non-fire tolerant species are reduced, 3) Deeper rooting species are favored, 3) Erosion potential is increased OPS: 1) Limited to specific moisture conditions, 2) Affects air quality and may require burning and emission permits, 3) Potential for wildfires and associated liabilities, 4) Labor intensive, 5) Atmospheric conditions affect ability to employ, 6) Potentially hazardous to personnel,
Topsoiling-Salvage and Replacement			
Rate: 0.5 to 0.75 acres per scraper shift (637's, push-pull ops)	$1,000 to $1,500	1) Conserves soil resource, 2) Spatial replacement with variable depths allows rehabilitation or improvement of specific habitat niches, 3) Transfers native plant component, especially when livehandled and rotocleared, 4) Allows mitigation of potentially acid or toxic forming materials in root growth zone, 5) Retains soil nutrients and microbiological populations	BIO: 1) Stockpiling prior to redistribution reduces biological component, 2) Undesireable pioneering species may invade redistribution sites, 3) Severely limits or prevents regrowth of species that do not propogate using underground methods or that are not prolific seeders, 4) Non-selective in removal of vegetation, 5) Completely disrupts established root mass, 6) Soil moisture conditions directly impact vegetation propogation effectiveness, OPS: 1) Operations are limited to slopes flatter than 2.5h:1v, 2) Slopes steeper than 3h:1v affect productivity since machinery is essentially limited to working downhill and deadheading back on flatter slopes for next pass, 4) Relatively expensive operation using expensive heavy equipment

APPENDIX A (cont.)

MANAGEMENT PRACTICE	COST PER ACRE	ADVANTAGES	LIMITATIONS-BIOLOGICAL (BIO), OPERATIONAL (OPS)
Seeding Rate: 5 to 10 acres per hour	$40 to $75	*All* 1) Allow selective addition of desired species, 2) Control location and application rate of additional species seeded, *Broadcasting* 1) Maximizes interstial spacing between seedlings improving survival rate, 2) Ideal for species which germinate best on or very close to the soil surface, 3) Broadcaster works well for species with large mechnical adaptations associated with seed-plugging is minimized *Drilling* 1) Seeding depth can be accurately controlled improving germination and survival of seedlings, 2) Distribution of seed unaffected by wind *Hydroseeding* 1) Supplies additional moisture which promotes increased seed germination, 2) Mulch normally added during operation conserves *moisture and protects seedlings with shade, 3) May be conducted on very steep slopes with reasonable cross-slope access*	BIO: 1) Seed mixes may be contaminated introducing undesireable species, 2) Soil moisture may limit survival, 3) Diverse mixes may require multiple passes to optimize planting conditions for the greatest number of species, 4) Seeding rotocleared or livehandled redistributed topsoil may destroy species that are propogating from materials in the soil, 5) Hydro-seeding may sprout prematurely and die back if rains do not occur OPS: 1) Operations are usually limited to slopes flatter than 3h:1v, 2) Low or high soil moisture will prevent proper application, 3) Multiple pass operations may adversely compact seed bed, 4) Weather conditions may prevent or limit operations, 5) Supplying hydroseeding operations with mulch, water and seed can be a logistic problem for large remote jobs
Mulching Rate: 5 to 15 acres per hour	$315 to $450	1) Conserves soil moisture, 2) Limits or controls water and wind erosion, 3) Shades young seedlings after germination, 4) Adds organic material to the soil	BIO: 1) Mulch may act as a source of undesireable species, 2) Native hay for mulching may be unavailable or extremely expensive, 3) Uneven application may result in smothering vegetation in localized areas OPS: 1) Operations are limited to slopes flatter than 3h:1v, 2) High soil moisture may prevent application, 3) Multiple pass operations may adversely compact seed bed, 4) Weather conditions may prevent or limit operations

APPENDIX A (cont.)

MANAGEMENT PRACTICE	COST PER ACRE	ADVANTAGES	LIMITATIONS-BIOLOGICAL (BIO), OPERATIONAL (OPS)
Herbicide Application			
Rate: Land-5 to 15 acres per hour Air -up to 100 acres per hour	$12 to $14	1) Available chemicals allow for broad control of either monocots or dicots, 2) Easy to apply, 3) No topographic limitations,	BIO: 1) Precipitation impacts effectvieness, 2) Lack of selectivity effects both desireable and undesireable species, 3) Removal of broadleafs can result in increase of undesireable grasses OPS: 1) Drift is difficult to control/contain, 2) Weather conditions must be optimum to apply, 3) Licensed applicators must be used and permits may be required, 4) Unintentional exposure may result in financial liability
Mechanical Brush Removal (Brushing/Windrowing)			
Rate: 5 to 15 acres per hour	$10 to $30	1) Used in lieu of burning, safer operations to conduct, 2) Area of application can be closely controlled, 3) May be performed under inclement weather conditions (winter preferred), 4) Useful in rejuvenating anticlimatic stands of vegetation since roots are left intact in soil, 5) Brush piles or windrows may act as cover during woody species regrowth, 6) A planned mosaic pattern may be used	BIO: 1) Windrowed vegetation may represent a fire hazard, 2) Wet soils may be damaged during operations and brush removal tends to be less efficient, 3) Potential for erosion is increased until regrowth occurs, 4) Herbaceous species may temporarily increase in percentage of total vegetation community OPS: 1) Limited to areas accessible to machinery (2h:1v or flatter), 2) Operations on excessively wet soils should be avoided, 3) Woody stumps tend to puncture rubber tired equipment causing increased downtime
Chaining			
Rate: 10 to 50 acres per hour	$1 to $5	1) Highly productive method for brush removal, 2) Favors regrowth of herbaceous component over woody component, 3) Affects limited to area where used, 4) Relatively inexpensive and productive method	BIO: 1) Tends to tear up plant roots along with tops, 2) Does not integrate removed vegetation as mulch, 3) Woody maaterials left on surface may present fire danger, 4) Relatively non-selective in plant removal within area of application OPS: 1) Difficult to coordinate machines in rougher terrain, 2) Limited to flatter slopes (2h:1v or flatter), 3) Spent brush is aesthetically unpleasing and maay require windrowing

APPENDIX A (cont.)

MANAGEMENT PRACTICE	COST PER ACRE	ADVANTAGES	LIMITATIONS-BIOLOGICAL (BIO), OPERATIONAL (OPS)
Surface Roughening			
Rate: Small temporary features 5 to 10 acres per hour Large permanent features 250 to 1,000 linear feet per hour	Small $10 to 35 $35 Large $1 to $10 (per linear ft)	*Both:* 1) Detain, retain and harvest stormwater runoff, 2) Improve soil moisture, 3) Decreaase erosion, 4) Improve stormwater runoff quality *Small:* 1) Easy and fast to construct, 2) Create microhabitats for plant germination and establishment, 3) Crimping mulch when used, 4) Firm seedbed and improve germination *Large:* 1) Protect respread soils from sheet and concentrated flow erosion by limiting slope length, 2) Route runoff safely off of site or retain runoff and improve surface water body and soil moisture resources, 3) Substitute and function as controlling bedrock for erosion control	BIO: Terraces and berms are difficult to revegetate and stabilize if cross-section is not lined with soil materials, 2) Small features last only a few years at best, 3) Gradient structures are difficult to structure to be self cleaning yet non-erosive OPS: 1) Poor design or construction may cause failure which locally accelerates erosion porblems, 2) Function best and are most efficiently constructed when planned in advance (can be difficult to do this with significant operational changes), 3) Effective slope length becomes very short on steeper slopes (3h:1v and steeper)
Fertilizing			
Rate: 5 to 35 acres per hour	$5 to $35	1) Poperly applied stimulates plant establishment and growth, 2) May be used to select for a particular group of plants, 3) Aids in nutrient rehabilitation of stockpiled soils	BIO: 1) May overstimulate plant growth and cause excessive dieback or death, 2) May supress diversity if one or more species are overstimulated, 3) May cause runoff effluent problems downstream OPS: 1) Improper application is waste of money, 2) Micronutrients are very expensive to apply, 3) Even application rates and distribution may be difficult to attain

APPENDIX A (cont.)

MANAGEMENT PRACTICE	COST PER ACRE	ADVANTAGES	LIMITATIONS-BIOLOGICAL (BIO), OPERATIONAL (OPS)
Planting-bareroot and containerized stock			
Rate: Variable	$1 to $500 per plant	1) Provides good source for spread of planted species, 2) Introduces desired species at exact locations, 3) Speeds successional processes	BIO: 1) Matching genetic stock to locality can be difficult and expensive, 2) Stock is difficult to keep in god condition over long periods of time, 3) Variable weather patterns may adversely affect plantings, 4) Weeds may be introduced OPS: 1) Expensive process, either labor or machine intensive, 2) Diverts specialized machinery from other operations, 3) Difficult to perform on steep slopes
Transplanting-Single plants, clumps and strips			
Rate: Variable	$5 to $500 per plant $6,000 to $11,000 per acre	1) Provides good source for spread of transplanted species, 2) Introduces desired species at exact locations, 3) Speeds successional processes, 4) May introduced other native species to area in soil accompanying transplant, 5) Transplanted stock is genetically adapted to area	BIO: 1) Materials are removed from adjacent lands affecting these communities if not scheduled for disturbance, 2) Soil conditions may make successful movement difficult OPS: 1) Expensive process, either labor or machine intensive, 2) Diverts specialized machinery from other operations, 3) Difficult to perform on steep slopes
Supplemental Moisture (irrigation)			
Rate: n.a.	$1,500 to $5,000	1) Aids in plant establishment or maintenance, especially in abnormally dry years	BIO: 1) Moisture dependency may be developed in plants OPS: 1) Expensive to dsitribute water over large areaas
Controlled Livestock Grazing			
Rate: Variable	Variable	1) May be used to maintain or modify vegetation habit	BIO: 1) Difficult to properly plan and manage OPS: 1) Can be expensive set up and manage

THE ROLE OF GEOGRAPHIC INFORMATION SYSTEMS IN ECOLOGICAL RESTORATION

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ABSTRACT

A Geographic Information System (GIS) is "a computer system that stores and links nongraphic attributes or geographically referenced data with graphic map features to allow a wide range of information processing and display operations, as well as map production, analysis, and modeling." GIS is an enabling technology, allowing us to store and visualize large data sets, analyze spatial data at a variety of scales and complexity, and model built and natural environments for planning and management functions. The application of GIS to inventorying, managing, and modeling man-made and natural resources is limited only by one's imagination. GIS has been used extensively in vegetation, soils, wildlife, and urban planning and management applications at local and global scales.

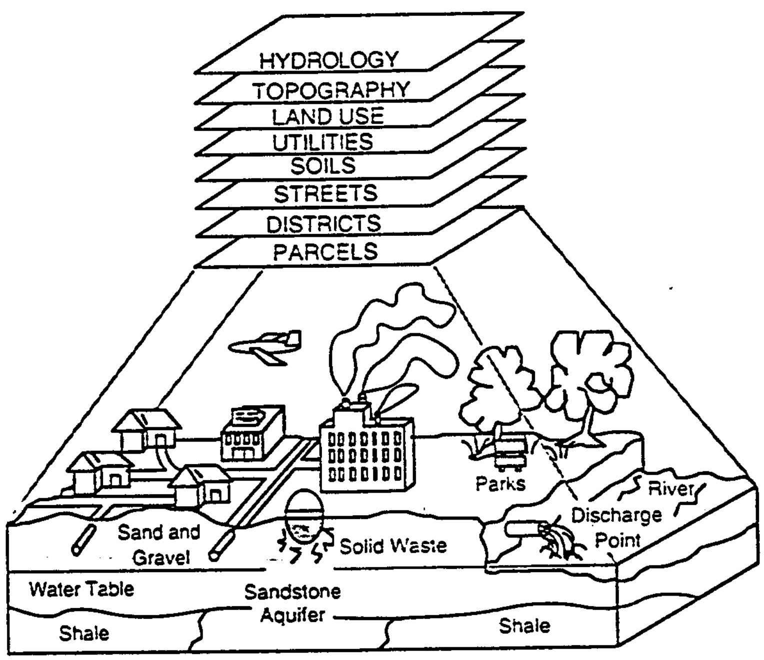
The purpose of this paper is to introduce GIS technology as an enabling tool. This paper also introduces a case study about how GIS was used to analyze the natural and man-made environment along the Sand Creek Corridor between the High Line Canal in Aurora and the confluence of the creek with the South Platte River in Commerce City, Colorado. Existing vegetation and wildlife habitats along the riparian corridor were analyzed and employed to aid regional planners in a trail alignment project.

Key Words: GIS, database, enabling technology

INTRODUCTION

A Geographic Information System (GIS) is "a computer system that stores and links nongraphic attributes or geographically referenced data with graphic map features to allow a wide range of information processing and display operations, as well as map production, analysis, and modeling." (Antenucci et al., 1991) Many think of GIS as computer mapping, but it is really much more than that. We have had the ability to make maps with computers for a long time, but the marriage of graphic and database capabilities makes GIS a technology worth considering when managing or analyzing spatial data sets. Analytical functions may be as simple as determining the area and perimeter of a given location, or as complex as doing prediction modeling of wildfire behavior. Finally, a GIS provides a technology for creating graphic output that can illustrate the contents of our database in a format that, given effective cartography, communicates the intended message.

What is a spatial data? Spatial data is the collection of geographic features in which we are interested. The spatial or geographic data you may be interested in may include boundaries of vegetation or wildlife habitat, individual plants or trees, water pipes, electric lines, voting districts, and the list goes on. One can think of spatial data in terms of layers of information that register with each other in and on the earth. The following figure taken from *Understanding GIS - The ARC/INFO Method* (ESRI, 1995) illustrates the concept of layers of spatial data.



Spatial data usually has attributes associated with it. Typical attributes may include, length, perimeter, area, age, date installed, quantity, owner, entity number, and that list goes on. For years scientists, planners, engineers, and managers of all sorts have maintained databases full of "attribute" information. GIS enables you to link attribute data with spatial data. That data linkage is in part, the essence of GIS. The data linkage between geographic or spatial data and attribute data is the function that enables us to perform queries about how much, how often, where, when, and even why?

GIS COMPONENTS

People

I would not introduce GIS without a discussion about the human resources required to make GIS useful and successful. The importance of people who understand geographic data and spatial analysis cannot be overemphasized. The adoption of GIS technology for most organizations usually represents a substantial change in the way they do business. In the past, geographic data was analyzed in tabular form and if maps were used at all, overlays were drafted on clear film and draped over a paper base map. Today geographic data is stored electronically in bits and bytes on hard drives, floppy disks, and magnetic tape. Data is organized in layers of information with databases attached or linked. Data needs span multiple departments within an organization or across local agencies.

Qualified individuals able to speak and work competently with geographic data and the computer systems upon which GIS is housed are required to make the application of GIS successful. Fortunately GIS education has flourished over the past decade and college graduates emerge with the theoretical knowledge and hands-on skills required to apply GIS to their chosen field. Can you teach an old dog new tricks? Can someone that grew up drafting maps by hand and typing on a typewriter begin to understand GIS? Of course. GIS software fortunately is becoming easier and easier to use. For the most part, gone are the days of the command line interfaces and now GIS software is characterized by graphical user interfaces (GUIs) in a windows environment with point and click ease.

Data

Data is the most important aspect of a GIS project. Data represents an investment that is essential to GIS analysis. However, proper data acquisition planning is crucial. You must understand the purpose of your GIS application before running off to acquire data. You need to think through your project and determine the data requirements as they pertain to data entities and attributes, geographic area to be mapped, sources of available data, and data quality characteristics. The following spatial data quality characteristics should be reviewed before deciding on a data source for your GIS project:

- Positional accuracy (horizontal and vertical)
- Lineage of data (description of source material)
- Attribute accuracy (categorization and description)
- Logical consistency (fidelity of spatial data structures)
- Completeness (geographic coverage)

Base Map:

A base map should be chosen wisely. After considering the spatial data quality characteristics listed above, you can begin reviewing the myriad sources available to compile a base map. Fortunately in this day and age, there are many existing sources of digital base map data. The federal government has spent years developing sources of cartographic data from paper maps that have been in print for years. Following is a brief list and description of several public domain GIS/Cartographic data sources. This table is illustrative only and does not include all of the data available in the public domain.

Data	*Agency*	*Scale*	*Geographic Availability*
DLG	USGS	1:100,000	Nationwide
DLG	USGS	1:24,000	"Spotty"
DEM	USGS	1:250,000	Nationwide
DEM	USGS	1:24,000	"Spotty"
Land Use/Land Cover	USGS	1:250,000	Nationwide
TIGER	Bureau of the Census	1:100,000	Nationwide

Base map data may also be compiled photogrammetrically although this is usually an expensive proposition. Data sharing or collaborative efforts with other agencies is increasing in the GIS community. The abundance of GIS-suitable data is beneficial if organizations can work through data sharing issues. Duplicative efforts in GIS database development are a waste of time and resources.

Thematic Data:

Most GIS projects include more than base map data. The purpose of the base map is to provide a framework on which to build data that is necessary or meaningful to performing a specific spatial application. Additional thematic layers of information may include vegetation, geology, soils, cadastral information, jurisdictional boundaries, vegetation and wildlife habitats, and the list goes on. It is usually upon these layers that GIS analysis can take place.

Software

There are literally hundreds of GIS software packages available. There are GIS packages available in the public domain, but most packages are developed by commercial software vendors. The two leading GIS software vendors in terms of market share according to Daratech Incorporated are Environmental Systems Research Institute (ESRI) with 30.3 percent market share and Intergraph with 24.1 percent market share (GIS World, 1995).

After determining what functions or applications one wishes to perform with GIS, one can begin to evaluate the myriad GIS software offerings to select a package suitable for their needs. The *1995 International GIS Sourcebook* published by GIS World, Incorporated is an excellent place to begin to review the functionality of GIS software offerings.

Hardware

After selecting a GIS software package, one is usually driven towards a certain hardware platform. What once was an important decision weighing the merits of UNIX versus DOS platforms has now been made fuzzy by the availability of GIS packages that operate similarly in both environments. This is not to say that GIS packages can run equally in two operating environments, but previous platform decision driven by the need for speed have been made less important by the emergence of high-performance DOS platforms.

One must also consider adequate input devices and output devices for entering and plotting GIS data. Digitizing tables and tablets, scanners, GPS receivers, and a host of similar devices may be required for data input. Laser printers, ink jet plotters, pen plotters, and electrostatic plotters in a wide variety of formats should be looked at to find the most suitable device for your output requirements.

Communications

Seldom do GIS workstations operate as an island removed from the rest of the corporate computing environment. In this day and age one must give consideration to networked environments and having access to data within and external to an organization. Pick up any magazine or newspaper and witness the importance of the Internet for accessing data from servers throughout the world. Within an organization, there are usually years of valuable databases that can or should be integrated into the GIS for spatial analysis.

In addition to accessing data from internal and external servers, count on GIS being coveted by other personnel within the organization. Therefore, it will be necessary to provide network access to the GIS from other "seats" in the organization. Userfriendly windows-based packages are available that enable users to "connect" to the GIS and access the GIS database thereby bringing GIS to the desktops of others in the organization.

GIS IN ECOLOGICAL RESTORATION

Spatial Analysis

So far GIS has been portrayed in a litany of components that take time and resources. Do the benefits outweigh the costs? Conventional wisdom says so. "Better, cheaper, faster" is the mantra of many when it comes to justifying GIS for projects emphasizing spatial data. If for no other reason, mass computer storage and speed of data retrieval go a long way towards making GIS worthwhile. More importantly, however, is the ability of GIS to enable us to perform analytical functions that were formerly time consuming and difficult to do with pens and ink on paper. Creating buffers around stream channels, developing a three-dimensional terrain model from digital elevation models or contour lines, and inventorying areal coverage of a variety of species are just a few samples of what can be done with GIS. One favorite definition of a GIS emphasizes its ability to create a new layer of data from two existing layers of data. Imagine being able to overlay layers of endangered species habitats to quantify and evaluate the most threatened geographic areas without having to map several overlays by hand to "visualize" the answer. The computer and GIS software enable us to perform this function in seconds.

The following sections of this paper discuss the specific issues and methodologies employed in a GIS project conducted by the University of Denver for planning, restoration, development, and management support efforts along Sand Creek in the Denver metropolitan area.

THE SAND CREEK CORRIDOR GIS PROJECT

Project Background

Sand Creek originates in the hills north of Franktown, Colorado. The creek winds its ways towards the Denver metropolitan area passing through Aurora, Denver, and Commerce City before it reaches its confluence with the South Platte River. This project focused on a 12-mile corridor from where Sand Creek crosses the High Line Canal to its confluence with the South Platte River.

With the closing of Stapleton International Airport early in 1995, a major portion of Sand Creek that traversed a "closed" area suddenly became "open." Park and trail planners in Aurora, Denver, and Commerce City recognized the opportunity to develop a recreation trail for hiking and biking linking the High Line Canal trail system with the

South Platte River trail system thereby providing a circuitous hiking and biking route around the metropolitan area.

The Role of GIS in the Project

Planners with the Stapleton Redevelopment Foundation and the three participating cities recognized the potential of GIS to manage data along the Sand Creek Corridor. Four objectives were outlined for the GIS to enable:

1. Inventory
2. Planning
3. Restoration
4. Management

A GIS is a useful tool with its data collection and storage capacity to keep an inventory of spatial data in the project area. Of course an inventory must be created. Data was collected along the corridor with the GIS serving as the repository for that data.

With a spatial data inventory complete, trail planners could initiate planning activities. Querying the database on a variety of attributes afforded trail planners to identify locations of suitable routes through the corridor for the trail.

The Sand Creek environment has been severely influenced by agriculture and urbanization. Several areas along the creek have been severely disturbed. It is the goal of the participating cities to restore the local ecology to a condition suitable for the projected land use. In some cases restoration means returning habitats to their natural conditions. In other places restoration means restoring the habitat from a disturbed location to a condition compatible with the impending recreation traffic.

Finally, when the trail is complete and human activity increases through the corridor, park managers will have a tool suitable for planning and scheduling planning activities along the trail.

Description of Base Map Compilation

The first phase of the project commenced in May 1995 and was completed in July. University of Denver personnel contacted and interviewed representatives in the three sponsoring communities to determine the types of data they currently maintain in a GIS format that were suitable for the Sand Creek GIS project. An inventory was made of the data available with a determination made as to the data's suitability for the project. A conceptual database design was compiled from the list of map features and attributes available or desired by the project participants. The conceptual database design is a "first cut" at identifying the data requirements for the Sand Creek GIS project. It may begin as a wish list of physical entities and attributes that must then be evaluated to determine the feasibility of entering the data into the GIS database.

After completion of the conceptual database design and review by the project team, a detailed database design was developed. The detailed database design addresses the contents, specifications, relationships, and sources of data to be incorporated into the GIS database. A detailed design is completed for each layer or coverage of information in the database. The database design is also software specific. For this project, the database design was done with ARC/INFO as the software environment of choice.

Data was available in an AutoCAD format in all three cities. The Aurora data was found to be suitable for the project because it was compiled via aerial photography and photogrammetric methods for the Sand Creek Project in May 1995. Denver data was compiled in AutoCAD by a local photogrammetric engineering firm to support design and engineering efforts on the Stapleton Airport property. Commerce City data was compiled in AutoCAD by a local photogrammetric engineering firm to support trail planning and creek corridor planning activities.

The problem associated with getting data from different sources is that the data may not be stored in the same map projection and map coordinate system. This means that the same x,y location for a given point may have one set of coordinates in one city's database while the same point would have a different set of coordinates in a second city's database. This is a problem when merging the three sources of data into a single, continuous, and seamless database.

To remedy the problems associated with different coordinate systems, University of Denver staff examined the data sets and decided which, if any, of the data coordinate systems were appropriate. Data was then transformed, or moved, to make the data sets fit together at city boundaries.

After a common coordinate system was established, the existing AutoCAD data was converted into the Drawing Interchange Format (DXF). DXF is a published file format used to produce an ASCII description of an AutoCAD drawing file. You can use DXF to exchange AutoCAD drawing data with other software applications, or to bring drawings made by other programs into AutoCAD. Once the AutoCAD drawings have been converted into DXF, the data was converted into ARC/INFO format. Each layer of information available in AutoCAD was converted into an ARC/INFO coverage. ARC/INFO coverages are roughly equivalent to AutoCAD layers of information, but they appear to the user as directories with a series of files that describe the data. For additional information regarding ARC/INFO data structure and format, please consult

Understanding GIS - The ARC/INFO Method, published by Environmental Systems Research Institute, Incorporated (ESRI), makers of ARC/INFO GIS software.

After coverages have been created from the DXF files, topology must be built. Topology is described as the mathematical method to define spatial relationships. Points are discrete locations at single x,y coordinates. Arcs or lines are described as an entity with length between two points. An area or polygon is described as space bordered by a series of arcs or lines giving area and perimeter.

Building topology is conceptually simple, but computationally difficult. The computer software must sort through every point in a database, build lines, and create areas. The larger the database, the longer this process takes. Features like contour lines, because of their volume, can take a long time to process when building topology.

The biggest problem associated with conflating, or combining different databases from different sources is working through various naming conventions for layers of data. For example, one city may consider retaining walls that stand alone a building structure and place retaining walls on the same layer as other building structures. Another city may put retaining walls on a layer with fences. Each city had their reason for creating the layers of data the way that they did. However, the database design for the Sand Creek project calls for walls to be treated as a separate entity on a layer or coverage of their own. Therefore, walls had to be extracted from the two disparate sources of data and merged into a single coverage of wall information.

The deliverables for the first phase of the GIS project included a detailed database design and a digital base map of the Sand Creek corridor in ARC/INFO format. The coverages created were delivered on QIC 80 tapes (DC 2120). For ease of display and viewing, the data was organized in ArcView projects. ArcView is a Windows-based GIS software developed by ESRI for display and query of ARC/INFO data.

Description and Development of Corridor Units

The 12-mile riparian corridor was divided into 20 corridor units that were numbered from east to west (from the High Line Canal to the confluence of Sand Creek with the South Platte River).

The second phase of the Sand Creek GIS project was to integrate the habitat units field data collected by Keammerer-Stoecker Ecological Consultants, Incorporated. The consultants delivered to the University photo maps with the habitat units identified in the field annotated on them. The photo maps were at a map or photo scale of one inch equals 100 feet, but the images were not rectified. In other words, the x and y measurements on the photos were distorted. Map scale becomes less accurate as you move away from the focal point on the image. However, this was not be a big problem. Spatial accuracy is suspect when mapping from unrectified photos, but the nature of habitat boundaries is that they are "fuzzy." A shift of a couple of feet here and there does not matter significantly when analyzing grass cover or cottonwood stands.

To merge the habitat unit data into the GIS database, ground control was established on the aerial photography. University personnel examined each photo and identified points on the photos that could be correlated to known points in the GIS base map developed in the first phase of this project. Photo control points include bridge corners, building corners, trail intersections, or other prominent point features. Accuracy again is not guaranteed when assigning coordinate values to photo points. The photos are reproductions and "pinpointing" objects is difficult because of the fuzziness of the image. Another problem is that many of the buildings that appear on the photos close to the creek corridor do not appear in the AutoCAD base map data. Other photos have few distinguishable features which makes locating photo control point identification points difficult. Again, given the nature of the data, these are not insurmountable problems, but the users of the data must understand the limitations of the source material.

After control had been established on the photos, each image was oriented with north at the top and then affixed to the digitizing table. Digitizing was done in AutoCAD because this package is extremely efficient for digitizing procedures. All of the habitat polygons were digitized. AutoCAD files were then converted into DXF format. DXF files were imported into ARC/INFO and polygon topology was built.

After polygon topology was built, university personnel went through the data and assigned the correct polygon number to each polygon. The correct polygon number is that number assigned to each polygon by the ecological consultants and annotated on the photo maps. Each polygon should have a unique number assigned.

The ecological consultants also built a database in Microsoft Excel of information associated with each of the polygons drawn on the photo maps. Each record in the database was prefixed with the unique habitat unit number. The database was translated from Microsoft Excel spreadsheets into a database format. Then a link was established to associate the database information with the polygons created for the GIS database.

The linkage of database information with the graphic polygons gives users of the system the ability to analyze the types of habitats along the corridor. Users of the system can query polygons for their habitat types. Users can also compile descriptive statistics on the habitats mapped such as area, perimeter, or frequency.

The Future of GIS Along Sand Creek

GIS data has been delivered to GIS professionals and planners in Aurora, Denver, and Commerce City. The data compiled for the Sand Creek Project will be integrated with the existing GIS programs in the participating cities. Planners and park managers will use the data to assist in trail planning activities and vegetation management. Where appropriate, restoration efforts will be implemented. For example, noxious weed control programs will be initiated and managed. Trail construction and maintenance activities will also be enabled with the GIS.

In addition, efforts are currently underway to create an organization that will monitor activities along the creek corridor as a whole. This group will use GIS to monitor and manage the habitat and trail activities in the creek corridor. In this way, individual community activities along the creek can be done with the guidance of an oversight group that can identify activities that may affect the other communities.

CONCLUSION

GIS is a tool that enables land use managers, resource managers, planners, engineers, and anyone who works with spatial data to efficiently collect, store, analyze and output geographic data. What traditionally may have been done by hand, if at all, can now be done in a fraction of the time. Large data sets can be analyzed that were once too large to work with. Discoveries can be made from existing data revealing trends or patterns that previously were not apparent. GIS is a tool that can be used for the management of resources and the management of ecological restoration.

MAP ILLUSTRATIONS

Plate 1: Sand Creek Corridor Base Map

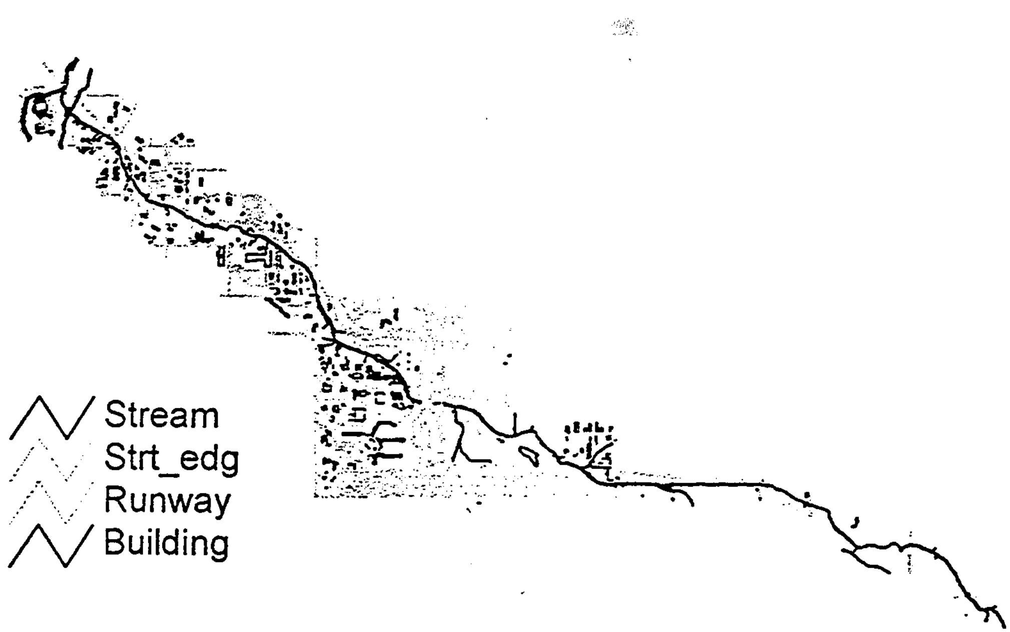
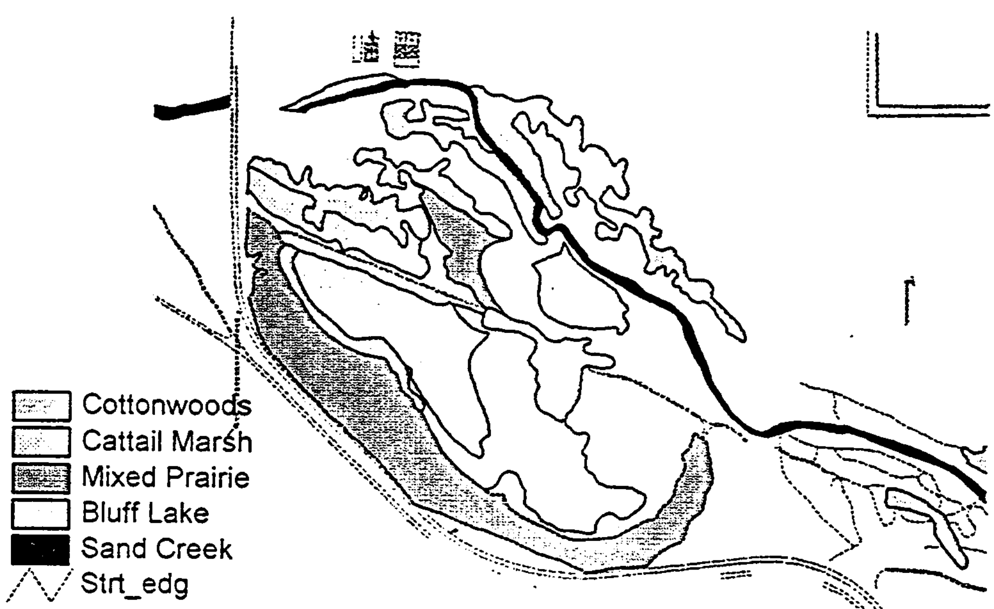


Plate 2: Bluff Lake Vegetation



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The Galloping Forester: Is It Fertilizer or Fact? Dirty Ideas for Ready -to-Go Soil in Thirty Minutes or Less.

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ABSTRACT

Ever wonder why no matter how well you plant and maintain your trees, they never seem to grow, let alone live! The solution might lie underneath your boots or as the case may be, crawler treads. Join the Galloping Forester in taking a down and dirty look at what soils are and what they do for woody plants. The problems encountered with disturbed soils in establishing woody plants will be discussed along with the role technological solutions can play. Speaking of play, those in front are forewarned about mud slinging!

INTRODUCTION

What is soil? Webster's Seventh Collegiate Dictionary defines soil as firm land, earth; the upper layer of earth that may be dug or plowed specifically the loose surface material of the earth in which plants grow. Don't we wish it were that simple. The definition exposes some of the problems inherent in revegetation of disturbed areas. For example, lets take a closer look at the at the word "firm".

The word "firm" implies that the soil is not moving or eroding. But erosion is an everyday occurrence. Erosion results in a loss of nutrients, soil structure and support to woody plants. "Firm" may also imply the loss of soil particle space from compaction; this might indicate the soil is "too firm". A combination of fine soil particles and summer drying may turn the earth into concrete, forming an "extremely firm" soil. So the definition, while succinct, leaves a lot to be desired when it comes to reclamation.

So then what is soil? Soil may be better defined as a mixture of mineral and organic matter, water and air. A cookbook combination of these materials might result in 45% mineral matter, 5% organic matter with the water and air composing 20 - 30 % each of the remaining mixture. The mineral portion may contain various sizes and composition. The organic layer is composed of plant and animal residue in a broad range of decay. Water and air play a dynamic interactive role. Water and air fill the pore spaces that exist between the individual mineral and organic components. This allows water along with soluble salts to be made available to plants. As water is depleted from the soil, air fills the pore spaces. This constant interaction affects the biochemical processes that supply the myriad of ingredients for plant growth.

So your goal, as a reclamation specialist is to try and mimic a soil that will support plant life with the material bestowed upon you from a disturbed area whether it be a mine, agricultural pasture, or an abandoned road bed. The development of a true soil requires the passage of a tremendous amount of time. Once disturbed, the interactive processes described above cannot be replaced, only reintroduced with the final restoration years down the road.

As with any discussion of soils, a tremendous number of factors come together to affect how a soil functions, such as plant handling, weather, precipitation and animal predation. These factors play a role, positively or negatively, in your revegetation efforts. Lets look at some simple items that may be affecting your tree and shrub planting success.

Topsoil

This item requires a decision prior to any disturbance, if possible. This is the practice of stockpiling topsoil for later use in the reclamation process. Due to the expense and difficulty in recovery, is it really critical to the growth of woody plants? Obviously, there are a number of factors that affect woody plant growth to provide a ready answer to this question. However, our own individual observations along road cuts include the sight of a lone tree growing out of bare rock with no evidence of any quantity of topsoil. What is most frustrating is that this scene is not an uncommon occurrence. Granted, the plants are not phenomenal specimens, but they are alive and growing. A study looking at the use of stockpiled topsoil in growing trees and shrubs on lignite mine soils in Louisiana found that replacing the topsoil was not critical to the success of the planting (Haywood).

The use of topsoil creates a more favorable environment for rapidly growing herbaceous species, particularly when seeded. This competition, particularly in semi-arid regions of the country, can make woody plant establishment difficult. A practical solution may be to use stockpiled topsoil in areas where woody plants are not scheduled for placement.

Compaction

As the reclamation process proceeds, the use of heavy equipment becomes evident. It has been said that 90% of reclamation involves earth moving in the forms of contouring, reshaping, and spreading soils. The number of times equipment moves over a site is uncountable. From the original contouring to the seed drill, the tires, treads and crawlers have all made their mark. So there may be some level of compaction in the soil you are about to plant. Soil compaction can have a detrimental effect on root development which leads the way in the overall growth of woody plants.

In a 1991 study (Stone & Kalisz) looking at the depth and length of tree roots, it was found that ponderosa pine had documented root depths of 1.7 meters (5.5 feet). However, the outward extent of roots in this review was 25.6 meters (83.9 feet). It was felt that the limits to downward root penetration were lack of oxygen or moisture, low soil temperatures and physical blockage of the roots. So here a case can be made for the long term effects of compaction on trees. As ponderosa pine had a root system that was fifteen times longer in width than depth, compaction over an entire area must be looked at, not just around the planting hole itself. Pore spaces affect the amount of oxygen and water penetration into the soil and this is one factor that can be influenced during reclamation.

A study looking at the effects of site damage due to logging activities (Bishop) found that the majority of compaction damage to soils occurred in the first three passes by rubber-tired skidders. So it is almost a certainty that compaction is playing a role in the success of your woody plants. Compaction affects the bulk density of the soil. Bulk density is defined as the mass (weight) of a unit volume of soil. The greater the weight of soil per volume inversely indicates a lesser volume of air or pore spaces. In the above mentioned study, the bulk density increased from 0.90 g/cm^3 to 1.10 g/cm^3 with just three passes of the equipment.

What does this mean to your woody plant establishment? Bulk densities that approached 1.4 g/cm^3 in silty clay soils and 1.75 g/cm^3 in sandy soils were found to limit growth in ponderosa pine. Height growth was reduced by 20 to 40% in a California study (Helms & Hipken) and in an extreme case, height was reduced by 48% in the first growing season alone.

The Sacramento Tree Foundation looked at trees that were planted in 1986 using holes that were as deep as the root ball and two times as wide. In 1990, trees were planted utilizing holes that were three to four times as wide as the root ball. After three years, the trees planted in 1990 were as tall as those in 1986.

This would point to the importance of loosening the soil immediately around and throughout the area your tree planting is to occur. By encouraging root growth, you have better and faster results from your tree and shrub planting efforts. An additional side benefit is an increase in the overall stability of the soil in which you are planting. A study in 1977 (Walden) determined there were large increases in the shear resistance of soils obtained from the roots of trees.

In most cases, rototilling the soil prior to planting will eliminate most compaction problems. The addition of organic material should lower the bulk density of the soil over the long term. In extreme cases, it may be necessary to rip the soil with a caterpillar tractor.

Fertilization

As with most disturbed soils, fertility is always an issue. There are six nutrients that are used in relatively large quantities by plants. They are nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. The absence of any one of these will cause a plant to cease growth. Another eight elements while essential are used in much smaller amounts. These are iron, manganese, boron, molybdenum copper, zinc, chlorine and cobalt.

For woody plants, substantial gains in growth and survival have been observed from the use of fertilizer treatments, particularly when the plant is just getting established. Most important here is the application of nitrogen. Nitrogen is the basic building block for proteins and is essential to chlorophyll formation. It is used in the largest amount by plants. However, nitrogen is not found in large quantities in most soils and what is present may not be in a form that can be used by plants. The majority of nitrogen is found in organic matter and is converted to an inorganic form through a series of biochemical processes. Obviously, these processes take time and you may be starting your planting next week.

So what is the best combination of fertilizers to use to obtain the best results? Again, there is no ready cookbook answer. The first step is to see what is missing by having a soil analysis performed. For example, results from the Colorado State University Soil Testing Laboratory has shown that 82% of the soils on Colorado farms are deficient in nitrogen. This is followed by deficiencies in phosphorus (72%), zinc (20%) along with iron and potassium. While each soil is unique, particularly in disturbed situations, a soil test can give you a target to shoot for.

As for formulations, there are many studies that provide a myriad of possibilities, including tablets that can be installed with the tree. These products, such as Agriform, Osmocote, and Woodace, consist of nutrient levels ranging from 14 - 3-3 up to 20-10-5. The key here is to keep the nitrogen level down to less than twenty. With fertilizers that contain a higher level of nitrogen, you run the risk of burning the roots. In addition, the tree or shrub you are planting is already experiencing some level of transplant shock. Adding excessive nitrogen may cause the plant to raid its stored carbon reserves to utilize this increased amount of nitrogen. This may cause the plant to enter its dormant period with insufficient reserves for the following growing season.

Research appears to show that there is no great differences in the type of fertilizer application made nor in its placement in regards to the tree. Fertilizers can either be broadcast within 15 cm (6 in.) of the seedling or placed in a hole within the same distance. There has also been studies where the fertilizer was placed in the bottom of the hole with no appreciable damage to the tree. The benefit of tablets comes from their ease in application and transport while planting.

One interesting note to fertilization is the application of triple superphosphate (0-45-0). Phosphate is important in the development of root tissue. So it is not surprising that in one study (Van Den Driessche), a marked increase in overall survival was noted with the application of high phosphorus levels. So if you are having difficulty in getting adequate survival, it may be more beneficial to add phosphorus and leave the nitrogen alone. Again, roots drive the growth of most woody plants. If you achieve good root growth, your height growth will follow.

Polymers

The use of polymers in dryland tree planting has been discussed in an earlier paper before this group. And it appears that nothing has changed concerning the controversy over these products and research continues to quantify their beneficial uses.

A Russian field trial (Mattis) achieved significant growth response with European weeping birch and Tamarix by incorporating a polymers into the soil at rates ranging from 3 to 3200 kg/ha (2.6 - 2,855 lbs/ac). With the addition of a straw mulch to retard moisture loss, dry seedling weight doubled versus polymer alone. So this test would indicate there is a potential for water storage on dry sites through the use of polymers. Similar results were achieved using polymers and weed barrier fabrics to create a water retention system in dryland raspberry production near Peyton, Colorado (Wofford).

It still appears that polymers can temporarily delay drought stress in trees and shrubs. The use of root dips on bare root stock can appreciably increase overall survival particularly in the first weeks after field planting. Utilizing polymers in this manner can cost up to five cents per plant. So the nominal expense may justify their use in most instances.

The concept of incorporating fertilizers with polymers for use as a single soil amendment has reached the marketplace. One of the formulations contains 5 grams of a 17-3-5 slow release fertilizer with 2 grams of a copolymer acrylamide. These are supplied in a biodegradable "teabag" packet. The recommendation is to place one "teabag" in the bottom of the hole at the time of planting. A potential drawback of this product is that water must be applied immediately after planting in order to hydrate the polymer crystals.

Mycorrhiza

The role of mychorizzae in the development and growth of forest trees has been known since the early 19th century. But exactly how this all works is still not completely known. It appears that the benefits derived from mycorrhizae are from the larger soil volume used by the fungi versus just the plant roots alone.

Mychorizzae can be separated in two groups, endotropic which actually penetrate the root cells and ectotrophic which penetrate the roots but do not enter the internal root cells. Research has indicated that ectomycorrhizae (ECM) can increase the drought resistance of trees. The more commonly used endomycorrhizae are vesicular-arbustular mycorrhizae (VAM) which appear to influence the absorption and translocation of nutrients..

Mycorrhizae assist a plant in the uptake of nutrients particularly in low nutrient level soils. Phosphorus has been found to increase markedly in mycorrhizae associations along with nitrogen, zinc, copper and sulfur. This association may be primarily responsible for tree growth in sites of marginal fertility. In addition mycorrhizae appear to provide resistance to attack by root pathogens and nematodes. There is also evidence that mycorrhizae provide protection from heavy metal concentrations, such as zinc, cadmium and manganese, in the root zone.

In many field research projects, the effects from mycorrhizal inoculation are not striking once the seedlings leave the nursery. This can be attributed to field influences such as browsing by deer. In addition, most mycorrhizae are usually already present in the soil where the plants are being placed. The cost to have seedlings inoculated is extremely low, running just about one penny per seedling. So based on the nominal cost versus the potential benefits, it would merit use in most cases.

One ectomycorrhizal fungus that is being marketed under a number of trade names is Pisolithus tinctoris (Pt). It appears that the main limiting factor for maximum benefit of Pt lies in a pH of 5.5. As pH increases, the effects of Pt appear to decline. There are other species of mycorrhizae available in the marketplace such as Rhizopogon vinicolor, Laccaria laccata, Hebeloma longicaudum, Paxillus involutus and Leucopaxillus cerealis - pini to name a few. It appears that some species of mycorrhizae show better performance than others on different tree and shrub species. It may be advisable to inoculate seedlings with a mix of mycorrhizal species than just using one. As to which combinations will work best in your situation will be determined by the species that currently exist in the soil at the site being planted.

A couple words of caution here. Mycorrhizal fungi are living organisms and do not tolerate exposure to sunlight for any period of time. So there can be an additional handling problem in using mycorrhizal fungi in field planting operations. Secondly, mycorrhizae depend on soluble carbon from the plant in order to survive. As mentioned earlier, stressed seedlings may cannibalize carbon from stored food reserves. The mycorrihzae use of carbon may place an additional drain on this reservoir.

It is important to remember that there are a number of factors that can affect the survival and growth of woody plants. If you are having difficulty in establishing trees and shrubs on your reclamation site, it would be wise not use a myriad of products or techniques without first looking at your entire planting program. Typically, no one item alone will solve your problem and what works at one location may not work at another. By looking specifically at the potential problems that can be encountered in planting trees and shrubs and planning for enhancing their survival and growth, you are well on your way to making the planting process a critical component of your reclamation efforts.

Acknowledgments

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SOUTH PARK RECLAMATION: FORAGE IMPROVEMENT ON FORMERLY IRRIGATED MOUNTAIN MEADOWS

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ABSTRACT

The South Park area of Colorado may be in danger of experiencing accelerated watershed deterioration. Historical mountain irrigation has drastically altered the natural vegetation on about 70,000 acres of South Park. Over irrigation in this high mountain park environment encouraged the development of the peat that now covers most of the formerly irrigated area. As a result of water transfers to Aurora and Denver, plants adapted to irrigated conditions died and natural regeneration began toward more xeric plant communities. This successional process is being retarded by the lack of a seed source from the indigenous plant species and negative impacts of the peat layer on seedling establishment and hydrologic cycling. A demonstration project was implemented on the Trout Creek Ranch located near Fairplay at an elevation of 9350 feet to explore realistic solutions to this problem. The project objectives were to, (1) investigate surface treatment techniques that remove strips of the peat layer down to mineral soil, and (2) investigate various plant species regarding suitability for intended economic uses and adaptability to the environmental conditions of South Park. A Hodder gouger (pitting treatment) was found to be the only equipment capable of consistently producing the optimum seedbed conditions. Through the Natural Resources Conservation Service plant materials program species trials consisting of 41 cultivars were established utilizing two planting dates consisting of a dormant planting season and a summer planting season. The results are showing that the summer seeding window yields better stands than does the dormant seeding time frame. The top performing cultivars are #9005308 Mountain Bromegrass, Arriba Western Wheatgrass, Redondo Arizona Fescue, Bandera Rocky Mountain Penstemon, and Hatch Winterfat. The double Hodder gouging treatments, with summer planting, continue to show the best stands.

CONCERNS

The South Park area of Colorado, having a mixture of various public lands, and with private ownership consisting of agricultural producers, land developers, and public water purchasing agencies, is in danger of experiencing their once stable watershed deteriorate to unacceptable conditions. The water quality now enjoyed by rapidly expanding front range cities will be negatively impacted by watershed deterioration.

Close to 100 years of mountain irrigation has drastically altered the natural vegetation on about 70,000 acres of South Park. This has impacted the soil and modified the soil surface by building a peat layer. Irrigation water supported introduced grasses with some indigenous rushes and sedges succeeding back into these areas. Over irrigation, combined with the high mountain park environment, encouraged the development of the peat that now covers most of the formerly irrigated area.

Rapid population growth of the front range in the late 1960's through the 1970's lead to increased water demands and resulted in large scale water transfers to the cities of Aurora and Denver. Today only about ten percent of the original 70,000 acres remains under irrigation. Plants adapted to irrigated conditions died and natural regeneration began toward more xeric plant communities. The successional process is being retarded by, (1) the lack of a seed source from the indigenous plant species, (2) negative impacts of the peat layer on seedling establishment, (3) unfavorable hydrologic and mineral cycling due to the influence of the peat layer, and (4) lack of mineral soil on or near the surface.

RESOURCE AND ECONOMIC IMPACTS

The resulting ecosystem deterioration is having negative impacts on the natural resources of South Park relative to water quality and quantity, grazing lands, wildlife habitat, aesthetic values and the tax base.

These important watersheds are on the threshold of experiencing impaired water quality through accelerated soil erosion due to deteriorated plant communities, low rangeland and meadow conditions and decreased plant cover. With the potential for noxious weed invasion and the subsequent need to implement control with increased herbicide usage, further water quality impairment could occur.

Also with the degraded rangeland and meadow conditions come low return values from grazing the existing forage plants. The current forage is very limited in terms of production and quality consisting primarily of mat muhly, baltic rush, and fringed sagebrush. Current forage productivity is estimated at providing 9 to 10 acres per cow/calf pair for one month. With proper reclamation and livestock management forage productivity could potentially triple.

Wildlife habitat has been degraded due to the low rangeland and meadow conditions. Primary species affected are pronghorn antelope, elk, upland game and non-game birds, and furbearers. Wildlife enhancements would be projected to increase income to the communities and to private landowners of South Park.

For reasons already mentioned, a productive, well managed rangeland and mountain meadow resource base will protect and sustain the very valuable beauty and aesthetics of the South Park area.

Valued land becomes important as an attractive land use that generates income and as a valuable property that should be advantageously returned to private ownership and placed back on the tax rolls.

RECLAMATION PROJECT

This project expanded on the work conducted in South Park by the Colorado State University Mountain Meadow Research Station at Gunnison. The Trout Creek Ranch site, located near Fairplay at an elevation of 9350 feet, was selected to implement a reclamation project aimed at restoring the ecosystem and maintaining the resource values described above. The project was begun in June of 1993. The project objectives are, (1) investigate surface treatment techniques that remove strips of the peat layer down to mineral soil, and (2) evaluate various plant species through the NRCS plant materials program regarding suitability for intended economic uses and adaptability to the environmental conditions of South Park.

The Trout Creek Ranch project site has conditions that are typical of most of South Park with a peat layer that varies in thickness from 3 to 6 inches. The pH of the peat is 6.2. There is approximately one-half inch of decomposed peat located at the interface between the peat and the mineral soil. The mineral soil is a sandy clay loam with stones, cobbles, or gravel on the surface and throughout the profile. The soil pH is 6.9 at a depth of 6 to 10 inches.

METHODS AND TECHNOLOGY

Surface modification methods included, (1) a ducksfoot furrower with sidecutters, (2) a combination rangeland interseeder with a scraper opener, and (3) a Hodder gouger/pitter implement developed at Montana State University by Dr. Richard Hodder. Both single and double pitting applications using the Hodder gouger were investigated.

The plant materials (grasses, forbs and shrubs) were investigated through, (1) variety trials consisting of 41 cultivars within two replicated blocks, (2) evaluation of two planting dates, replicated twice, consisting of a dormant season (i.e. late fall to early spring) and a summer season (i.e. circa late June) planting windows, and (3) supplemental practices to enhance seedling survival including application of nitrogen, phosphorus and potassium fertilizer, seed packing treatment, and double or twice over Hodder gouging. The Upper Colorado Environmental Plant Center located near Meeker provided all of the plant materials used in the project. The plant materials base used with the supplemental practices consisted of a standard seed mixture being recommended in the area. All of the plots were planted by hand broadcasting premeasured amounts of each species at a rate of 40 to 50 pure live seeds per square foot. Tables 1 and 2 show the cultivars used in the variety trials and standard mixture seeded plots, respectively. About half of the seeded plots were tractor wheel packed to provide better seed and soil contact. The Field Plan Map, Drawing 1, shows the plot layout and experimental design for the project. Table 3 is a list of the treatments as coordinated on the Field Plan Map. The fertilizer treatment was applied only to half of the blocks that were seeded to the standard seed mixture. None of the variety trial blocks were fertilized. Rate of fertilization application was 46, 45, and 60 pounds per acre of available nitrogen, phosphorus, and potassium, respectively.

DRAWING 1: TROUT CREEK RANCH DEMONSTRATION PROJECT PLOT LAYOUT AND EXPERIMENTAL DESIGN. (Not to Scale.)

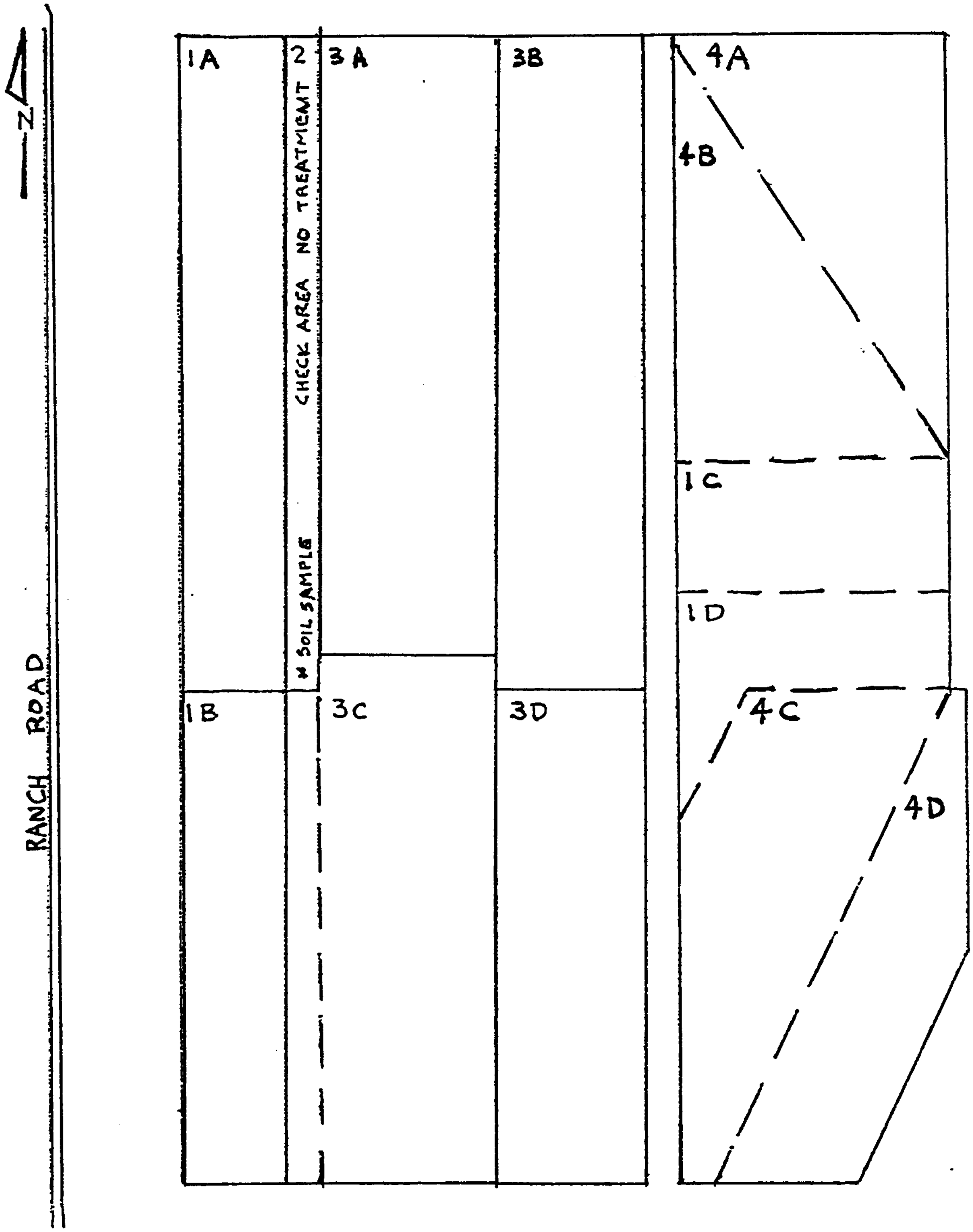

TABLE 1. CULTIVARS TESTED IN THE VARIETY TRIALS.

Common Name	Scientific Name
Antelope Bitterbrush, Maybell	Purshia tridentata
Arizona Fescue, Redondo	Festuca arizonica
Basin Wildrye, Trailhead	Leymus cinereus
Basin Wildrye, Magnar	Leymus cinereus
Big Bluegrass, Sherman	Poa ampla
Birdsfoot Trefoil, Viking	Lotus corniculatus
Blue Grama, Alma	Bouteloua gracilis
Bluebunch Wheatgrass, Goldar	Pseudoroegneria spicata
Bluebunch Wheatgrass, Secar	Pseudoroegneria spicata
Bottlebrush Squirreltail, #9040189	Elymus elymoides
Bottlebrush Squirreltail, #9040187	Elymus elymoides
Canbi Bluegrass, Canbar	Poa canybyi
Cicer Milkvetch, Monarch	Astragalus cicer
Columbia Needlegrass, #9040137	Stipia nelsonii
Columbia Needlegrass, #9024804	Stipia nelsonii
Crested Wheatgrass, Hycrest	Agropyron cristatum
Emerald Crownvetch, Chemung	Coronilla varia
Forage Kochia, Immigrant	Kochia prostrata
Fourwing Saltbush, Wytana	Atriplex canescens
Green Needlegrass, Lodorm	Nassella viridula
Kura Clover, ARS 2678	Trifolium ambiguum
Kura Clover, Rhizo	Trifolium ambiguum
Idaho Fescue, Joseph	Festuca idahoensis
Indian Ricegrass, Nezpar	Oryzopsis hymenoides
Lewis Flax, Appar	Linum lewisii
Mountain Big Sagebrush, Hobble Cr.	Ar. tridentata vaseyana
Mountain Bromegrass, #9005308	Bromus marginatus
Pubescent Wheatgrass, Luna	Elytrigia intermedia
Rocky Mountain Penstemon, Bandera	Penstemon strictus
Rush Wheatgrass, #291863	Elytrigia pontica
Russian Wildrye, Bozoisky-select	Psathyrostachys juncea
Sainfoin, Renumex	Onobrychis viciaefolia
Sheep Fescue, Covar	Festuca ovina
Siberian Wheatgrass, P27	Ag. fragile sibiricum
Sideoats Grama, Niner	Bouteloua curtipendula
Slender Wheatgrass, San Luis	Elymus trachycaulus
Small Burnet, Delar	Sanguisorba minor
Thickspike Wheatgrass, Critana	Elymus lanceolatus
Utah Sweetvetch, Timp	Hedysarum boreale
Western Wheatgrass, Arriba	Pascopyrum smithii
Winterfat, Hatch	Krascheninnikovia lanata

TABLE 2. STANDARD SEED MIXTURE.

CULTIVAR	PERCENT OF MIXTURE
Redondo Arizona fescue	25
Arriba western wheatgrass	25
San Luis slender wheatgrass	12
9005308 Mountain bromegrass	12
Nezpar Indian ricegrass	12
Lodorm green needlegrass	7
Bottlebrush squirreltail	7

TABLE 3. TREATMENTS AS COORDINATED ON FIELD PLAN MAP.

BLOCK 1A
Single peat pitted on contour June 30, 1993.
Broadcast seeded with standard seed mix June 30, 1993.
Tractor wheel packed June 30, 1993.

BLOCK 1B
(Treated only part of BLOCK 1B)
Single peat pitted on contour June 30, 1993.
Broadcast seeded with standard seed mix May 2, 1995.
Wheel packed May 2, 1995.

BLOCK 1C
Single peat pitted on contour June 30, 1993.
Broadcast seeded with standard seed mix June 30, 1993.
Not fertilized.
Not wheel packed.

BLOCK 1D
Single peat pitted on contour June 30, 1993.
Broadcast seeding to standard mix not completed.
Not fertilized.
Not wheel packed.

BLOCK 2
No treatment check area. Utilized for forage production comparison and collection of soils data. Note the area is primarily on the north half of the project.

BLOCK 3A
Single peat pitted on contour June 30, 1993.
Variety trial planted by hand broadcast June 30, 1993. See Table for cultivars tested. Wheel packed June 30, 1993.

BLOCK 3B
Single peat pitted on contour June 30, 1993.
Variety trial planted by hand broadcast March 25, 1994. See Table for cultivars tested. Wheel packed March 25, 1994.

BLOCK 3C
Single peat pitted on contour June 30, 1993.
Variety trial planted by hand broadcast May 2, 1995. See Table for cultivars tested. Wheel packed about one-half of the plot May 2, 1995.

BLOCK 3D
Single peat pitted on contour June 30, 1993.
Variety trial planted by hand broadcast June 30, 1993. See Table for cultivars tested. Wheel packed June 30, 1993.

TABLE 3 (continued).

BLOCK 4A

Double peat pitted with first pitting on the contour and the second on the diagonal done June 30, 1993.
Broadcast the following fertilizers at the estimated rates June 30, 1993.

Nitrogen	46	available pounds per acre.
Phosphorus	45	available pounds per acre.
Potash	60	available pounds per acre.

Broadcast with standard seed mix June 30, 1993.

BLOCK 4B

Single peat pitted on the contour June 30, 1993.
Broadcast the following fertilizers at the estimated rates June 30, 1993.

Nitrogen	46	available pounds per acre.
Phosphorus	45	available pounds per acre.
Potash	60	available pounds per acre.

Broadcast with standard seed mix June 30, 1993.

BLOCK 4C

Double peat pitted with first pitting on the contour and the second on diagonal done June 30, 1993.
Broadcast the following fertilizers at the estimated rates June 30, 1993.

Nitrogen	46	available pounds per acre.
Phosphorus	45	available pounds per acre.
Potash	60	available pounds per acre.

Broadcast with standard seed mix March 25, 1994.

BLOCK 4D

Single peat pitted on the contour June 30, 1993.
Broadcast the following fertilizers at the estimated rates June 30, 1993.

Nitrogen	46	available pounds per acre.
Phosphorus	45	available pounds per acre.
Potash	60	available pounds per acre.

Broadcast with standard seed mix March 25, 1994.

ACCOMPLISHMENTS AND RESULTS

Surface Treatments

Cutting through and displacing the peat layer to allow exposure of the mineral soil was found to be difficult. Occasional large stones occurring on the surface of the mineral soil but hidden by the peat layer were snagged by all of the implements tested. The ducksfoot furrower implement prepared furrows that were relatively free of peat but was unable to handle the rocks. Shear bolts were broken on the sidecutters, and eventually the ducksfoot was broken and required welding. The combination rangeland interseeder with scraper opener implement was designed to make shallow scraped furrows on the soil surface. For this project, the tractor's three-point hitch rocker arm system would not extend low enough to force the scraper through the peat. Therefore, this implement was unable to achieve the peat layer manipulation objectives.

The Hodder gouger/pitter was found to be the only equipment capable of consistently producing the optimum seedbed conditions and meeting the desired manipulation of the peat layer. This implement was capable of impacting about 25 to 40 percent of the surface with a single pass. Sixty to eighty percent of the pits made contact into the mineral soil. The Hodder gouger/pitter was operated with the maximum vertical displacement motion of the disks. The three heavy duty disks were not impacted by the large rocks and often just snagged the stone releasing it during the upward cycle of the disks. The side disks cut narrower pits while the main center disk was most effective in moving peat from a greater area. A 40 horse power tractor is the minimum we would recommend to effectively handle the Hodder gouger/pitter where stoniness and peat conditions exist that are similar to those encountered for this project. The double Hodder gouger/pitter treatment blocks had the implement operated on the same ground in two directions. While this process did increase the exposure of the mineral soil it did not double the amount of prepared seedbed. Therefore, the double pitted treatment produced the most favorable seedbed, although the increased cost over single pitting would need to be weighed against the expected benefits especially for large scale applications.

Plant Materials

Species establishment and vigor were evaluated and rated in October of 1993, September of 1994 and again in 1995. Three complete growing seasons have occurred for the summer planted blocks while the dormant planted blocks have experienced only two complete growing seasons. Relative to the species trials, the results are showing that the summer seeding window yields better stands than does the dormant seeding time frame. The following cultivars appear to have a definite place in the reclamation of formerly irrigated mountain meadows in South Park: #9005308 Mountain Bromegrass, Arriba Western Wheatgrass, Redondo Arizona Fescue, #291863 Rush Wheatgrass, #9040189 Bottlebrush Squirreltail, Hycrest Crested Wheatgrass, Bozoisky-select Russian Wildrye, Covar Sheep Fescue, Bandera Rocky Mountain Penstemon, Appar Lewis Flax, Chemung Emerald Crownvetch, and Hatch Winterfat. The following cultivars have gone out of both the summer seeded and the dormant seeded variety blocks and therefore should not be recommended for the situation in South Park: Niner Sideoats Grama, Hachita Blue Grama, Immigrant Forage Kochia, Maybell Antelope Bitterbrush, and Hobble Creek Mountain Big Sagebrush.

Utilizing the standard seed mixture, the double Hodder gouging treatments continue to show the best stands for both planting dates. Again, however, it appears that the summer planting time frame produces better results. The evaluations thus far indicate that fertilizer application and the seed packing treatment do slightly aid stand establishment but only when combined with either single or double Hodder gouging treatments. As previously mentioned, the economics of incorporating any or all of these supplemental practices into large scale use would need to be evaluated against the expected benefits. We recommend continuing the evaluation of the project results to confirm long-term suitability and adaptability of the plant materials information.

Soil Nitrogen Thresholds for Revegetation of Degraded Soils

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Abstract

Soils were collected from several revegetation projects visited during the 1995 High Altitude Revegetation Workshop summer field trip. Revegetated and unvegetated soils as well as soils from under nearby native vegetation were sampled. Soils were measured for total C, total N, mineralizable N, extractable ammonium and extractable nitrate. Photographs of plant cover taken on each plot were used to interpret soil fertility data. Previous studies suggest that plant communities must have a minimum total soil nitrogen content before adequate N cycling occurs and the plant-soil system becomes sustainable. Based on these preliminary data, several of the revegetated plots visited may not contain enough soil nitrogen to maintain their vegetative cover.

Introduction

Overview

Many biological and environmental factors contribute to successful revegetation projects on degraded soils. Examples of these factors includes the use of appropriate plant materials, suitable seed germination conditions, adequate rooting depth, soil physical condition and water holding capacity, adequate temperature and moisture regimes, slope, aspect, mulch cover, and the availability of essential plant nutrients. Of all these conditions for successful revegetation, the establishment of adequate soil nitrogen (N) pools is viewed as a keystone for regenerating the plant-soil-microbial system.

Nitrogen is required in relatively large amounts as an essential plant nutrient and is essential for development of a root system which is adequate for water and nutrients acquisition on degraded soils. Restoration of nitrogen pools is crucial because this element is easily lost from degraded sites by topsoil removal or nutrient leaching. Adequate N availability also increases litter production and root activity, which, in turn, improves soil conditions by supporting beneficial rhizosphere microbial populations and by returning organic materials to the soil.

The objective of this study and other related projects at the University of California, Davis, in conjunction with the California Department of Transportation, is to measure various pools of soil N in disturbed sites, correlate plant response to soil N, and to identify the amount and form of soil N necessary for sustained revegetation of degraded sites.

Background

Studies conducted for the California Department of Transportation in decomposed granites cut- and fill-slopes in Northern California indicated that soil N pools were greatly reduced on barren, raveling slopes compared to adjacent, well vegetated slopes. Typical total N values on the barren sites were 300 kg ha^{-1} compared to 1300 kg ha^{-1} on the adjacent, vegetated soils (Claassen and Zasoski, 1996). If a moderate value of 2 % of the total soil organic nitrogen were mineralized and made available for plant uptake per year (Keeney, 1982; Bradley, 1984; Alexander, 1977), then soil derived N would amount to 26 kg N ha^{-1} on the vegetated sites compared to only 6 kg N ha^{-1} on the barren sites.

Because of the native soil's large reserve of soil organic matter and mineralizable nitrogen, this annual release of plant available N is sustainable for several decades until plant litter production and cycling are re-established. The native soil's slow, steady release of mineralized N is well suited to the slow, steady growth of perennial plant species. In contrast, degraded soils amended with soluble fertilizers have a brief burst of plant available N, but little further N release. Additional fertilizer applications are then required. The short duration and relatively high availability of soluble fertilizers that are intended to help establish the plant community can have the negative side effect of promoting growth of weedy annuals (McLendon and Redente, 1991).

The use of N fixing plants has often been advocated for use in revegetation schemes. *Purshia tridentata*, an actinomycete N fixer, generated about 316 kg N ha^{-1} within a 40 year period on andesitic mud flows on Mt. Shasta, Northern California, giving an average rate of 8 kg ha^{-1} yr^{-1} (Glauser, 1967). European glacial tills accumulated about 10 kg N ha^{-1} yr^{-1} (Jenny, 1980). Alaskan glacial tills accumulated 12.6 kg ha yr^{-1} during a 100 year period (Crocker and Major, 1955). These values indicate that N fixing plants can provide supplemental N but may not generate the large amounts of N required to reestablish an entire plant community rapidly.

In addition, it is questionable whether the N fixed by these plants would efficiently accumulate in the soil on steep, sparsely covered, eroding slopes typical of roadside cut- and fill-slopes. Zavitkowski and Newton (1968), studying N cycling underneath *Ceanothus* in the Oregon Cascades, identify litterfall and under-canopy decomposition and mineralization as the main mechanism for N addition to the soil. Processes within the soil such as root sloughing or exudation contributed relatively little nitrogen to the soil. Erosional processes that remove the N rich litter and duff must therefore be arrested to avoid continual loss of the plant's fixed N.

In addition to plant uptake and erosional losses of soil N, another reason for low levels of plant available N is through sorption to the soil matrix itself (Stevenson, 1994). Proteins released during decomposition may become organically complexed and become unavailable for plant uptake. Clays electrostatically adsorb organic N which becomes physically shielded from microbial attack and remineralization. Iron and aluminum oxides covalently bond to N-containing soil organic residues. Some of the organic N occurs in pores or voids that are too small for physical access by microbes. Processes such as these continue for decades or centuries until soils accumulate thousands of kg N ha^{-1} (Zinke, 1984). On the positive side, these inevitable processes promote accumulation of soil organic N which is gradually remineralized and made available at an estimated rate of 2 % per year. Until the soil has accumulated a sizable "capital investment" in stabilized, organic N, however, these immobilization processes result in a net reduction in plant available N.

Potential Solutions

Bradshaw *et al.* (1982) found that the eventual establishment of stable shrub or wooded vegetation on china clay wastes in England was associated with accumulation of soil total N to levels of 700 to 1100 kg N ha^{-1}, a process that took an estimated 50 years to occur naturally. A strategy for reaching the desired N levels more quickly would be to preload the site with large amendments of organic N that is only slowly available for plant uptake, fixation or leaching losses. Colorado Department of Transportation's use of large amendments of a fungal fermentation residue by-product (Biosol) and a humate extract (Humagro) may help achieve this goal.

California Department of Transportation is also pursuing methods of preloading soil N pools. Nitrogen release rates and chemical characteristics of various organic matter amendments are being determined and will be used to match amendments to plant materials and site conditions. The threshold soil N levels required for revegetation of high, arid sites in the Lake Tahoe Basin in California are being determined through correlation of soil N pools with plant species, plant cover, and soil litter accumulation.

A similar, cursory investigation to identify threshold soil N levels in Colorado soils was made in conjunction with the High Altitude Revegetation Workshop's 1995 summer field trip. The remainder of this presentation involves a brief summary of the results of this work.

Materials and Methods

In late July, 1995 the High Altitude Revegetation Workshop summer field trip convened at the west portal of the Eisenhower Tunnel on Interstate-70 in west-central Colorado. The first site was a nearly 20-year-old plant selection trial established in 1976 by Robin Cuany and Steve Kenny of Colorado State University. The site was located at approximately 3566 m elevation and had a northerly aspect. The site had been topdressed with 56 kg N ha^{-1} the year after establishment but had no subsequent fertilizer (Cuany, 1982). Samples were collected from under native vegetation at the foot of the slope located to the east of the plots. The revegetation trial was sampled across the midline of the study plot, running east to west. These first samples are labeled on the figures as "DG/tunnel/native soil" and "DG/tunnel/reveg trials".

The next site included the Colorado Department of Transportation study plots along I-70 a few miles west of the Eisenhower Tunnel at an elevation of approximately 3550 m. Sites here included a revegetated cut-slope ("DG/1-70/revegetated cut-slope"), a revegetated fill-slope ("DG/1-70/revegetated fill-slope"), an unvegetated cut-slope ("DG/I-70/unvegetated cut-slope"), and the native soil above the unvegetated cut-slope

("DG/I-70/native soil"). All slopes were steep with a southerly aspect. The revegetated cut-slope and revegetated fill-slope sites were amended two years previously with 2240 kg ha^{-1} fungal fermentation by-product (Biosol), 2240 kg ha^{-1} humate extract (Humagro) and 4480 kg ha^{-1} hay mulch.

Soils at the third site are derived from sedimentary parent materials (Pennsylvanian sandstones and siltstones), sampled from the Cordillera development 2 miles west of Edwards, Colorado. Elevation at these sites is approximately 2,280 m with northerly aspects. These sites included grass and aspen covered native soils ("SED/native soil"), grass covered revegetated cut-slopes ("SED/cut/revegetated") and a poorly vegetated cut-slope ("SED/cut/poorly vegetated"). These sites were amended 5-6 years previously with 1232 kg ha^{-1} of Biosol.

The sampling procedure at all sites consisted of collecting three replicate soil samples from each of the native and revegetated plots. Each replicate was composited from three soil samples collected within a 1 m^2 area. Soil sampling depths were 0 - 15 cm. All soils were air dried and sieved to < 2 mm. The fine fraction of the soil (< 2 mm) averaged about 53.4 % of the decomposed granite samples and 82.8 % of the sedimentary materials. Mineralizable nitrogen (one week, anaerobic, 40 °C) and extractable ammonium and nitrate were determined on 50 g samples using a conductimetric nitrogen analyzer (Carlson, 1978). Three gram subsamples of soil were ground to < 100 μm. Total carbon and total nitrogen were determined by combustion and gas chromatography on a Carlo-Erba/Fisons NA1500 analyzer.

Results plotted on bar graphs are means of three field sampling replicates and include error bars indicating one standard deviation.

Results

Carbon content of the soils was highest in the native soils, moderate in the revegetated soils and lowest in the poorly vegetated or unvegetated cut-slopes (Fig. 1). Granitic parent material sites had lower C contents than the sedimentary sites. This may result from climatic conditions and from amount and type of organic adsorbing clay in the soil. The unvegetated plots typically had no surface litter, indicating that C accumulation from decomposing plant residues was slow to nonexistent.

Total N contents (Fig. 2) of the native soils were also higher than that of the revegetated sites, although N levels even in the undisturbed native soils of the south facing I-70 plots may be reduced by the dry site conditions. The total N content of the revegetated plots was consistently greater than that of the unvegetated sites.

Site differences were also seen in the much higher C:N ratios of the unvegetated versus the vegetated soils. Unvegetated sites had C:N ratios of 40.8 (I-70/cut/unvegetated) and 76.7 (SED/cut poorly vegetated), while C:N raitos in native soils were 10.4 (I-70/tunnel/native), 29.6 (I-70/native soil), and 14.4 (SED/native soil). The high C:N ratios on the unvegetated plots may have resulted fromresidual effects of revegetation treatments such as straw amendment. In any case, the total N pool appears to be depleted in both quantity of N containing soil organic matter and in the N content of the soil organic matter which remains.

Fig. 1. Percent total C in soils

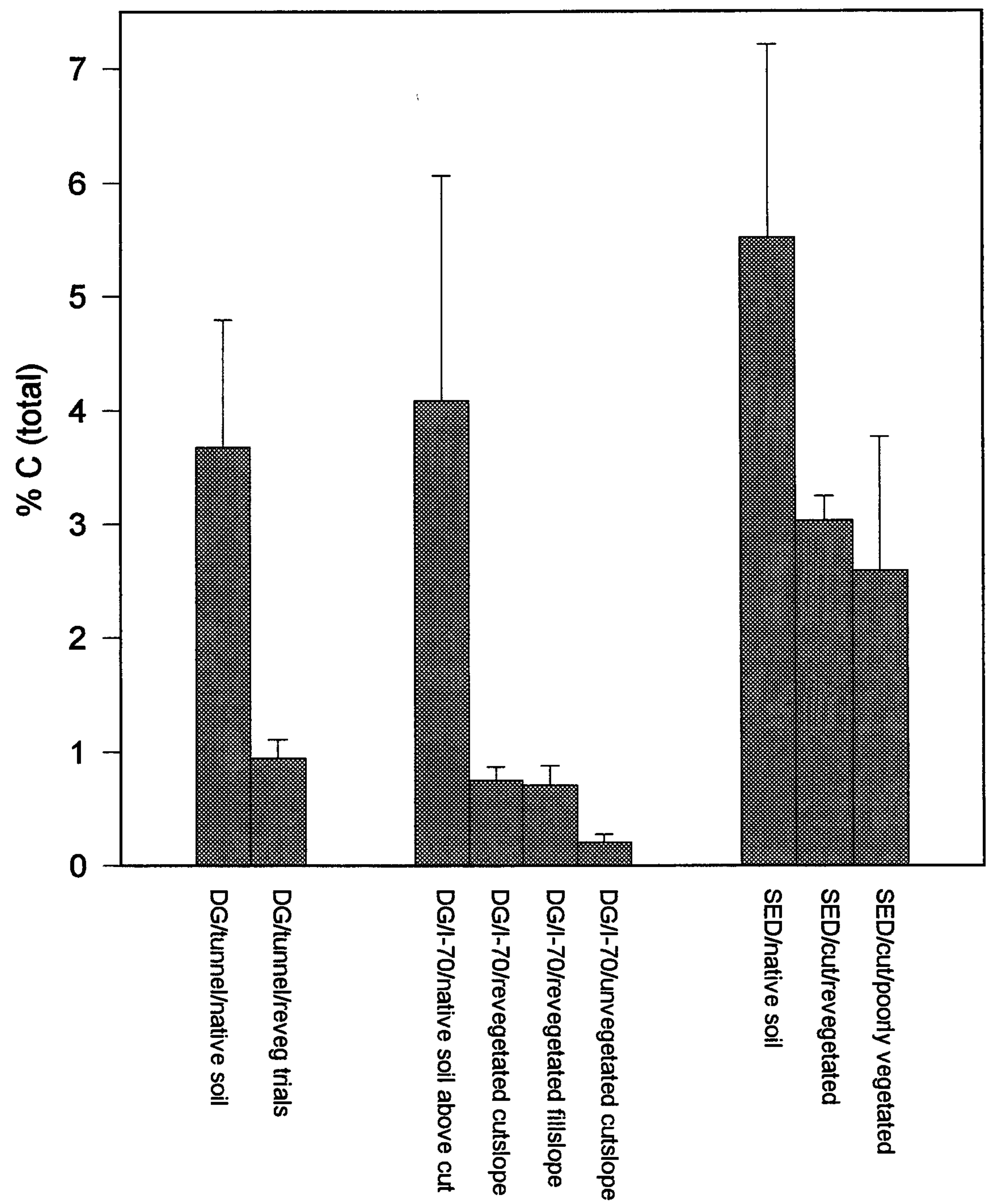
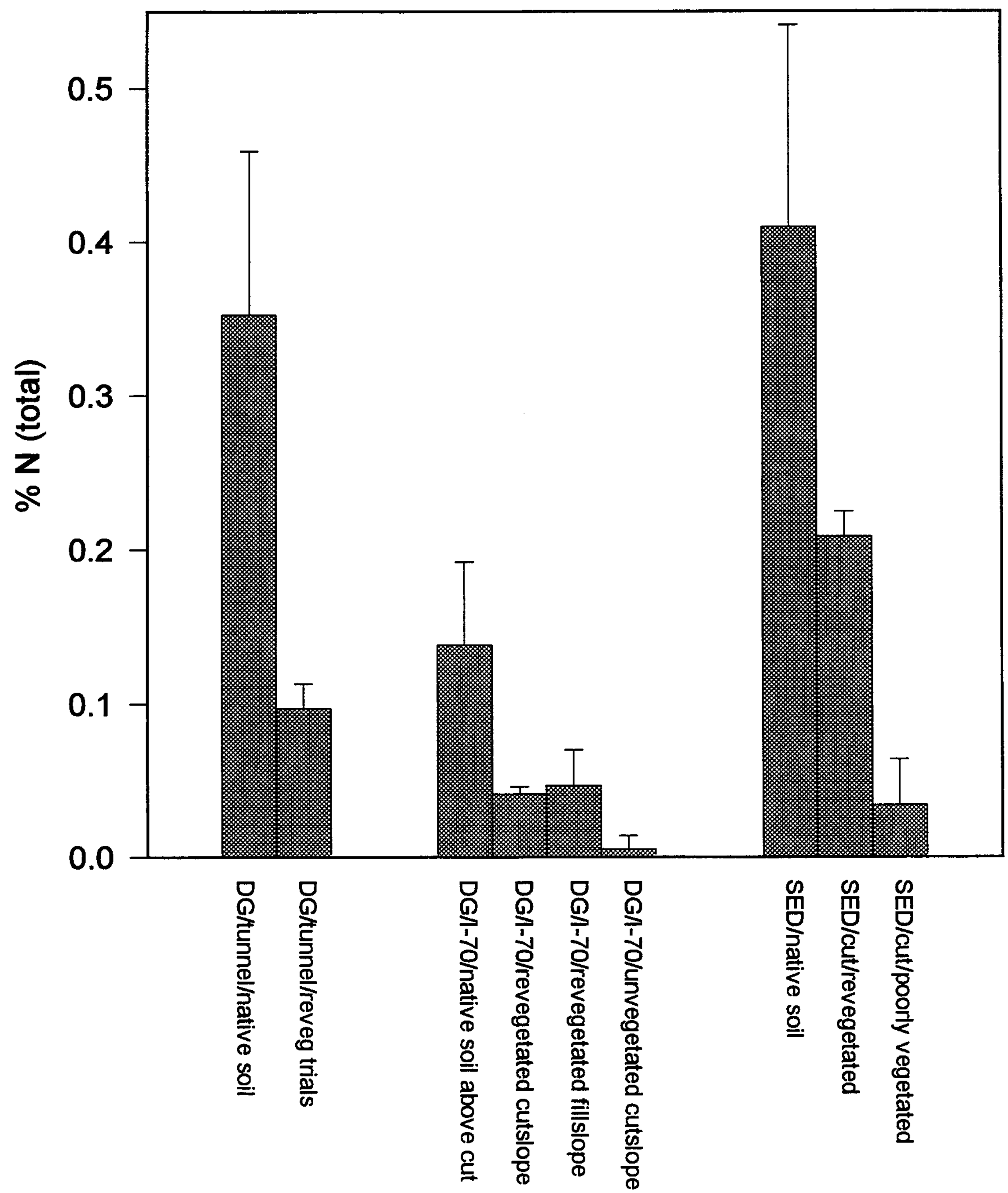


Fig. 2. Percent total N in soils



The plant available N pool resulting from decomposition over a period of months was be estimated by the mineralizable N assay (Fig. 3). Mineralizable N levels decreased between the native, revegetated and unvegetated plots. The high mineralizable N content of the sedimentary materials was attributed to high clay contents and high levels of adsorbed soil organic matter.

The extractable ammonium (Fig. 4) values were used to screen for high levels of available N, such as with soluble chemical fertilizer applications. Sites with high extractable N but low mineralizable N levels would not be expected to maintain a consistent supply of N to the plant while the site ages. Samples from the DG/I-70/cut-slope had high extractable N levels relative to mineralizable N. This may indicate that the hot southerly exposure accelerated conversion of mneralizable N to leachable, extractable forms.

The native and revegetated sedimentary soils, conversely, had relatively large mineralizable N contents but low extractable levels. Lush grass growth may have quickly absorbed available N. The poorly vegetated sedimentary site, however, had low mineralizable N and low extractable N, and is predicted to have low N availability for future plant production.

The native soil near the Eisenhower tunnel (DG/tunnel/native soil) had a large level of extractable nitrate (Fig. 5), indicating adequate organic matter mineralization and nitrification rates. This indicated that plant growth may be limited by other nutrients, water or determinant growth patterns.

Discussion

Comparison of revegetation sites must be done cautiously, since plant requirements and climatic and soil parameters vary widely. The soil N pool sizes reported here can be subjected to the usual interpretations of relative rates of N mineralization, leaching and plant uptake, but because of the rapid flux of N between pools, more thorough sampling would be needed to confirm whether patterns are significant. Additional data correlating pool sizes to plant response will be required to provide dependable target levels for amendment and maintenance of soil fertility on degraded soils.

Although only a limited amount of data were acquired during the summer field trip, the following calculations give an example of how the potential for sustained plant growth can be estimated from soil N values. These estimates were based on the following assumptions: if the weight of the 0 - 15 cm soil depth is assumed to be 2×10^6 kg ha^{-1}, and the N threshold as indicated in the Bradshaw *et al.* (1982) study is set at 1000 kg N ha^{-1}, then the total N content in the soil associated with sustained plant communities should measure at least 0.05 % N. This calculation indicated that the I-70 unvegetated cut-slope (0.005 % N) and the poorly vegetated sedimentary site (0.03 % N) fall below this threshold level and would not be expected to persist without further N inputs or natural soil N accumulation. The I-70 revegetated cut-slope (0.041 % N) and revegetated fill-slopes (0.046 % N) had borderline soil N levels, according to these criteria.

Not all of the 0 - 15 cm soil depth was composed of fine (< 2 mm) soil materials. The granitic cut- and fill-slopes averaged 53.4 % coarse sands and gravels. This means that the fraction of the soil that contains nutrients and was available for root exploration constitutes only half of the volume of the 0 - 15 cm depth. In other words, the total soil N

Fig. 3. Mineralizable N in soils

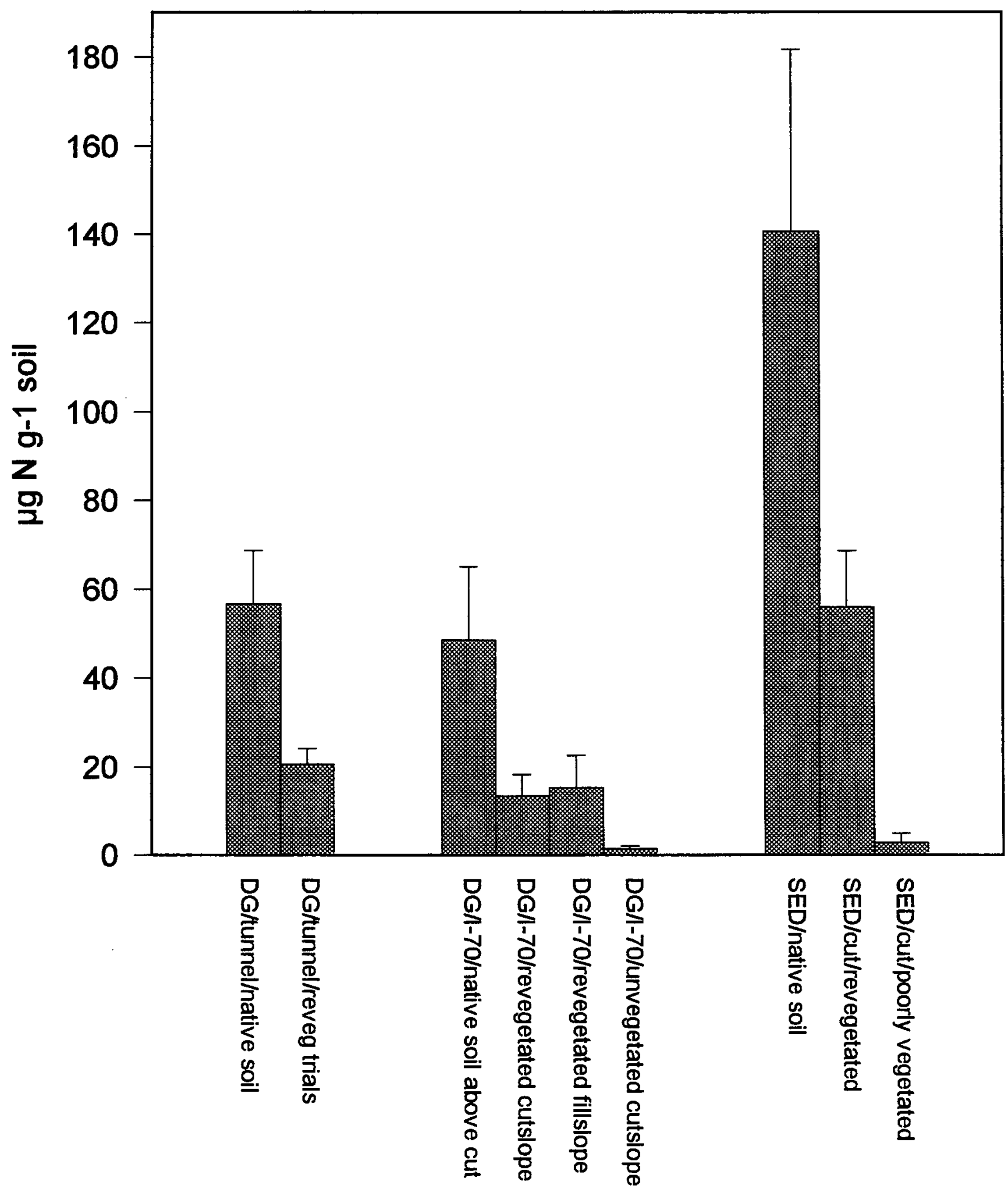


Fig. 4. Extractable NH_4 in soils

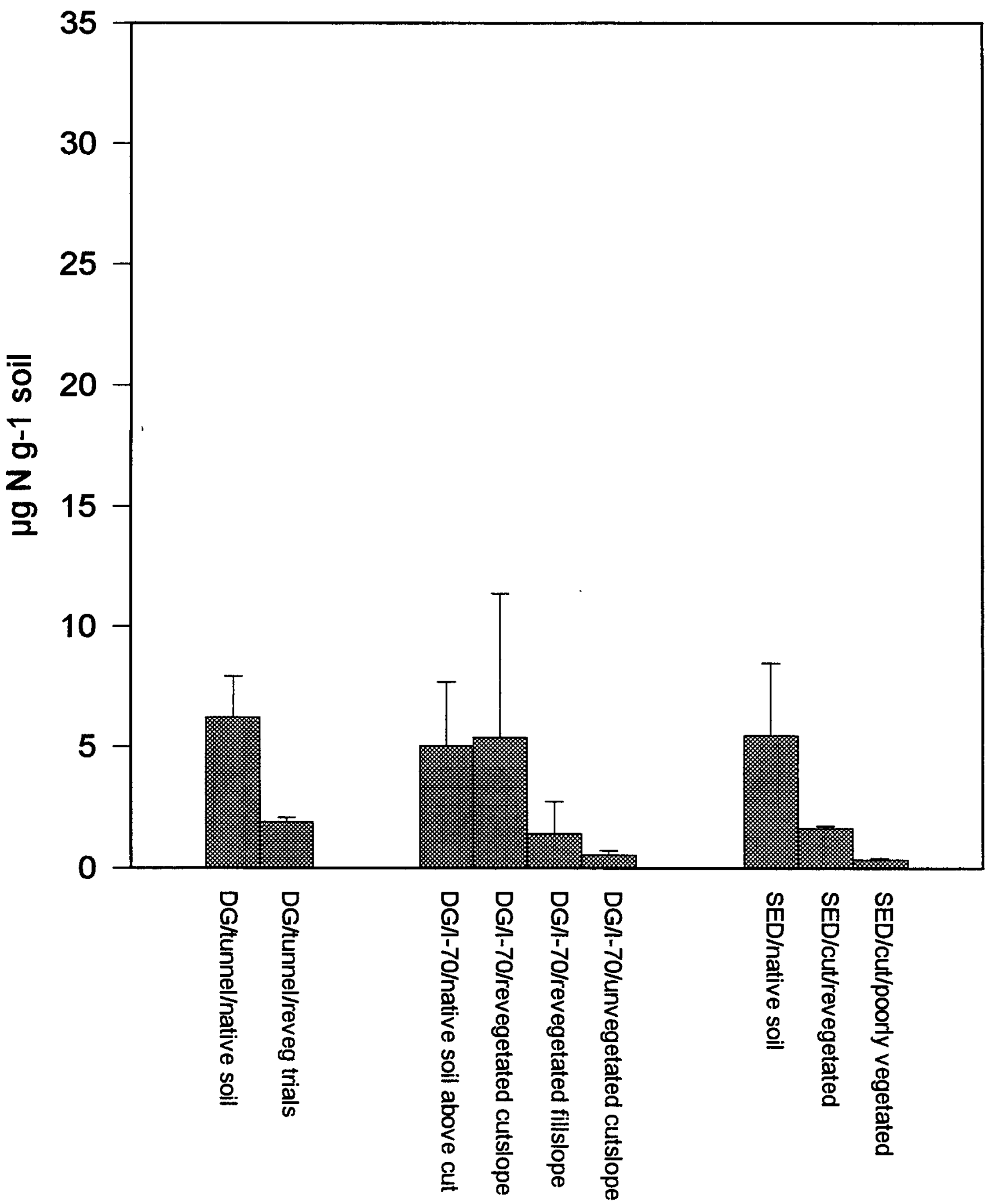
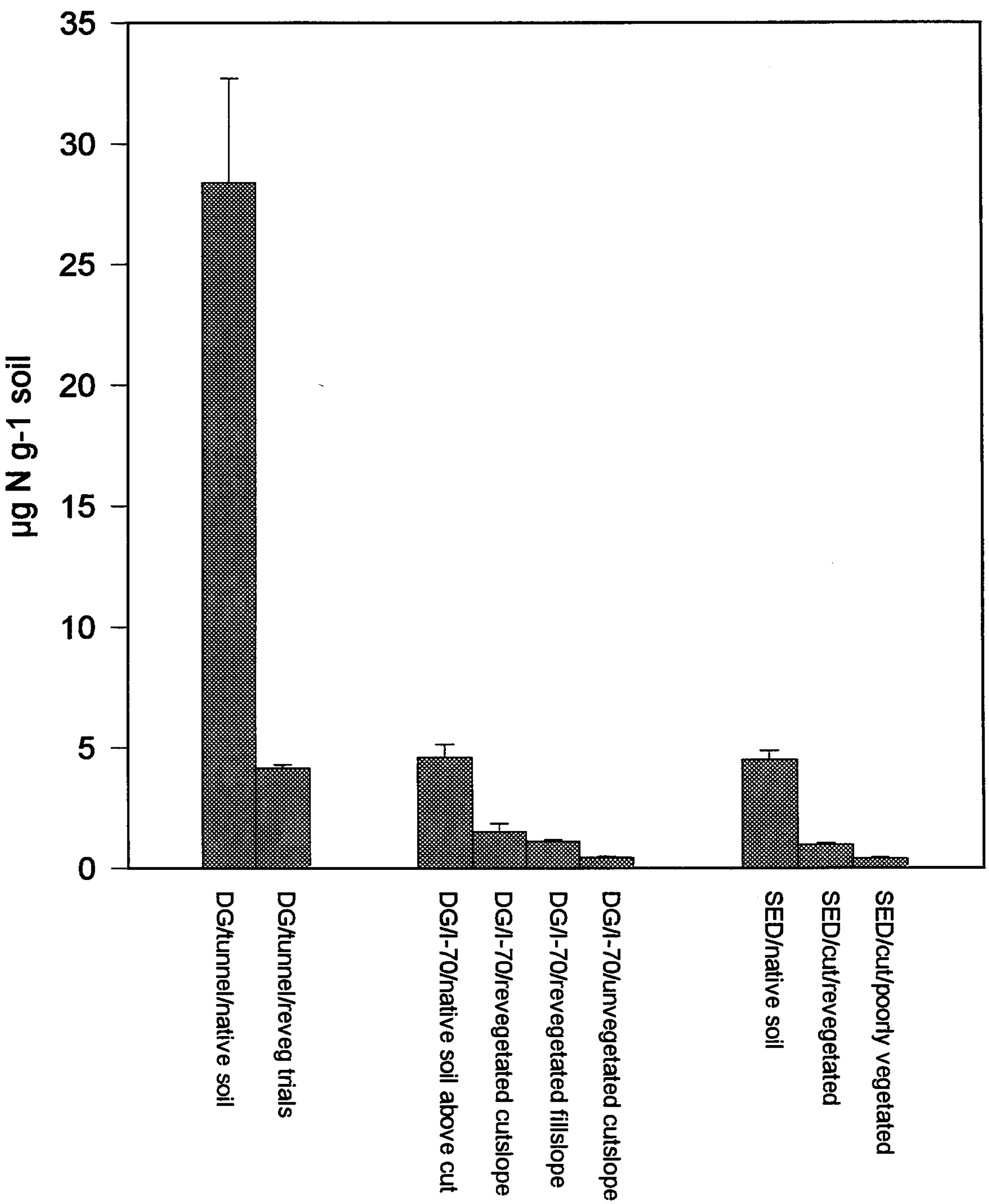


Fig. 5. Extractable NO_3 in soils



content on a per-hectare basis was only half of that measured in the < 2 mm fraction. When the soils were corrected for the fraction of coarse sand and gravel, all the decomposed granite revegetation and unvegetated soils fall at or below the 0.05 % total soil N threshold, including the revegetation trials at the Eisenhower tunnel. These soils, for example, have 0.0504 % N in the fine fraction, but only 0.0269 % N on a whole soil basis.

Empirical observations of plant growth on the nearly 20-year-old field plots ("DG/tunnel/reveg trials") give a glimpse of the future of a revegetated site. Bare ground surface was exposed and plants were sometimes on erosional pedestals, indicating surface losses of soil and N rich litter. However, total N was nearly as high as the native soil at the I-70 site and mineralizable N was greater than the recently amended I-70 cut- and fill-slopes. Soil accumulation processes appear to be occurring on this relatively shallow slope. Since these plots have undergone a lengthy period of plant selection from among the many original species tested, the remaining plants may be assumed to be site adapted and may now continue to stabilize the soil surface.

Conditions were tougher on the south facing I-70 cut- and fill-slopes. These slopes were steep and the plant canopy was often not dense enough to cover the soil. If erosional losses of N rich plant litter continue, these sites will require additional amendments to maintain plant growth.

The sedimentary sites were at lower elevations and had a mineralogy that is more retentive of organic matter and nutrients than the decomposed granite of the first two sites. These conditions were reflected in the relatively larger N pools of the sedimentary sites.

Conclusions

These initial measurements indicate that soil N fraction data can provide a tool to evaluate whether degraded soils can support sustainable plant communities. Data correlating soil N fractions and plant response for various soil materials can be used to predict whether soil conditions at revegetation sites are improving or declining and whether the soil-plant-microbial system was sustainable. Additional data are needed to confirm the correlation of soil N fractions and plant sustainablility on these and other types of sites.

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MOLYBDENUM UPTAKE BY 33 GRASS, FORB, AND SHRUB SPECIES GROWN IN MOLYBDENUM TAILINGS AND SOIL

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ABSTRACT

A concern resulting from the revegetation of molybdenum mill tailings is the possible occurrence of elevated molybdenum concentrations (Mo) and molybdenum/copper concentration ratios (Mo/Cu) in aboveground plant biomass; molybdenosis might be induced in animals grazing or browsing plants growing on these reclaimed areas. A controlled uptake experiment was conducted to determine Mo levels and Mo/Cu ratios in the shoots of 33 plant species grown in soil-covered tailings and in soil alone. The species tested represent a range of plant growth forms including cool- and warm-season grasses, herbaceous legumes, forbs and half-shrubs, and woody shrubs.

The results of our study show 3 species with less than 10 µg/g Mo when grown in tailings: summer cypress (*Kochia scoparia*), rubber rabbitbrush (*Chrysothamnus nauseosus*), and mountain mahogany (*Cercocarpus montanus*). Three shrubs and two forbs had shoot Mo/Cu ratios less than 2.5 when grown in tailings: rubber rabbitbrush, mountain mahogany, one ecotype of four-wing saltbush (*Atriplex canescens*), summer cypress, and purple aster (*Machaeranthera bigelovii*). Significant differences in shoot Mo concentration and Mo/Cu ratio exist between ecotypes within individual species. As an example, Mo/Cu ratios for two ecotypes of little bluestem (*Schizachyrium scoparium*) were 7.2 and 3.3. The presence of these differences illustrates that germplasm selection might allow the production of releases which discriminate against Mo uptake and translocation.

INTRODUCTION

A common concern resulting from the reclamation of mineral waste dumps is the potential for plant uptake of toxic constituents present in the waste material. Specific concerns related to the revegetation of molybdenum mill tailings and mine spoils include the molybdenum (Mo) concentration in aboveground plant biomass and the concomitant molybdenum/copper (Mo/Cu) concentration ratio; high levels of these parameters are indicators of potential toxicity to animals grazing or browsing plants on reclaimed areas. Studies to determine Mo concentrations of plants growing on waste dumps are often complicated by the presence of varying amounts of surficial particulates (i.e. soil, tailings, or waste rock) and their accompanying contaminants. The constituents in these particulates can mask the actual uptake and translocation of Mo from the plant roots to the aboveground plant tissues. Other complicating variables influencing uptake include a) spatial variability in total and available Mo within the substrate (i.e. tailings or spoils), b) soil cover thickness, c) heterogeneity of soil physical and chemical characteristics, d) depth and spread of root systems of sampled plants, and e) time of year the plants are sampled.

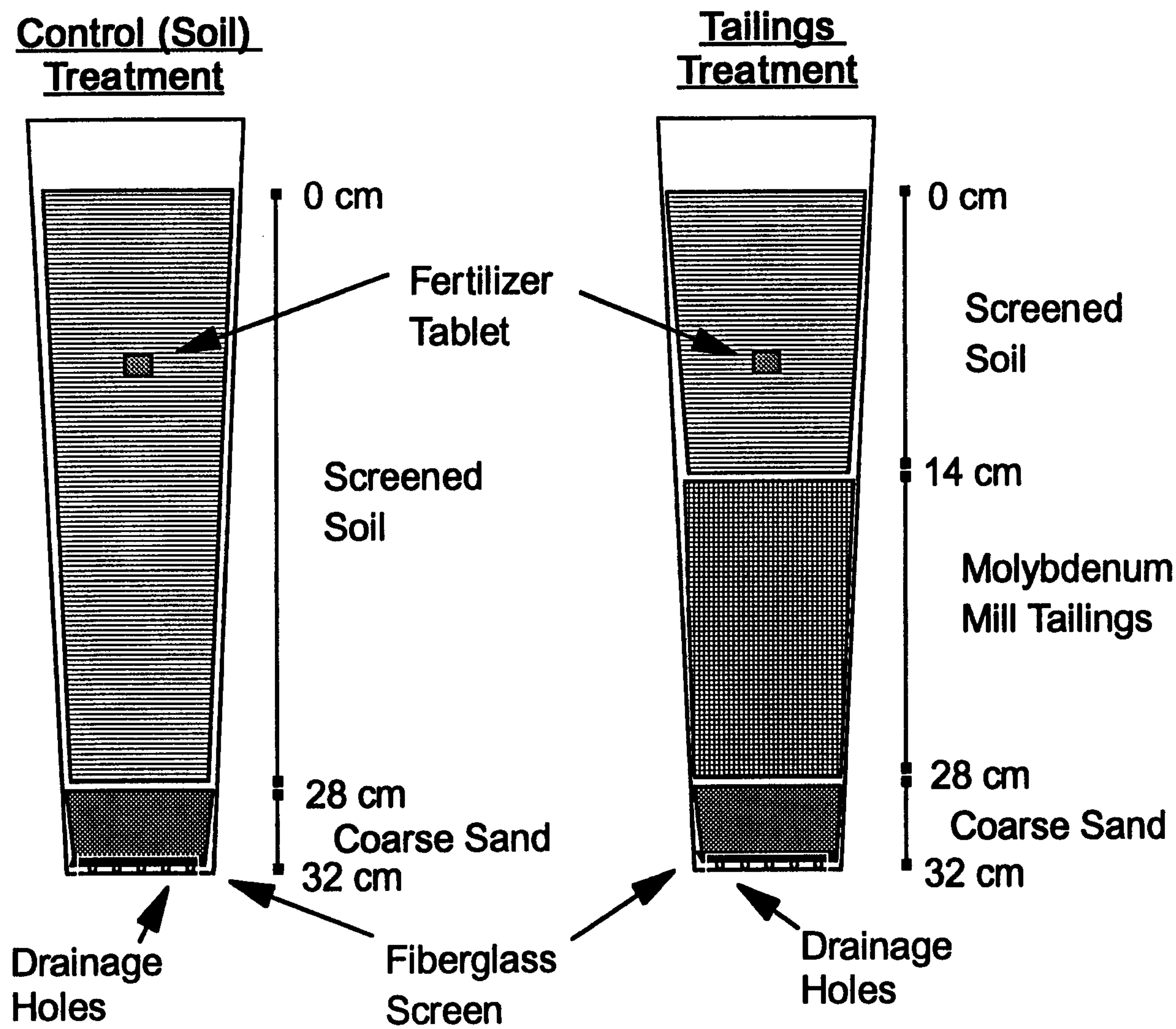
The Los Lunas Plant Materials Center has conducted a preliminary assessment to determine which plant species are least likely to take up and translocate toxic quantities of Mo from soil-covered molybdenum tailings disposal areas. The difficulties outlined above regarding measurement of Mo shoot concentrations and Mo/Cu ratios in samples collected in situ prompted us to perform a controlled uptake experiment. The objective was to reduce the influence of surficial contaminants and substrate variability while allowing a statistically valid examination of differences in Mo and Cu uptake as affected by plant growth form, species, and ecotype (i.e., source identified germplasm, release, cultivar).

METHODS

Molybdenum mill tailings and subsoils were collected from an active mine/mill operation in the southern Rocky Mountains. The silty sand tailings were obtained from the top 0.5 m of an inactive tailings disposal area and the clayey silt soil from a stockpile used in reclaiming decommissioned tailings disposal areas. The testing unit was a 35 cm deep tree pot with dimensions of 10 x 10 cm (top) and 7 x 7 cm (bottom). The control soil treatment consisted of 3 components (top to bottom): a screened (<6 mm) soil layer from 0 to 28 cm deep, a coarse sand layer from 28 to 32 cm deep, and a fiberglass screen covering the bottom drainage holes (Figure 1). A slow-release fertilizer tablet containing 4.2 g N, 0.9 g P and 0.8 g K as well as minor nutrients was placed at an 8 cm depth in the control and tailings testing units. The tailings treatment consisted of 4 components (top to bottom): a screened soil layer from 0 to 14 cm deep, a tailings layer from 14 to 25 cm deep, a coarse sand layer from 28 to 32 cm deep, and the fiberglass screen. When sufficient plant numbers were available, 4 plug seedlings (root ball dimensions of 2.5 x 2.8 x 9 cm {l x w x h}) were planted in each pot. For a few species, one to three plugs were planted but the control and tailings units always received equal plant numbers for each species.

For statistical analysis, the species were grouped into classes based on plant growth forms (grasses, forbs, and woody shrubs), plant families (grasses - *Poaceae*, legumes - *Fabaceae*), and plant physiology (cool-season grasses, warm-season grasses). Half-shrub species with woody bases were lumped with forbs. The resulting 5 "plant growth form" groups were as follows:

Figure 1. Configuration of the control (soil) and tailings testing units.



a) ten cool season grass species including 3 releases of western wheatgrass, *Pascopyrum smithii* (PASM-1 through -3, Table 1);

b) six warm-season grass species including 3 ecotypes of little bluestem, *Schizachyrium scoparium* (SCSC-1 through -3, Table 2);

c) five legume species, see Table 3;

d) four forb species and 2 half-shrub species, see Table 4;

e) six woody shrub species including 3 ecotypes of four-wing saltbush, *Atriplex canescens* (ATCA2-1 through -3, Table 5).

For most species, three replicate control and three replicate tailings testing units were planted with plug seedlings during late May to early June. Testing units with barley, oats, and winter wheat were seeded eight weeks later. The control and tailings units were arranged randomly in four large outdoor tanks which allowed periodic subirrigation of all testing units; one tank contained xeric species and the other mesic species. Plants grew for 17 weeks (9 weeks for grains) under outdoor conditions before harvesting in early October. All aboveground tissue 2.5 cm above the soil surface was harvested. The biomass was air dried for two months before weighing and grinding for analysis. Elemental contents of Mo, Cu and nine other elements were determined by inductively coupled plasma emission spectrometry of solutions prepared by acid digestion of plant dry matter.

The experiment was analyzed as a complete random design. Plant growth form group means were compared by a Fisher's F-protected least significant difference (LSD) test. Within plant growth form groups, species and ecotypes (cultivars, releases) were compared by the least square means procedure. The effect of substrate (soil versus tailings) on elemental concentrations in shoots was determined with a F test for each element.

RESULTS

Plant Growth Form Groups

Mean molybdenum (Mo) concentrations for all the groups (Table 6) in the control treatment were less than 5 μg/g (dry matter basis). In tailings, four groups had Mo concentrations which were not statistically different; the forb and half-shrub group had a significantly higher mean of 67 μg/g as shown in Table 6. All the molybdenum to copper ratio (Mo/Cu) group means were less than 1.4 in soil. In tailings, the group means of Mo/Cu ratios were generally in the range of 6.0 to 9.3 except for the forbs and half-shrubs with a mean ratio of 18.5 (see Table 6). For all groups, greater shoot Mo concentrations and Mo/Cu ratios were found in the tailings treatment than in the soil treatment.

Table 1. Cool-season grass species and ecotypes used in molybdenum uptake experiment.

Common Name	Traditional Scientific Name	Release, Variety, or 'Collection Location'	Current Scientific Name	Symbol
Crested Wheatgrass	*Agropyron cristatum*	Ephraim	*Agropyron cristatum*	AGCR
Hybrid Crested Wheatgrass	*Agropyron cristatum x desertorum*	Hycrest	*Agropyron cristatum x desertorum*	AGDE2
Oats	*Avena sativa*	unknown	*Avena sativa*	AVSA
Bottlebrush Squirreltail	*Sitanion hystrix*	'Grand Canyon AZ'	*Elymus elymoides*	ELEL5
Arizona Fescue	*Festuca arizonica*	Redondo	*Festuca arizonica*	FEAR2
Barley	*Hordeum vulgare*	unknown	*Hordeum vulgare*	HOVU
Mammoth Wildrye	*Leymus racemosus*	Volga	*Leymus racemosus*	LERA5
Indian Ricegrass	*Oryzopsis hymenoides*	Paloma	*Oryzopsis hymenoides*	ORHY
Western Wheatgrass	*Pascopyrum smithii*	Arriba	*Pascopyrum smithii*	PASM-1
Western Wheatgrass	*Pascopyrum smithii*	Rosana	*Pascopyrum smithii*	PASM-2
Western Wheatgrass	*Pascopyrum smithii*	Barton	*Pascopyrum smithii*	PASM-3
Winter Wheat	*Triticum aestivum*	Scout	*Triticum aestivum*	TRAE

Table 2. Warm-season grass species and ecotypes used in molybdenum uptake experiment.

Common Name	Traditional Scientific Name	Release, Variety, or 'Collection Location'	Current Scientific Name	Symbol
Sideoats Grama	*Bouteloua curtipendula*	Niner	*Bouteloua curtipendula*	BOCU
Blue Grama	*Bouteloua gracilis*	Hachita	*Bouteloua gracilis*	BOGR2
Galleta Grass	*Hilaria jamesii*	Viva	*Hilaria jamesii*	HIJA
Sprangletop	*Leptochloa dubia*	unknown	*Leptochloa dubia*	LEDU
Spike Muhly	*Muhlenbergia wrightii*	El Vado	*Muhlenbergia wrightii*	MUWR
Little Bluestem	*Schizachyrium scoparium*	'Tucumcari, NM'	*Schizachyrium scoparium*	SCSC-1
Little Bluestem	*Schizachyrium scoparium*	Pastura	*Schizachyrium scoparium*	SCSC-2
Little Bluestem	*Schizachyrium scoparium*	'Panhandle, TX'	*Schizachyrium scoparium*	SCSC-3

Table 3. Legume species used in molybdenum uptake experiment.

Common Name	Traditional Scientific Name	Release, Variety, or 'Collection Location'	Current Scientific Name	Symbol
Cicer Milkvetch	*Astragalus cicer*	Lutana	*Astragalus cicer*	ASCI4
Birdsfoot Trefoil	*Lotus corniculatus*	unknown	*Lotus corniculatus*	LOCO6
Black Medic	*Medicago lupulina*	unknown	*Medicago lupulina*	MELU
Alfalfa	*Medicago sativa*	unknown	*Medicago sativa*	MESA
Yellow Sweetclover	*Melilotus officinalis*	unknown	*Melilotus officinalis*	MEOF

Table 4. Forb and half-shrub species used in molybdenum uptake experiment.

Common Name	Traditional Scientific Name	Release, Variety, or 'Collection Location'	Current Scientific Name	Symbol
Fringed Sagebrush	*Artemisia frigida*	unknown	*Artemisia frigida*	ARFR4
Blanketflower	*Gaillardia aristata*	unknown	*Gaillardia aristata*	GAAR
Prostrate Kochia	*Kochia prostrata*	Immigrant	*Kochia prostrata*	KOPR80
Summer Cypress	*Kochia scoparia*	'Los Lunas, NM'	*Kochia scoparia*	KOSC
Purple Aster	*Aster bigelovii*	unknown	*Machaeranthera bigelovii var. bigelovii*	MABIB
Scarlet Globemallow	*Sphaeralcea coccinea*	unknown	*Sphaeralcea coccinea*	SPCO

Table 5. Shrub species and ecotypes used in molybdenum uptake experiment.

Common Name	Traditional Scientific Name	Release, Variety, or 'Collection Location'	Current Scientific Name	Symbol
Big Sagebrush	*Artemisia tridentata*	unknown	*Artemisia tridentata*	ARTR2
Fourwing Saltbush	*Atriplex canescens*	Rincon	*Atriplex canescens*	ATCA2-1
Fourwing Saltbush	*Atriplex canescens*	NM 155	*Atriplex canescens*	ATCA2-2
Fourwing Saltbush	*Atriplex canescens*	NM 812	*Atriplex canescens*	ATCA2-3
Shadscale	*Atriplex confertifolia*	'Northwest, NM'	*Atriplex confertifolia*	ATCO
Mountain Mahogany	*Cercocarpus montanus*	unknown	*Cercocarpus montanus*	CEMO2
Rubber Rabbitbrush	*Chrysothamnus nauseosus*	'San Juan County, NM'	*Chrysothamnus nauseosus*	CHNA2
New Mexico Olive	*Forestiera neomexicana*	Jemez	*Forestiera pubescens var. pubescens*	FOPUP

The warm-season grass group and forb and half-shrub group had the greatest shoot mass in soil (Table 7). The legumes and cool-season grasses yielded the least shoot mass in both soil and tailings treatments. The shoot mass did not differ between tailings and soil treatments for any group. The shoot Mo content was consistently greater in the tailings treatment for all groups.

Cool-Season Grasses

Two annual grains in the tailings treatment, oats (*Avena sativa*) and barley (*Hordeum vulgare*), showed significantly higher levels of Mo in shoots (Table 8) compared with winter wheat (*Triticum aestivum*). Among the native perennial cool-season grasses, Arizona fescue (*Festuca arizonica*) and bottlebrush squirreltail (*Elymus elymoides*) showed significantly higher Mo concentrations (54 to 56 μg/g) in tailings than 2 western wheatgrass releases (PASM-1 and -3) and mammoth wildrye (*Leymus racemosus*) which had Mo concentrations ranging from 18.0 to 28.3 μg/g. Two annual grains (oats and barley) exhibited higher Mo shoot concentrations than all the perennial cool-season grasses in the soil control.

High Mo/Cu ratios (12.8 to 16.5) in the tailings treatment were found for oats and bottlebrush squirreltail, and one release of western wheatgrass (PASM-3). In contrast, winter wheat and crested wheatgrass (*Agropyron cristatum*) exhibited low Mo/Cu ratios (3.4 to 4.8), as shown in Table 8. The three western wheatgrass releases exhibited similar Mo shoot concentrations (i.e., 23.7 to 32.3 μg/g) and Mo/Cu ratios (i.e., 8.8 to 12.0).

Warm-Season Grasses

The highest Mo concentrations and Mo/Cu ratios in the tailings treatments (Table 9) were found for galleta grass (*Hilaria jamesii*). The molybdenum level in little bluestem ecotype SCSC-1 was significantly greater than ecotype SCSC-3 (31.3 versus 13.5 μg/g). In the control treatment, spike muhly (*Muhlenbergia wrightii*) had significantly greater shoot Mo levels (4.3 μg/g) than the other warm-season grasses (1.9 to 2.3 μg/g). The little bluestem ecotype SCSC-1 in tailings had a greater Mo/Cu ratio (7.2) than ecotypes SCSC-2 and SCSC-3 (ratios of 3.3 and 3.9, respectively).

Legumes

As shown in Table 10, black medic (*Medicago lupilina*) had a significantly greater Mo level (51.7 μg/g) and Mo/Cu ratio (12.0) in the tailings treatment than alfalfa (*Medicago sativa* - Mo concentration of 21.7 μg/g and a Mo/Cu ratio of 5.0). In the control treatment, birdsfoot trefoil (*Lotus corniculatus*) exhibited a greater Mo

Table 6. Group means (across species) for shoot Mo concentration and shoot Mo/Cu concentration ratios for plants grown in molybdenum tailings and soil.

Plant Growth Form Group		Shoot Mo Conc. in Tailings Treatment (µg/g)	Shoot Mo Conc. in Soil Treatment (µg/g)		Shoot Mo/Cu Conc. Ratio in Tailings Treatment	Shoot Mo/Cu Conc. Ratio in Soil Treatment
Cool-Season Grasses		40.3 bA*	3.1 bB		9.3 bA	0.8 bB
Warm Season Grasses		25.1 bA	2.3 bB		6.1 bA	0.6 bB
Legumes		35.8 bA	4.7 aB		8.1 bA	1.3 aB
Forbs and Half-Shrubs		66.6 aA	2.4 bB		18.5 aA	0.5 bB
Shrubs		23.3 bA	2.6 bB		6.0 bA	0.7 bB

* Means within columns having the same lower case letter are not significantly different ($P<0.05$) by Fisher's F-protected LSD. Tailings and soil treatment means within rows (for one characteristic) having the same upper case letter are not significantly different ($P<0.05$) by least square means testing.

Table 7. Group means (across species) for shoot mass and shoot Mo content for plants grown in molybdenum tailings and soil.

Plant Growth Form Group		Shoot Mass in Tailings Treatment (g/plant)	Shoot Mass in Soil Treatment (g/plant)		Shoot Mo Content in Tailings Treatment (µg/plant)	Shoot Mo Content in Soil Treatment (µg/plant)
Cool-Season Grasses		3.1 bA*	3.8 bA		102.0 aA	9.9 aB
Warm-Season Grasses		5.5 aA	5.8 aA		116.0 aA	13.2 aB
Legumes		2.9 bA	3.5 bA		88.2 aA	12.8 aB
Forbs and Half-Shrubs		4.5 abA	5.6 aA		144.0 aA	13.8 aB
Shrubs		4.1 abA	5.2 abA		78.7 aA	13.7 aB

* Means within columns having the same lower case letter are not significantly different ($P<0.05$) by Fisher's F-protected LSD. Tailings and soil treatment means within rows (for one characteristic) having the same upper case letter are not significantly different ($P<0.05$) by least square means testing.

Table 8. Mean shoot molybdenum concentrations and mean molybdenum/copper ratios for cool-season grass species and releases grown in molybdenum tailings and soil.

Common Name	Current Scientific Name	Mean Mo Conc. for Tailings Treatment (μg/g)	Mean Mo Conc. for Soil Treatment (μg/g)	Mean Mo/Cu Ratio for Tailings Treatment	Mean Mo/Cu Ratio for Soil Treatment
Oats	*Avena sativa*	89.5 a*	6.0 a	16.5 a	1.37 ab
Barley	*Hordeum vulgare*	61.5 ab	6.0 a	6.8 cde	1.41 a
Arizona Fescue	*Festuca arizonica*	55.7 bc	3.0 bc	10.5 abcd	0.50 cd
Bottlebrush Squirreltail	*Elymus elymoides*	54.0 bcd	2.4 bc	13.9 ab	0.81 abcd
Hybrid Crested Wheatgrass	*Agropyron cristatum x desertorum*	41.3 bcde	3.0 bc	7.2 cde	0.58 cd
Indian Ricegrass	*Oryzopsis hymenoides*	35.3 bcde	3.0 bc	8.2 bcde	0.80 abcd
Crested Wheatgrass	*Agropyron cristatum*	33.8 cde	1.9 c	4.8 de	0.34 d
Western Wheatgrass	*Pascopyrum smithii* PASM-2	32.3 cde	3.3 bc	10.8 abcd	1.07 abc
Winter Wheat	*Triticum aestivum*	30.5 cde	4.0 ab	3.4 e	0.61 bcd
Western Wheatgrass	*Pascopyrum smithii* PASM-3	28.3 e	1.9 c	12.0 abc	0.74 bcd
Western Wheatgrass	*Pascopyrum smithii* PASM-1	23.7 e	1.9 c	8.8 bcde	0.85 abcd
Mammoth Wildrye	*Leymus racemosus*	18.0 e	1.9 c	7.7 cde	0.83 abcd

* Means within columns having the same letter are not significantly different ($P<0.05$) by Fisher's F-protected LSD.

Table 9. Mean shoot molybdenum concentrations and mean molybdenum/copper ratios for warm-season grass species and ecotypes grown in molybdenum tailings and soil.

Common Name	Current Scientific Name	Mean Mo Conc. for Tailings Treatment (μg/g)	Mean Mo Conc. for Soil Treatment (μg/g)	Mean Mo/Cu Ratio for Tailings Treatment	Mean Mo/Cu Ratio for Soil Treatment
Galleta Grass	*Hilaria jamesii*	58.0 a*	1.9 b	15.7 a	0.63 bc
Little Bluestem	*Schizachyrium scoparium* SCSC-1	31.3 b	2.0 b	7.2 b	0.46 bcd
Sprangletop	*Leptochloa dubia*	26.0 bc	2.3 b	4.5 bc	0.45 cd
Little Bluestem	*Schizachyrium scoparium* SCSC-2	22.0 bc	1.9 b	3.3 c	0.41 cd
Spike Muhly	*Muhlenbergia wrightii*	17.3 c	4.3 a	5.3 bc	1.06 a
Blue Grama	*Bouteloua gracilis*	13.7 c	1.9 b	5.3 bc	0.95 a
Little Bluestem	*Schizachyrium scoparium* SCSC-3	13.5 c	1.9 b	3.9 c	0.69 b
Sideoats Grama	*Bouteloua curtipendula*	11.7 c	1.9 b	3.2 c	0.37 d

* Means within columns having the same letter are not significantly different ($P<0.05$) by Fisher's F-protected LSD.

Table 10. Mean shoot molybdenum concentrations and mean molybdenum/copper ratios for legume species grown in molybdenum tailings and soil.

Common Name	Current Scientific Name	Mean Mo Conc. for Tailings Treatment (μg/g)	Mean Mo Conc. for Soil Treatment (μg/g)	Mean Mo/Cu Ratio for Tailings Treatment	Mean Mo/Cu Ratio for Soil Treatment
Black Medic	*Medicago lupulina*	51.7 a*	4.0 b	12.0 a	0.97 b
Cicer Milkvetch	*Astragalus cicer*	41.0 ab	1.9 b	9.4 ab	0.59 b
Birdsfoot Trefoil	*Lotus corniculatus*	39.0 ab	12.3 a	8.2 ab	3.65 a
Yellow Sweetclover	*Melilotus officinalis*	26.7 ab	2.1 b	5.9 b	0.62 b
Alfalfa	*Medicago sativa*	21.7 b	3.1 b	5.0 b	0.84 b

* Means within columns having the same letter are not significantly different ($P<0.05$) by Fisher's F-protected LSD.

shoot concentration than the other legumes (12.3 versus 1.9 to 4.0 µg/g) and a greater Mo/Cu ratios (3.7 versus 0.6 to 1.0) than the other legumes.

Forbs and Half-Shrubs

In the tailings treatment, the forbs, purple aster (*Machaeranthera bigelovii*) and summer cypress (*Kochia scoparia*), had significantly lower Mo shoot concentrations (18.7 and 9.0 µg/g) and Mo/Cu ratios (2.3 and 2.5) than the other species in the group (see Table 11). Fringed sage (*Artemisia frigida*), scarlet globemallow (*Sphaeralcea coccinea*), and blanketflower (*Gaillardia aristata*) had the highest shoot Mo levels of any species tested in the tailings treatment (100 to 110 µg/g). Two of these species, scarlet globemallow and blanketflower, had the highest Mo/Cu ratio of any species tested in the tailings treatment (51.8 and 22.7, respectively). These extreme values in tailings for scarlet globemallow and blanketflower were not reflected in the soil treatment which had shoot Mo levels similar to other species within the forb and half-shrub group and species in other groups. Prostrate kochia (*Kochia prostrata*) and summer cypress had significantly greater Mo/Cu ratios (0.75 and 0.87) than the other forbs and half-shrubs (0.31 to 0.45) grown in soil.

Shrubs

Big sagebrush (*Artemisia tridentata*) and shadscale (*Atriplex confertifolia*) in tailings had significantly greater shoot Mo concentrations (57 µg/g) than the other shrubs (see Table 12). Mountain mahogany (*Cercocarpus montanus*) and rubber rabbitbrush (*Chrysothamnus nauseous*) had extremely low levels of Mo in shoots (8.6 and 8.0 µg/g, respectively); these concentrations were the lowest of all the tested species grown in tailings. New Mexico olive (*Forestiera pubescens*) in tailings had a significantly greater Mo/Cu ratio (16.1) in tailings than the other shrubs. Mountain mahogany, rubber rabbitbrush, and one ecotype of four-wing saltbush ATCA2-3 had among the lowest Mo/Cu ratios (1.8 to 2.4) of all tested species. Mountain mahogany was the only species tested which had almost equivalent Mo/Cu ratios in the tailings and soil treatments (2.2 and 1.9, respectively).

Major, Minor, and Trace Element Shoot Concentrations

The elemental analysis of shoot tissue revealed patterns of uptake and translocation among the plant growth form groups (see Table 13). The grass groups (warm-season and cool-season) had the lowest concentrations of Ca, Mg, Al, and B. The warm-season grasses had the lowest S. The two grass groups differed in concentrations of S, P, Fe, and Zn. The legumes had the lowest Mn concentration. The forb group had the greatest concentrations of S and Mn. The shrub group and forb

Table 11. Mean shoot molybdenum concentrations and mean molybdenum/copper ratios for forb and half-shrub species grown in molybdenum tailings and soil.

Common Name	Current Scientific Name	Mean Mo Conc. for Tailings Treatment (µg/g)	Mean Mo Conc. for Soil Treatment (µg/g)	Mean Mo/Cu Ratio for Tailings Treatment	Mean Mo/Cu Ratio for Soil Treatment
Fringed Sagebrush	*Artemisia frigida*	110 a*	2.3 ab	16.7 a	0.31 b
Scarlet Globemallow	*Sphaeralcea coccinea*	110 a	1.9 b	51.8 a	0.45 b
Blanketflower	*Gaillardia aristata*	100 a	2.6 ab	22.7 a	0.40 b
Prostrate Kochia	*Kochia prostrata*	51.3 a	3.3 a	15.4 a	0.75 a
Purple Aster	*Machaeranthera bigelovii var. bigelovii*	18.7 b	1.9 b	2.3 b	0.32 b
Summer Cypress	*Kochia scoparia*	9.0 b	2.6 ab	2.5 b	0.87 a

* Means within columns having the same letter are not significantly different ($P < 0.05$) by Fisher's F-protected LSD.

Table 12. Mean shoot molybdenum concentrations and mean molybdenum/copper ratios for shrub species and ecotypes grown in molybdenum tailings and soil.

Common Name	Current Scientific Name	Mean Mo Conc. for Tailings Treatment (μg/g)	Mean Mo Conc. for Soil Treatment (μg/g)	Mean Mo/Cu Ratio for Tailings Treatment	Mean Mo/Cu Ratio for Soil Treatment
Big Sagebrush	*Artemisia tridentata*	57.3 a*	1.9 a	11.6 b	0.23 b
Shadscale	*Atriplex confertifolia*	56.7 a	1.9 a	4.9 c	0.22 b
New Mexico Olive	*Forestiera pubescens var. pubescens*	23.7	2.3 a	16.1 a	0.53 b
Fourwing Saltbush	*Atriplex canescens* ATCA2-2	22.0 bc	2.3 a	4.8 c	0.61 ab
Fourwing Saltbush	*Atriplex canescens* ATCA2-1	13.0 bc	4.0 a	4.3 c	1.32 ab
Fourwing Saltbush	*Atriplex canescens* ATCA2-3	11.7 bc	1.9 a	1.8 c	0.39 b
Mountain Mahogany	*Cercocarpus montanus*	8.6 c	4.5 a	2.2 c	1.91 a
Rubber Rabbitbrush	*Chrysothamnus nauseosus*	8.0 c	2.6 a	2.4 c	0.63 ab

* Means within columns having the same letter are not significantly different ($P < 0.05$) by Fisher's F-protected LSD.

Table 13. Elemental concentrations averaged across substrates for each plant growth form group.

Element (conc. units)	Cool-Season Grasses	Warm-Season Grasses	Legumes	Forbs and Half-Shrubs	Shrubs
Ca (mg/g)	6.5 c*	4.9 c	12.7 b	15.5 a	13.9 ab
S (mg/g)	3.3 b	1.7 c	3.4 b	4.9 a	3.9 b
Mg (mg/g)	2.6 c	2.1 d	3.8 b	4.5 a	4.5 a
P (mg/g)	1.7 a	1.1 b	1.6 a	1.6 a	1.9 a
Al (μg/g)	100 c	79 c	133 b	183 a	189 a
Mn (μg/g)	96 b	92 bc	75 c	124 a	99 b
Fe (μg/g)	91 a	62 b	83 ab	111 a	98 a
Zn (μg/g)	33 c	57 a	51 ab	40 bc	41 bc
B (μg/g)	22 d	15 d	71 a	56 b	40 c
Cu (μg/g)	4.5 a	4.6 a	4.1 a	5.1 a	5.2 a

* Means within rows (for each element) having the same letter are not significantly different ($P<0.05$) by least square means testing.

Table 14. Comparison of element concentrations between tailings and soil treatments. Mean concentration from data pooled across all groups and all species.

Element (conc. units)	Shoot Concentration in Soil Treatment	Shoot Concentration in Tailings Treatment
Ca (mg/g)	9.7 a*	10.2 a
S (mg/g)	3.3 a	3.4 a
Mg (mg/g)	3.3 a	3.3 a
P (mg/g)	1.6 a	1.5 a
Al (μg/g)	125 a	139 a
Mn (μg/g)	96 a	99 a
Fe (μg/g)	85 a	92 a
Zn (μg/g)	41 a	46 a
Mo (μg/g)	2.9 b	37.4 a
B (μg/g)	36.6 a	35.6 a
Cu (μg/g)	4.5 a	4.9 a

* Means within rows (for each element) having the same letter are not significantly different ($P<0.05$) by least square means testing.

group had the highest Mg and Al levels. The legumes had the greatest B concentration. When elemental concentration data for all groups was pooled, the only element which was significantly different between the soil and tailings treatments was molybdenum (see Table 14).

CONCLUSIONS

Past research by others has shown that pastures containing plants with Mo at 10 to 20 µg/g (dry weight basis) pose risks of molybdenosis to domestic ruminants and Mo levels between 20 and 100 µg/g have been linked to teart disease (Eisler, 1989). The results of our study show 3 species with less than 10 µg/g when grown in tailings (summer cypress, rubber rabbitbrush, and mountain mahogany). Ten species showed less than 20 µg/g; these include the 3 species above and mammoth wildrye, purple aster, 2 ecotypes of four-wing saltbush ATCA2-1 and ATCA2-3, sideoats grama , blue grama, one ecotype of little bluestem SCSC-3, and spike muhly.

Molybdenosis is probable in cattle if their forage contains Mo and Cu at a ratio (Mo/Cu) of greater than 2.5 (Eisler, 1989). Three shrubs and two forbs grown in tailings have shoot Mo/Cu ratios less than 2.5: rubber rabbitbrush, mountain mahogany, one ecotype of four-wing saltbush ATCA2-3, summer cypress, and purple aster. The only species grown in the soil control with a Mo/Cu ratio greater than 2.5 and Mo concentration greater than 10 µg/g was birdsfoot trefoil.

Mule deer are at least 10 times more resistant to the adverse effects of Mo than domestic ruminants (Eisler, 1989). If this assumption is translated into criteria for forage Mo levels, Mo concentrations of 100 µg/g and Mo/Cu ratios greater than 25 in forage may pose a risk to mule deer. Fringed sage, scarlet globemallow, and blanketflower when grown in tailings had Mo concentrations greater than 100 µg/g and only scarlet globemallow had a Mo/Cu ratio of greater than 25.

A list of species for revegetation of molybdenum tailings areas in pinon-juniper and ponderosa pine ecosystems can be developed based on low Mo shoot concentrations (less than 30 µg/g) or low Mo/Cu ratios (less than 6) found in the tailings treatment.

Plant Growth Form Group	Criteria Mo ≤ 30 µg/g	Criteria Mo/Cu ≤ 6
Cool-Season Grasses	Western Wheatgrass Mammoth Wildrye* Winter Wheat (annual)*	Crested Wheatgrass* Winter Wheat (annual)*
Warm-Season Grasses	Little Bluestem Blue Grama Sideoats Grama Spike Muhly Spangletop**	Little Bluestem Blue Grama Sideoats Grama Spike Muhly Spangletop**
Legumes	Yellow Sweet Clover* Alfalfa*	Yellow Sweet Clover* Alfalfa*
Forbs and Half-Shrubs	Purple Aster (biennial) Summer Cypress (annual noxious weed)*	Purple Aster (biennial) Summer Cypress (annual noxious weed)*
Shrubs	Rubber Rabbitbrush Mountain Mahogany Four-wing Saltbush New Mexico Olive	Rubber Rabbitbrush Mountain Mahogany Four-wing Saltbush Shadscale

*Introduced species
**Questionable hardiness at high elevations

Significant differences in Mo shoot concentrations exist among ecotypes. As an example, Mo/Cu ratios for little bluestem SCSC-1 and SCSC-2 were 7.2 and 3.3. The presence of these differences illustrates that germplasm selection might allow the production of cultivars which discriminate against Mo uptake and translocation. Plant breeding might provide means of further reducing the Mo/Cu ratios below that achieved through selection.

LITERATURE CITED

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REVEGETATION OF PYRITIC SPOILS AT 10,400 FEET (CREATING A TOPSOIL SUBSTITUTE)

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INTRODUCTION

The purpose of this study is to provide input and data on how local waste materials might be utilized to create a soil medium in revegetating pyritic waste rock. The work was carried out on the California Gulch Superfund Site, Leadville, Colorado, at an elevation of about 10,400 feet. This endeavor began in the late summer of 1989 with the idea of providing useful information in the reclamation of the Superfund area.

In many subalpine settings topsoil is scarce to non-existent. The amount of soil organic matter is typically quite low with parent material covering the surface. For areas disturbed many years ago any topsoil that did exist is a resource of the past. Furthermore, it has frequently been shown that topsoil, although often desirable, is not always needed to achieve reclamation objectives.

In addition to seeing if local waste products could be recycled, tests were run on other soil amendments. Because several variables were being considered and working space was limited, some comparisons of results (controls) were left for the future. The work was experimental in nature. It was assumed that some tests would produce no vegetation, and indeed, such was the case. However, in all but one situation (the use of a chemical surfactant), plots were established on the basis of results obtained from previous experiments. It is not the author's goal to figure out a way to obtain lush cover and growth since such traits do not characterize the natural environment of the area.

Most of the work in establishing the plots was from volunteer efforts, including class exercises in the Environmental Technology program of Colorado Mountain College. Waste material was acquired from the local area, while other reclamation amendments (discussed below) were donated by various companies and the local college.

It should be noted that data collected from the results of this study is limited in scope to the growth of vegetation. No figures were obtained from leaching and bioavailability. Although the original plan called for acquiring leachate samples to determine how successful revegetation might be in reducing soil acidity and heavy metal content, limitations in time and funding from volunteer efforts eliminated this endeavor. It is still the intent of the author, though, to collect tissue samples for ascertaining metal uptake.

SITE DESCRIPTION

Regarding temperature, the climate of the area is actually quite mild, at least in relation to many other mountain towns. Nevertheless, only cool season plant species can survive. The annual rate of precipitation averages about the equivalent of 18.5 inches of rain, most of this obviously being in the form of snow. One of the factors that makes the area rather harsh for plant life is that the snow lasts longer than in most other mountain communities. This, of course, affects what will grow.

Most of the surrounding area consists of lodgepole pine forest with very little undergrowth. Englemann spruce and quaking aspen occur to a much lesser extent. Subalpine fir, bristlecone pine, and limber pine also occur in the area, but not near the test sites. Beneath the pine trees, one is apt to find kinnikinnick, huckleberry, silvery lupine, and common juniper growing on a rocky, sandy loam surface with a shallow coating of organic matter. Some eight to nine inches down from the surface a clay loam subsoil can be found, which tends to limit the depth to which tree roots can extend. In the open plant species become more diverse. Wildlife is rather limited, squirrels being the predominant animal.

The parent material of the area is very heterogeneous, including ores of sulfides, carbonates (an abundance of dolomite), and manganese oxides. Some specific mine locations (inactive) have rock that is relatively homogeneous in nature, while others have a much more diverse mix, often seen on the surface due to previous mining.

Work occurred on two inactive mine sites, the "Denver City" and the "Greenback". Both of these areas are located about one-half mile east of the residential part of Leadville up East 5th Street. Numerous abandoned mine workings are in the area. A decision was made to establish plots on these sites because they represent two different situations, both quite common to the area, and because the author was able to obtain permission to work on the sites from the mine owners.

In the case of the "Greenback", Rock Hill Mines Company being the principal owner, a more homogeneous and acidic mix of pyritic minerals was encountered. The pH of the material was generally between one and two with a hard sulfide crust on the surface. No plant life was found on the immediate test site prior to establishment of the plots. This was definitely the most contaminated of the two areas being tested. It was also the site having the least successful results in revegetation. Within just a few feet of the plots an open, abandoned mine shaft was discovered. It has recently been sealed.

On the "Denver City", owned by Leadville Silver & Gold, Inc., a more heterogenous mix of material was encountered. Both oxidized and unoxidized pyritic spoils were found. The acidity of the surface fluctuated between a pH of 2.0 and 5.5. Some of this material was not that acidic when one considers the natural acidity of the surrounding forest soil to have a pH of about 4.5 to 5.5. Due to time limitations, the greater abundance of this heterogeneous mix of waste rock, and the more successful results of this site compared with the "Greenback", most of the rest of the report, including all data, will relate to the "Denver City".

MATERIALS USED

Discussion and Rationale

The materials used and donated include: dried sewage sludge (from the local wastewater treatment facility), dolomitic limestone (obtained from Leadville Corporation in an unoxidized and crushed state), a lead-based slag (from Orin Diedrich's operation in Leadville), a chemical surfactant ("ProMac", from B.F. Goodrich Company, now sold by MVTech, Inc., Akron, Ohio), lime kiln dust (from CALCO, Inc., Salida, CO), an organic amendment ("Biosol", from Rocky Mountain Bio-Products, Inc., Edwards, CO), and a variety of supplies provided by Colorado Mountain College, including a chemical fertilizer (diammonium phosphate, "18-46-0"), a seed mix (described later), a straw mulch, erosion control netting, wire staples, and colored flags.

The sludge and dolomite were mixed (separately) with the pyritic spoils to create two types of soil medium. It was felt that some organic matter would be needed to establish plant life. The sludge was a natural source. It has been used to reclaim mine waste in other areas. Dolomite is an abundant form of waste rock in the Leadville area, although typically in an oxidized condition mixed with other material. Within the same locality it has been observed that this resource serves as a soil base for considerable vegetation. The question remained whether or not the unoxidized dolomite provided for this experiment would support plant life when mixed with the pyritic spoils, and if so, to what extent.

In looking at this experiment, one might question why a lead-based slag, a seemingly infertile material, was used. The resource is locally abundant. The author had used a few years prior to this project a zinc-based "slag" (actually a zinc oxide kiln waste) from the local area in a revegetation experiment. This material turned out to be highly fertile all by itself in greenhouse and outside conditions. Presumably, though, much of the growth of grasses on this "slag" was due to the dark color of the material. Increases in temperature in this soil medium had probably stimulated the growth of roots and rhizomes.

Again, being an experiment at the "Denver City", it was thought maybe the lead-based slag might have some reclamation value due to heat generation if used sparingly as a topdressing over other waste material. Mere observation in the area indicated it most likely did not have any soil fertility value, but then if mixed with fertilizer or organic amendments on the surface, in addition to a mulch, as planned, possibly plants could become established just enough to extend themselves into more fertile waste below. The problem would probably be one of germination.

When first seen before being picked up for delivery to the site, the slag appeared to have a medium texture, indicating that if its moisture holding capacity could be increased with soil amendments, seed might germinate and easily extend roots into other material below. A light colored straw mulch (less preferable than hay, but readily available) was placed over the slag. Besides helping to conserve moisture, it was felt that over the two years it would take to decompose, a thick cover of straw might alleviate desiccation of the seed on a dark surface and then add organic matter to the soil medium.

As it turned out on arrival at the site, the slag had a considerable quantity of fine particles mixed with the larger particles. Maybe the seed, if it germinated, would be prevented from sending roots to the material below. Nevertheless, given the experimental nature of the project and a desire to follow up on previous work done on a similar material, the slag was used. As shown below, some interesting results were obtained.

The reason for using the chemical surfactant, "ProMac", relates to the origin of acid mine drainage and the nature of nonpoint source pollution. As is well known, acid drainage typically begins with the oxidation of iron pyrite, initiated when water and air flow over its surface in the presence of acid-generating bacteria, most notably Thiobacillus ferrooxidans. The function of this chemical, a biodegradable substance approved by EPA, is to reduce the populations of this bacteria sufficiently over time, namely seven years, to enable the more favorable heterotrophic species of bacteria (needed by plants) to become established. This was an attempt to get at the source of a nonpoint water quality issue, as well as to create a more favorable environment in which plants could grow. Be getting vegetation established, water quality would undoubtedly improve due to a decrease in erosion and, perhaps (because of root absorption), due to a decrease in water percolation to iron pyrite below.

Costs

It is not the intent of the author to list the costs of all items that might be used in a revegetation project. It is recognized that some expense may be involved in acquiring the use of sludge, dolomite, and slag, such as transportation costs, however, being locally available, it is assumed that purchasing costs would be minimal to non-existent. The aim here is to mention the expense of other items used on this project with which comparisons will be made. There are three such amendments: ProMac ($1200 - $1500/acre, or up to $2500/acre for service included), Biosol ($1760/acre --- includes three applications), and diammonium phosphate ($136/acre).

It is important to recognize that the prices mentioned above are approximate. The "Biosol" usually needs to be reapplied in future years, the number of times depending on site conditions and revegetation goals. In the case of this project, a total of three applications were made. The figure above is based on an initial rate of 1600 pounds/acre with 1200 pounds/acre being used for the other applications. This rate will vary depending on site conditions. The price indicated is based on $29.04 for a 66 pound bag. Regarding the diammonium phosphate, the figure shown is based on a price of $17 for a 50 pound bag at a rate of 400 pounds/acre. It would probably be necessary to add the cost of reapplying a chemical nitrogen fertilizer, such as ammonium nitrate, to this figure. However, no such reapplication was made on the project. The possibility of discounts for purchasing large quantities was not taken into account for either amendment.

SPECIES DISCUSSION

In deciding on what species to use in a seed mix, several factors were considered, not the least of which was availability of a viable source. Obtaining seed of species native to the Leadville area that would adapt to conditions of high acidity and heavy metal content was somewhat problematic. Of course, then the topic of what is native comes to the surface. It is beyond the scope of this report to delve into that area of discussion. However, suffice it to say that attempts were made to use species native to the same habitat as exists in the local area. Attention was also placed on what species had previously worked well for the author in the Leadville area. In addition, it was noted at the time that some success had been obtained on acidic soils at high altitudes with relatively new varieties of grasses. The first four species indicated on the list below are in this category.

One of the main problems in seed acquisition for a project of this nature is finding a company that sells seed collected at high elevations. One of the species that the author wanted to use was tufted hairgrass (Deschampsia cespitosa).

This plant thrives under acidic conditions in the Leadville area, including within the drainage of California Gulch itself. In fact, this is the only grass species seen growing (just barely) on its own in some of the local tailing ponds. Due to time constraints, though, no attempts have been made to locate and collect viable seed sources of this species. Unfortunately, at the time this experiment began, the author was also unable to find a company having a good seed supply of this species. Thus, it is not on the list.

Another problem area with seed mixes at high altitudes, and, in fact, throughout Colorado, is the acquisition of native legume seed. For years the author had relied on white Dutch clover (Trifolium repens) and cicer milkvetch (Astragalus cicer), but neither of these species is considered native, even to the state. In the case of the latter species, it often takes awhile to become established, but when it does, it may tend to dominate the site. For this reason, it was deleted from the mix. Attempts were made to find a good supply of birdsfoot trefoil (Lotus corniculatus) seed, but none could be found at the time. The only other legume seed, besides white Dutch clover, that was available at the time and appeared to have any chance at all of becoming established was a variety ("Spreader II") of alfalfa that had done well under acidic conditions, although at slightly lower elevations. Normally, one does not think of this species in relation to the environmental conditions described in this report. But then this was an experiment and the seed was available. Unfortunately, neither legume used in the study performed well. One other legume that may show promise in the future, but which was not available for this experiment, is Utah sweet vetch (Hedysarum boreale). The author is currently conducting work with this species, as well as with birdsfoot trefoil.

The seed mix for the "Denver City" site included the following species:

Common Name	Scientific Name
Beardless wild rye (Shoshone)	Leymus (Elymus) triticoides
Arizona fescue (Redondo)	Festuca arizonica
Slender wheatgrass (San Luis)	Elymus (Agropyron) trachycaulus ssp. trachycaulus
Giant wild rye (Volga)	Leymus (Elymus) cinereus
Timothy (Climax)	Phleum pratense
Creeping red fescue (Penlawn)	Festuca rubra
Tall fescue (Fawn)	Festuca arundinacea
Hard fescue	Festuca ovina var. duriúscula
Redtop	Agrostis alba (gigantea)
Smooth brome (Manchar)	Bromus inermis
Orchard grass (Potomic)	Dactylis glomerata
Canada bluegrass (Rubens)	Poa compressa
Annual rye	Secale cereale

White Dutch clover	Trifolium repens
Alfalfa (Spreader II)	Medicago sativa

It is felt that a listing of the species that did well would be most appropriately placed in the "DATA AND PLOT LAYOUT" section of the report under the various soil treatments. Also included in the same section are volunteer species.

WORK DESCRIPTION

Not counting much of the planning, work began on the project in August, 1989 when the author approached Mr. Bob Elder, a representative of Leadville Silver & Gold, owner of the "Denver City" mine. After discussing various possibilities and visiting both this inactive site and the "Greenback" with Mr. Elder, the author acquired permission from owners of the two sites to establish test plots. It is the wish of the author to express his appreciation to Leadville Silver & Gold and to Rock Hill Mines Company for allowing him to work on these areas.

The surface of both sites was hard and could not be broken up manually. This provided for a class exercise in September for students at Colorado Mountain College under the supervision of their instructor for the equipment operations course. A ripper would have been ideal for the job, however, the only piece of heavy equipment that the college could provide was a backhoe. Thus, using this piece of equipment, the surface at both sites was broken up and leveled. Due to the heterogeneous nature of the waste rock at the "Denver City", the material was mixed from one end of the test site to the other as much as possible. This would create a more homogeneous mix of rock, which would allow for a more valid comparison of test results. Students then raked over the areas manually to further even them out, filling in low spots. At the "Denver City" one corner had to be raised and supported with a side wall of boards to provide for enough space to include all the plots.

Also during September, waste rock samples were taken at both sites and sent to B.F. Goodrich in Ohio for analysis. This is the company that sold the "ProMac" (now marketed by MVTech, Inc.). They wanted to analyze samples to know how much of the product would be needed for the plots. The product was packaged in small plastic bags and sent to Leadville. The author wishes to express his appreciation to MVTech for donating this amendment. Without it, much of the project would not have been possible.

After making contacts with various local entities, the three waste materials were collected and transported to the two sites. By October it was time to mark the individual plots for each area with flags according to a predetermined design. The dolomite and sludge were then distributed and mixed with the spoils by students, one-third of the plots receiving dolomite and one-third receiving sludge. The equivalent of three inches of each of these materials (nine cubic feet/plot, or about 400 yards/acre) was added.

Normally, the liming agent is applied before the surfactant, however, since there was a delay in obtaining the liming agent and time was critical in completing the work before permanent snow for the season arrived, the "ProMac" was applied next. A representative of the company in Denver supervised the application. He indicated that the liming agent had been applied after the surfactant with other cases and that results were successful.

The surfactant came in two forms, a powder and pellets. The powder was mixed with water and sprayed on three of the four subplots for each of the six soil mediums, leaving one fourth of all the plots as a control on which "ProMac" was not used. This powder was to have an effect on the acid-generating bacteria for one growing season.

Another type of control was with the soil medium in which no sludge, dolomite, or slag were used. Indeed, there was a large number of variables, and some comparisons could not be made due to a lack of enough space to establish controls for each variable.

The bactericide pellets were then applied (raked in as much as possible, given the hard, crusty surface). There were three different types of pellets, each color-coded, for each plot. One would have its leaching effect during the second and third years of the project, another during the fourth and fifth years, and the other during the sixth and seventh years. It is now the seventh year of the project, however, the final effect of the surfactant will not be complete until the end of the 1996 growing season. Due to upcoming reclamation work on the Superfund site during the summer of 1996, when results of this project could be used, it is felt that a report should now (February, 1996) be done. The data shown below, taken at the end of the last growing season, should be indicative of final results.

Shortly after applying the surfactant, the liming agent arrived. It was a lime kiln dust (69%CaO) that was applied using respirators at the rate of 3 & 1/4 tons/acre, or the equivalent of four tons/acre, calcium carbonate, on the "Denver City" site. A much higher rate was applied on the "Greenback".

A thin layer of slag (about 1 & 1/2 inches) was then applied as a topdressing over half of the sludge plots and half of the dolomite plots. The same amount was also applied directly over the spoils for a fifth type of soil medium, much like the author had done successfully with a previous experiment using a zinc-based "slag", except that six inches of this latter material was used as a soil medium by itself. As mentioned above, the sixth soil medium was a control. Of the six, the use of slag directly over the spoils was least effective in establishing vegetation.

Before October was over, it had snowed six to seven inches on the plots. There was obvious concern that the project may not be completed that year. However, in early November the snow melted long enough for the rest of the project construction to be completed. "Biosol" was placed on one of the four plots within each soil medium, while the diammonium phosphate was applied to a second plot, both sets of plots having the "ProMac". In all, there were 24 separate types of plots with three replications each for a total of 72 plots on each site. Not counting any organic matter in the dolomite, which was minimal, organic amendments in the form of sludge and "Biosol" were applied to one-half of all the plots, some of these receiving applications of both products. By not having organic matter applied to many of the plots, another control was established, this one for determining the effectiveness of the sludge and "Biosol". A clearer view of the arrangement of these plots can be acquired by reviewing the "DATA AND PLOT LAYOUT" section. A plot design, separate from this report, is also available upon request.

The final field work, outside of monitoring results in years to come, involved preparing the seed for application, placing it down, mulching, and placing erosion control netting and staples. All of this work was done on both sites.

EXPLANATION OF CRITERIA FOR DATA EVALUATION

In monitoring the results of these plots, it became increasingly evident that the conclusions to the study would be very dependent on the criteria used for data evaluation and on the weight given to each criteria. Although observations of species development is important, for purposes of this study, it has less significance than the overall performance of vegetation on each soil treatment. During the first few years of the experiment, data was collected on a species basis. Later, due to time constraints, this type of data collection was discontinued. Nevertheless, those species that appeared to do the best on plots showing most promise are shown in the "DATA AND PLOT LAYOUT" section.

It seemed fairly obvious that plant cover and height growth should be criteria. It was also relatively easy to obtain objective data on these two parameters. Another factor, namely vigor, also seemed to be important. This would be an indication of color, stem strength, leaf development, and overall appearance. Plots with more height growth generally had better vigor. However, despite plots with better vigor often having more height growth, the correlation was not that strong. In other words, some species would show good vigor, but only medium height growth, due to the nature of the species. These species should not be given a lower evaluation just because they are shorter.

Thus, it was decided to use vigor as a third criteria, but it would be given less weight, 20% compared with 40% for cover and height growth. The author felt it was important to give vigor less weight since, indeed, considerable correlation (overlap) does exist between height growth and vigor, and because an ample amount of subjectivity exists in rating vigor.

At first, cover was estimated using a 1/10 square meter frame, marked with references to various percentages of cover. After becoming accustomed to making such determinations, ocular estimates without the frame were made. As for height growth, averages for all species within each plot were recorded to the nearest inch.

If these plots were to be evaluated for their overall performance in relation to each other, a score, determined in as objective a manner as possible, would have to be given to each plot. This was done by rating each category (% cover, average height growth, and vigor) from zero to five and weighting the score of each category as indicated above. The ratings were done as shown below with interpolations being made in an arithmetic progression and scores being assigned in the "DATA AND PLOT LAYOUT" section to the nearest 0.1. These values, including the averages for the three replications, became the basis for making comparisons among various treatments of waste rock.

% Cover	Score
0-20	0-1
21-40	1-2
41-60	3-4
61-80	4-5

Average Height Growth - Inches	Score
1-5	0-1
5-10	1-2
10-15	2-3
15-20	3-4
20-25	4-5

Vigor --- This is where the greatest amount of subjectivity entered. A score of zero to five was assigned.

DATA AND PLOT LAYOUT

Plot Legend for Data

Legend for Soil Medium
A --- Dried Sewage Sludge Mixed With Spoils
B --- Dried Sewage Sludge Mixed With Spoils --- Slag on Top
C --- Dolomite Mixed With Spoils
D --- Dolomite Mixed With Spoils --- Slag on Top
E --- Slag on Top
F ---- Control

Legend for Plots Within Each Soil Medium
1 --- Surfactant ("ProMac") & Liming Agent
2 --- Surfactant , Liming Agent, & Organic Amendment ("Biosol")
3 --- Surfactant, Liming Agent, & Inorganic Amendment ("18-46-0")
4 --- Control

Field Data and Scores

Row #1	Spoils Treatment*	% Cover	Aver. Height Growth - In.	Vigor	Plot Score	Aver. of 3 Rows
	D-1	1	4	1	1.4	2.1
	D-2	0	0	0	0	2.0
	D-3	10	18	3.5	5.85	4.4
	D-4	0	0	0	0	0.5
	C-1	0	0	0	0	3.1
	C-2	1	4	1	1.4	5.8
	C-3	50	5	1	4.0	4.6
	C-4	0	0	0	0	3.1
	B-1	15	19	5	7.0	6.9
	B-2	20	10	4	5.0	5.5
	B-3	75	18	5	9.9	6.7
	B-4	7	8	2	3.0	5.6
	A-1	75	25	5	11.3	6.5
	A-2	35	19	5	8.0	7.1

	Spoils Treatment	% Cover	Aver. Height Growth - In.	Vigor	Plot Score	Aver. of 3 Rows
	A-3	25	15	5	6.8	7.2
	A-4	25	12	4	5.7	5.2
	E-1	1	6	1	1.8	1.4
	E-2	3	8	2	2.8	1.5
	E-3	9	7	2	2.9	2.0
	E-4	1	3	1	1.1	0.7
	F-1	12	5	1	2.1	1.3
	F-2	75	10	4	7.8	4.6
	F-3	50	7	2	4.9	3.1
	F-4	2	7	1	2.0	1.2
Row #2	F-1	0	0	0	0	
	F-2	20	5	2	3.0	
	F-3	7	4	1	1.7	
	F-4	5	4	1	1.6	
	E-1	0	0	0	0	
	E-2	0	0	0	0	
	E-3	0	0	0	0	
	E-4	0	0	0	0	
	D-1	1	6	1	1.8	
	D-2	5	12	2	3.7	
	D-3	15	11	2	4.0	
	D-4	1	5	1	1.6	
	C-1	75	6	1	5.5	
	C-2	75	12	4	8.2	
	C-3	50	5	2	4.5	
	C-4	50	4	2	4.3	
	B-1	30	14	5	6.8	
	B-2	30	12	5	6.4	
	B-3	35	12	4.5	6.45	
	B-4	25	12	4.5	5.95	

	Spoils Treatment	% Cover	Aver. Height Growth - In.	Vigor	Plot Score
	A-1	10	14	4.5	5.55
	A-2	80	20	5	10.50
	A-3	40	15	4.5	7.25
	A-4	25	25	4.5	8.55
Row #3	A-1	2	5	3	2.6
	A-2	2	9	2	2.9
	A-3	6	7	2	2.7
	A-4	1	4	1	1.3
	B-1	15	19	4.5	6.85
	B-2	23	10	3.5	4.95
	B-3	5	9	3.5	3.85
	B-4	15	22	5	7.7
	F-1	2	6	1	1.8
	F-2	5	7	2.5	2.95
	F-3	5	7	2	2.7
	F-4	0	0	0	0
	E-1	1	9	1	2.4
	E-2	1	5	1	1.6
	E-3	10	10	1	3.0
	E-4	1	2	1	0.9
	D-1	4	8	2.5	3.05
	D-2	3	8	1	2.3
	D-3	6	10	2	3.3
	D-4	0	0	0	0
	C-1	50	4	1	3.8
	C-2	77	8	5	7.9
	C-3	75	5	1	5.3
	C-4	75	4	1	5.1

* The order of the letters shown here indicates field position.

Frequency Distribution of Plot Scores (With Ranks by Categories)

Score Range	Plot Frequency	Rank
0-1.5	16	8
1.6-3.0	22	7
3.1-4.5	8	6
4.6-6.0	10	5
6.1-7.5	7	4
7.6-9.0	6	3
9.1-10.5	2	2
10.6-12.0	1	1

Frequency (F) and Rank of Spoils Treatments in Top Four Ranks

Legend for Spoils Treatment: Sewage Sludge (SS); Dolomite (D); Slag (S); Soil Medium Control (SMC); ProMac (PM); ProMac Control (PMC); Biosol (B); Diammonium Phosphate (DP)

Plot Code	Spoils Treatment	(F)	Ranks
A-1	SS-PM	1	1
A-2	SS-PM-B	2	2,3
A-3	SS-PM-DP	2	4,4
A-4	SS-PMC	1	3
B-1	SS-S-PM	3	4,4,4
B-2	SS-S-PM-B	1	4
B-3	SS-S-PM-DP	2	2,4
B-4	SS-S-PMC	1	3
C-2	D-PM-B	2	3,3
F-2	SMC-PM-B	1	3
		16	

Rank of Overall Performance of Plots With Top 16 Scores

Rank #	Spoils Treatment	Principal Species
1	SS-PM	Smooth brome, slender wheatgrass, giant wild rye, rockcress (V-Volunteer), meadow barley (V)
2	SS-PM-B	Slender wheatgrass, orchard grass, haplopappus (V), tansy mustard (V), soft potentilla (V)
3	SS-S-PM-DP	Beardless wild rye
4	SS-PMC	Various

5	D-PM-B	Various
6	SS-PM-B	Various
7	D-PM-B	Canada bluegrass, junegrass (V)
8	SMC-PM-B	Timothy, red fescue, orchard grass, Canada bluegrass, Ky. bluegrass (V)
9	SS-S-PMC	Beardless wild rye
10	SS-PM-DP	Various
11	SS-S-PM	Various
12	SS-S-PM	Red fescue, Ky. bluegrass (V)
13	SS-S-PM	Canada bluegrass, Ky. bluegrass (V)
14	SS-PM-DP	Various
15	SS-S-PM-DP	Various
16	SS-S-PM-B	Beardless wild rye

CONCLUSIONS

Be patient when looking for results!! At the end of the first growing season, the author was rather discouraged since relatively few plants had germinated on any of the plots. By the second growing season, though, vegetation on numerous plots was doing rather well. Conditions continued to gradually improve, although there was a temporary setback in the summers of 1993 and 1994 when there were two successive periods of drought. Last summer helped to turn that around.

Since the overall results of the use of slag were not positive, the general appearance of the plots at first glance is not especially favorable. However, appearances can be deceiving. In the environmental arena, work is (or should be) data-driven. After examining the data thoroughly, a large number of conclusions were made, even regarding the use of slag.

It is important to look at all three criteria together, especially cover and height growth, when making conclusions. Thus, comments here will often refer to the average plot scores of the three replications shown above since these values reflect the overall performance of the plots. It is recognized, though, that these scores should be interpreted in a relative manner, and not be an indication that any one spoils treatment be offered as the best approach in revegetating the waste rock. Although no statistical comparisons are made in this experiment to determine significant differences, the author is using a difference in average plot score of 1.0 or more to be an indication of "noticeable" difference.

<u>Organic Material and Dolomite</u>

In looking at the data, it should be no surprise that those plots having more organic matter did better. The plots with sewage sludge (code "A") outperformed those with dolomite (code "C"), both overall and with respect to height growth and vigor. However, when looking at the cover of sludge plots, one sees rather low values (average of 27% for 12 plots) compared with those of dolomite (average of 48% for 12 plots).

When organic matter ("Biosol") is added to dolomite (Code "C-2"), the result (5.8) is rather close to that of sludge with no amendment (Code "A-1", or 6.5). This comparison is important since sewage sludge may not be as available as "Biosol" (or some other organic amendment, such as compost). As one might expect, the best results overall were obtained when a fertilizer amendment was added to the sludge (Code "A-2 & 3", or 7.1 and 7.2, respectively). When comparing these scores to that of 6.5 for the use of sludge with no amendment, there is not much difference. The question then becomes one of expense. It does not seem economically justifiable (or necessary) to use both sewage sludge and "Biosol" (two organic amendments). However, the diammonium phosphate is relatively inexpensive.

Since some form of organic material should be added and there is some question as to the availability of sewage sludge, it is important to note the contribution of "Biosol". Where sludge is not used, "Biosol" makes a noticeable difference. Such a statement may seem obvious in that comparisons are being made here between plots having little to no organic matter and plots with an organic amendment. However, it should be noted that just because a product is organic in nature does not necessarily mean it will perform well. Even on the soil medium control plots "Biosol" makes a significant difference (Code "F-2", or 4.6) compared with the same plots not having any fertilizer amendment (Code "F-1", or 1.3).

A logical question might then be whether or not dolomite is needed. There is a noticeable difference between the use of dolomite and "Biosol" (5.8) and "Biosol" only (4.6). Although both treatments fell in the top 16 scores, only one out of three plots of the latter did so, while two out of three of the former performed in the same manner.

<u>Slag</u>

Hindsight often seems to be better than foresight. In looking back on the use of slag, and certainly on the results of the experiment, it might easily be said that the use of this material was a waste of time, at least to the extent to which it was used. The data clearly shows that there was no apparent beneficial effect of using slag over either dolomite (Code "D") or the spoils itself (Code "E"). The author worked with this material in a manner consistent with the results of previous experiments using a similar substance, although that material, unlike the lead-based slag, had some fertility. Had the slag used on this experiment consisted entirely of a medium-textured material, as originally planned, the results might have been more favorable.

When comparing the results of slag over sludge with sludge alone, not counting other amendments, the overall performance of the two is about the same (6.2 compared with 6.5, respectively). In fact, for the control plots (Code "A-4 & B-4") and the "ProMac" plots not having fertilizer amendments (Code "A-1 & B-1"), the slag over sludge slightly outperforms the sludge alone. In other words, the benefit of the sludge was at least maintained when a thin layer of slag was placed on top. The extent to which the high scores of the plots having slag over sludge are due to a thermal effect of the slag versus the presence of the sludge below is not known.

Would heat generated from slag stimulate growth once plants became established in the sludge/spoils mix below? The data suggests that when fertilizer amendments are used, the answer is less favorable (perhaps due to too much heat created from nitrogen in the fertilizer), but when such amendments are not used, scores are slightly higher. However, it is worth noting that when slag is used over sludge or dolomite, the diammonium phosphate plots do noticeably better than the 'Biosol" plots.

Perhaps most recognizable was the effect that slag had on encouraging the spread of rhizomes. Most of the vegetation in the plots having slag did not appear until the fourth growing season. Then, in some cases, there was a substantial invasion from plot borders, especially on plots having sludge, of rhizomatous species, including beardless wild rye, creeping red fescue, Canada bluegrass, and Kentucky bluegrass. The growth and vigor of these plants are good. Each of these species, except the latter one, is used in the seed mix. Since the presence of these species is more conspicuous in the plots having slag, one could assume there is probably a thermal effect from the slag on the material below.

"ProMac"

Although the author acquired mixed results with this product, overall, the performance of those plots having "ProMac" was noticeably better than those not having the substance, other conditions being equal. On three of the six soil mediums (sludge/spoils, slag over sludge/spoils, & slag over dolomite), the plots with the chemical surfactant outperformed the controls (6.5 vs. 5.2; 6.9 vs. 5.6; & 2.1 vs. 0.5, respectively). Neither of these sets of plots had a fertilizer amendment. In the other three mediums, no conspicuous difference was observed.

The major question is whether or not the benefit produced from the "ProMac" is sufficiently great enough to warrant the expense of using the product. This, of course, depends on the buyer. On one of the three sludge replications, the control plot did conspicuously better than the surfactant (8.55 vs. 5.55). On a second sludge replication, the surfactant did better than the control, but only in vigor. Neither did well (2.6 vs. 1.3). On the third sludge replication, the "ProMac" not only did better than the control (11.3 vs. 5.7), but did well in all three criteria, producing a higher score than any other plot in the experiment. Again, no fertilizer amendments were used in either case.

RECOMMENDATIONS

Stating what should be done to revegetate pyritic waste rock on the California Gulch Superfund Site depends greatly on the extent to which the waste materials discussed in this report are available. Serious consideration should be given to the use of dried sewage sludge. Should sufficient quantities needed to accomplish revegetation goals not be locally available, thought should be given as to whether or not it would be economically justifiable to transport sludge from another location, as is currently being done from Summit County.

However, given the overall low performance of sludge regarding plant cover, attention should also be placed on using locally available dolomite. This material could not only help to cover more of the ground with vegetation, but would probably also help to alleviate some of the acidity of the waste rock, thereby improving water quality.

If sewage sludge is not economically available in adequate amounts from any location, then deliberation could be given to using an organic amendment, like "Biosol", in combination with dolomite. It is worth noting that there is a substantial difference in score between plots having "Biosol" on dolomite (Code "C-2", or 5.8) and plots having no "Biosol" on dolomite (Code "C-1", or 3.1). This, of course, shows the effect of and the need for an organic amendment of some kind. Both of these plots, though, have the surfactant, which would add an additional expense. Unfortunately, there was no space to include plots with "Biosol" and dolomite on which "ProMac" was not used. Should the cost of the bactericide be more than acceptable, even more attention should be focused on attempting to utilize sewage sludge from somewhere. The average score of 5.2 for the sludge control plots, which have no "ProMac" (Code "A-4"), is considerably higher than all other control plots not using sludge.

Finally, as the spoils environment of these plots is alterred over time, it would be appropriate to monitor the extent to which volunteer and/or local native species, including trees, invade the experiment. Several such species have already begun to take root. This should be considered as an encouraging sign.

PROSPECTING FOR GOLD IN THE GREAT BASIN WITH SAGEBRUSH--RESULTS OF GREENHOUSE STUDIES

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INTRODUCTION

Sagebrush has been proposed as a biogeochemical prospecting medium for gold in the Great Basin of Nevada (Erdman et al., 1988; Busche, 1989; Smith and Kretschmer, 1992). Sagebrush would be an ideal sampling medium because it shows widespread distribution in areas of the Great Basin overlying concealed Carlin-type disseminated gold deposits and because its extensive root system may tap migrating water sources that contain ions associated with the disseminated deposits (West, 1983, Weaver and Clements, 1938; Brooks, 1983). In arid desert regions, however, aeolian contamination may obscure true anomalies in sagebrush content of gold because of small contrasts in anomaly-to-background rations, poor precision of analyses, and the abundance of submicron-sized gold particles in these deposits (Busche, 1989; Dunn et al., 1992; Joralemon, 1951; Kretschmer, 1984; Radke, 1985).

PURPOSE

The purpose of this study was to determine if sagebrush that is endemic to the area of the Great Basin where Carlin-type disemminated gold deposits are found can accumulate gold in an environment where aeolian contamination is drastically reduced. For this purpose we transferred basin big sagebrush seedlings to soils containing Carlin-type disseminated gold ore, grew them in a greenhouse, and measured their content of gold and other indicator elements associated with Carlin-type deposits, arsenic, antimony, and tungsten.

SOILS

Soil was obtained from the Osgood Mountains in Humbolt County west of Preble, Nevada. Soil from several holes approximately 0.6 m in diameter by 1.5 m deep was transported to the U.S. Geological Survey (USGS) labs in 5-gallon buckets. Approximately 200 kg of soil was disaggregated with a mechanical mortar and pestle, sieved through a 10-mesh (2mm) sieve to break up large clods of dirt and remove small rocks, and mixed in a V-blender. Gold ore from the Pinson and Getchell mining districts in Nevada was crushed with a jaw crusher and ground with ceramic plates to pass a 100-mesh (150 μm) sieve. Gold is found in these ores as submicroscopic elemental gold associated with quartz, pyrite, realgar and orpiment (Joralemon, 1951; Erickson et al., 1964; Kretschmer, 1984). Soil and ores were combined in different proportions to obtain three potting mixtures. Soil mixture M1 was prepared without ore to represent a "natural" soil found in Humboldt County, Nevada. Soil mixtures M2 and M3 were

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prepared with different concentrations of gold. The concentrations of arsenic, antimony and tungsten were kept as uniform as possible in order to minimize interactions. A standard potting medium was added to the mixtures to increase permeability (26% by weight).

SAGEBRUSH

Seeds of basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) were collected from an individual plant west of Preble, Nevada, and were germinated and grown to the seedling stage under optimal greenhouse conditions. Six-month old seedlings approximately 12 cm tall were transplanted into gallon pots containing the soil mixtures and were placed in a greenhouse in a standard ranzomized-block design (Freese, 1967). Six plants were used for each soil mixture and two plants from each mixture were randomly placed in three blocks. Plants were grown 4 months (October-February) under ambient light conditions at temperatures between 21 °C and 30 °C. Moisture content was kept at 20% by weight.

SAMPLE PREPARATION AND ANALYSIS

After 4 months growth, aerial biomass for each plant was composited to obtain one sample per plant. Samples were cleaned by sonication and air-dried at room temperature. Five random samples of each potting mixture were taken from the V-blender, dried at 100 °C, ground with ceramic plates to pass a 100-mesh sieve, and rehomogenized.

Gold, arsenic, antimony and tungsten concentrations were determined by instrumental neutron activation analysis (INAA) (Baedecker and McKown, 1987). Sagebrush, potting mixtures, and reference standards were placed in precleaned polyethylene vials and irradiated in the USGS nuclear research reactor. The elements were then quantified from the individual spectral peaks of their induced radioactivity with a high-resolution gamma-ray spectrometer.

Statistical programs for analysis of variance (ANOVA) were used to determine significance of the results (Duncan, 1955: Grundy and Miesch, 1988). Values less than the reporting limit were replaced by 0.7 times the lower limit of determination (LLD) for purposes of calculation.

RESULTS

Table 1 shows mean concentrations for gold, arsenic, antimony and tungsten in the five random samples of each potting mixture (Stewart and McKown, 1995). Concentrations of all elements were significantly different in all potting mixtures, except antimony which was not significantly different in M2 from M3 ($p<0.05$). Mean gold concentration of 1.4 ng/g in M1 was slightly below its abundance in world soils; tungsten concentration in M1 was approximately twice its abundance in world soils (Brooks, 1983). Arsenic and antimony concentrations in M1 were within baseline ranges for soils of the western United States (Shacklette and Boerngen, 1984). Gold, arsenic and antimony concentrations in M2 and M3 fell into the ranges for soils in gold-mining districts in Nevada and California (Erdman, 1988: Busche, 1989). Tungsten concentration in M3 was higher than for world soils (Brooks, 1983).

Table 2 shows mean concentrations of gold, arsenic, antimony, and tungsten in above-ground biomass of sagebrush after 4 months growth in the above potting mixtures (Stewart and McKown, 1995). Sagebrush seedlings showed statistically significant uptake of arsenic,

Table 1. Mean concentrations[*] of gold, arsenic, antimony and tungsten in potting mixtures determined by INAA analysis.

Mixture	Au, ng/g[†]	As, μg/g	Sb, μg/g	W, μg/g
M1[§]	1.4a[‡]	6.9a	1.3a	2.3a
M2	36b	224b	13b	3.1b
M3	190c	242c	12b	13c

[*]means of five random samples from original mixtures (Stewart et al., 1994).
[†]determination limits: Au=1 ng/g; As, Sb, W=0.1 μg/g.
[§]M1 is nonmineralized (control) mixture; M2 and M3 contain gold ore from Getchell and Pinson, Nevada.
[‡]means within a column followed by same letter are not significantly different ($p<0.05$) according to Duncan's test for multiple ranges (Duncan, 1955).

Table 2. Mean concentrations[*] of gold, arsenic, antimony and tungsten in aerial biomass of basin big sagebrush after 4 months growth in various soil mixtures under greenhouse conditions. Results determined by INAA analysis.

Mixture	Au, ng/g[†]	As, μg/g	Sb, μg/g	W, μg/g
M1[§]	1.6 ± 1a[‡]	0.4 ± 0.7a	0.03 ± 0.005a	<0.05a
M2	<1a	6.4 ± 3.3b	0.20 ± 0.1b	0.07 ± .04a
M3	2.6 ± 2.2a	4.4 ± 1.5b	0.19 ± 0.04b	0.10 ± 0.03b

[*]Means of 6 plants, 2 plants in each of 3 randomized blocks (Stewart et al., 1994).
[†]Determination limits: Au=1 ng/g; As, W=0.05 μg/g; Sb=0.01 μg/g, all on dry weight basis.
[§]M1 is nonmineralized soil; M2 and M3 contain gold ore from the Getchell and Pinson, Nevada.
[‡]Means within a column followed by same letter are not significantly different ($p<0.05$) according to Duncan's test for multiple ranges (Duncan, 1955).

antimony, and tungsten, but not gold. Means for sagebrush gold were not significantly different among the plants grown in the three soil mixtures ($p<0.05$), but mean arsenic and antimony concentrations in plants from the mineralized mixtures were significantly higher than in plants from the unmineralized mixture. Mean plant tungsten levels for the two lowest concentrations of soil tungsten (M1 and M2) could not be distinguished ($p<0.05$), but its concentration in plants from the mixture with elevated tungsten (M3) was significantly higher than in plants from the other two mixtures. Arsenic showed the greatest absolute uptake from the mixtures, but the relative uptake of antimony was higher by a factor of 2 compared to its concentration in the mixtures.

Plants grown in mineralized mixtures (M2 and M3) showed distinctly reduced root growth after 8 months, but ash weights of aerial biomass from these plants were not significantly different from those grown in the nonmineralized mixture ($p<0.05$) (Stewart et al., 1994)

CONCLUSIONS

The results of the greenhouse study suggest that interpretation of gold data from sagebrush collected in the field cannot rule out the possibility of windblown contamination since plants in this controlled environment did not accumulate significant gold, at least over a time period of 4 months. On the other hand, the study indicates that sagebrush has good potential to prospect for concealed Carlin-type deposits in the Great Basin and other arid environments using the pathfinder elements arsenic, antimony and tungsten. Arsenic and antimony are especially sensitive indicators because they appear to accumulate in aboveground biomass to levels that are well above determination limits for INAA. Results also show that species endemic to particular areas of geologic interest can be grown and used effectively in controlled studies.

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REVEGETATION TEST PLOTS AT CRATER LAKE NATIONAL PARK: Evaluation of Soil Treatments on Stand Establishment of Native Species

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INTRODUCTION - Revegetation test plots were installed in October, 1991 at Crater Lake National Park, Oregon to determine the effect of species and soil treatment on stand establishment using locally collected native grass, sedge and forb seed. The study was conducted as part of a cooperative agreement between the National Park Service and the Natural Resources Conservation Service (formerly SCS) to propagate seeds and plants for revegetation within the park. 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* (ELGL), 2) *Stipa occidentalis* (STOC), 3) *Elymus elymoides* (ELEL5), 4) *Festuca* (FERU3), 5) *Carex* spp. (primarily *C. spectabilis*, *C. pachystachya*, and *C. hallii*, 6) *Lupinus latifolius* (LULA4), and 7) mix of 1-6. A randomized complete split block with four replications was used. Data was recorded from spring 1992 through fall 1994 by NRCS staff; the plots continue to be monitored by NPS staff.

RESULTS: Species affected initial plant density in June, 1992; soil treatment did not affect density. ELGL and ELEL5 plots exhibited best initial seedling density, followed by the mixed plots. Other species exhibited low initial seedling densities; but STOC and LULA4 emerged later, as evidenced by September, 1992 cover values. Species and soil treatment interacted to affect stand establishment, as measured by plant cover, in September, 1992. Incorporation of peat moss and slow-release fertilizer best promoted stand establishment in ELGL, STOC, ELEL5, and mixed plots. Lupine establishment was promoted by incorporation of peat moss with or without slow-release fertilizer. In addition, significant flowering percentages were observed in STOC and mixed plots in September, 1992. Incorporation of peat moss and slow-release fertilizer best promoted flowering in these plots. Establishment of certain species was hindered by the addition of erosion control netting.
Similar treatment interactions and results were observed in plots in 1993 and 1994. Overall, species and soil treatment interacted to affect stand establishment in plots. Incorporation of peat moss and slow-release fertilizer promoted stand establishment and growth of certain grass species and lupine. *Carex* 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; however, netting may be important for successful establishment of plant cover in years with below normal precipitation or on slopes.

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POST-RESTORATION DEVELOPMENT OF PLANT COVER IN A MACHINE-GRADED ALPINE SKI RUN

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ABSTRACT

Transplants of indigenous grasses were used in the mid 1980s to restore four plots on a machine-graded ski run above the timberline in the Swiss Alps. A survey including demographic monitoring was carried out in 1993-95 to assess the success of the restoration. None of the planted species was lost and transplants survived very well. The number of species and individuals increased during the monitoring period. The main demographic feature was a pronounced rejuvenation of the communities which were numerically dominated by individuals of *Cardamine resedifolia* and *Chrysanthemum alpinum*, the most successful colonizers. The total plant cover of the restoration plots was significantly higher than on the control plot. The vegetation development and the increase in biodiversity was strongly influenced by survival, growth, and reproduction of transplants as well as extensive immigration.

INTRODUCTION

In machine-graded alpine ski runs where the topsoil has been removed and discarded, natural colonization and development of plant cover may take centuries (Meisterhans 1988). Ecological restoration, which mainly aims to reintroduce a community as a whole and to increase biodiversity, is thus indispensable. Since vegetation dynamics are often affected by local conditions and stochasticity (Glenn-Lewin 1980, Glenn-Lewin and van der Maarel 1992, Myster and Pickett 1988), the successional processes on a restored site may lead to different end points and not just to one "climax" or to the predisturbance state (Pickett and Parker 1994).

Previous restoration trials above the timberline have already shown the importance of using indigenous plant material, especially transplants, and the utility of biodegradable geotextiles which provide safe-site conditions (Flüeler 1992, Gasser 1989, Hasler 1992, Schütz 1988, Tschurr 1992, Urbanska 1995 a).

A survey of restored plots was initiated in 1993 to assess the success of the restoration. The following aspects were considered: (1) community size and age-state structure, (2) transplant survival, growth and reproduction, (3) immigration process, and (4) development of plant cover. The present paper deals with some preliminary results obtained within a three-year period of monitoring which started eight years after the restoration plots were set up.

MATERIAL AND METHODS

The research area is located within the alpine belt of the Jakobshorn mountain near Davos (NE Swiss Alps), where snowfall and frost may occur at any time throughout the summer, and the vegetation period is confined to two or three months. In the early 1970's a ski run was constructed across an alpine sedge grassland on siliceous substratum. Grading brought about the following results: (1) lack of plant cover and of developed soil, (2) high skeletal content of the soil, (3) low content of humus and organic matter, (4) deficiency in nutrients and especially in nitrogen, and (5) lack of a soil seed bank.

In 1985-86, four restoration plots were established on the ski run with a distance of 1-6 m between plots. They were situated at 2450 m a.s.l. on a SW slope (*c.* 5°) of the Jakobshorn. In these plots 1040 clonal transplants of eight alpine indigenous grasses were planted in single-species sectors (Fig. 1). The plots were covered with biodegradable mats (Curlex®) to provide safe-site conditions, but no further measures were undertaken to protect them from damage by skiing, ski run maintenance machines, or herbivores.

plot 1; transplantation 7.9.1985

Hv 22	*Df* 22	*Td* 22	*Pa* 22	*Df* 22	*Phla* 22
Phla 18	*Ts* 18	*Df* 18	*Hv* 18	*Ts* 18	*Hv* 18

plot 2; transplantation 7.9.1985

Hv 22	*Df* 22	*Ts* 22	*Pa* 22	*Hv* 22	*Phla* 22
Phla 18	*Ts* 18	*Df* 18	*Hv* 18	*Ts* 18	*Hv* 18

plot 3; transplantation 17.-20.7.1985

Ar 22	*Pa* 22	*Sd* 22	*Ar* 22	*Pa* 22	*Sd* 22
Pa 18	*Sd* 18	*Ar* 18	*Pa* 18	*Sd* 18	*Ar* 18

plot 4; transplantation 15.-18.7.1986

Ts 22	*Phla* 22	*Pa* 22	*Td* 22	*Ts* 22	*Phla* 22	*Pa* 22	*Td* 22
Td 18	*Pa* 18	*Ts* 18	*Phla* 18	*Td* 18	*Pa* 18	*Ts* 18	*Hv* 18

1 m

Fig. 1. Transplantation plan of alpine grasses used in the restoration trial. Numbers refer to the number of transplants. *Ar* = *Agrostis rupestris*, *Df* = *Deschampsia flexuosa*, *Hv* = *Helictotrichon versicolor*, *Pa* = *Poa alpina* ssp. *vivipara*, *Phla* = *Phleum alpinum*, *Sd* = *Sesleria disticha*, *Td* = *Trisetum distichophyllum*, *Ts* = *Trisetum spicatum*; nomenclature according to Hess *et al.* (1976-1980).

A fixed-point monitoring was carried out throughout the period 1993-95 with a metal frame of 1 m^2 divided into one hundred subsquares of 10 x 10 cm each. Individuals of different age-state classes (Rabotnov 1945) were first recorded in each of the subsquares and then totalled for each plot. The following abbreviations were used:

s = seedlings with only functional cotyledons in dicots, or with a single leaf in monocots;
y = juveniles, *i.e.* individuals of an intermediate size relative to those found in all plots;
nr = adult newcomers consisting of several ramets but without reproductive structures;
r = newcomers bearing flowers or fruits;
NR = non-reproducing transplants;
R = reproducing transplants.

Transplants and adult newcomers were easily determined, but this was not always possible for seedlings or juveniles, especially in monocots.

To assess the ecological characteristics of the immigrant species, the indicator values according to Landolt (1977) were considered. These express the importance of six environmental factors (light, temperature, alkalinity, humidity, nutrient status, and humus content of the soil) in the preferred habitat of the species. The values are organized as a five-point scale, reflecting increasing intensity of the factor.

The ground cover of the restoration plots was estimated by using a regular pattern of 100 points · m^{-2} (pin-point overlay method). Each point was correspondingly classified as bare ground, stones, or vegetation (incl. transplants, transplant offspring, immigrants, and mosses). Five square meters of the ski run were randomly chosen close to the restored plots as control.

Statistical analyses were conducted using SYSTAT, applying analysis of variance and Fisher's LSD test.

RESULTS

Community size and age-state structure

The number of individuals increased during the monitoring period in all plots studied (Table 2), and in 1995 the whole community was nine times larger than that reintroduced in 1985-86. On average, 432 individuals · m^{-2} were found at the restored surface with significant differences among single plots (Table 1). Also, the number of individuals varied greatly even among 1 m^2-sectors of the same plot owing to the irregular distribution of the newcomers. For example twice as many individuals were recorded in the first rather than in the second sector of plot 1.

Table 1. Density of plants in single plots ten years after restoration (mean ± SE), the initial density was 48 individuals · m^{-2}. Values followed by different superscripts are significantly different from each other (Fisher's LSD test, $p < 0.05$).

	plot 1	plot 2	plot 3	plot 4
No. individuals · m^{-2}	643 ± 110 ^{a}	598 ± 52 ^{a}	240 ± 36 ^{b}	277 ± 39 ^{b}

The study revealed a strong increase in the percentage of juveniles in all plots: after two years the class was increased by *c.* 20% in plots 1-3 and even by 32% in plot 4 where the number of juveniles registered in 1994 was nearly triplicated one year later (Table 2). The dynamic of the plot communities and in particular their pronounced rejuvenation became more clear when age-state classes were grouped into the TYN- (total of young newcomers), TAN- (total of adult newcomers), and TT- (total of transplants) categories. In 1995, transplants represented only 12% of the whole individuals. Their numerical importance was even less for the single communities of plots 1 and 2 (7.2%). Young newcomers were now the large majority in all plots (Fig. 2).

Among the newcomers, immigrants played a prominent role in the group contribution to the community of plot 4 where they represented 80% of all individuals, while transplant offspring were less than 2%. Plot 3 was characterized by a high percentage of both immigrants (50%) and transplant offspring (30%). The corresponding values of plots 1 and 2 were not calculable because of the numerous undetermined monocots.

Table 2. Annual changes in total number of age-state classes in the studied plots throughout the three-year monitoring period. s = seedlings, y = juveniles, nr = non-reproducing newcomers, r = reproducing newcomers, NR = non-reproducing transplants, R = reproducing transplants.

Plot	Year	s	y	nr	r	NR	R	Total
1	1993	155	825	30	139	125	102	1376
	1994	100	1851	42	192	92	128	2405
	1995	63	2481	52	231	91	129	3047
2	1993	187	1133	58	232	131	85	1826
	1994	168	1998	53	322	82	120	2743
	1995	39	2319	45	249	80	125	2857
3	1993	62	330	23	31	149	72	667
	1994	23	558	27	77	120	95	900
	1995	11	806	33	98	80	135	1163
4	1993	11	275	26	43	256	35	646
	1994	15	500	22	105	221	51	914
	1995	26	1383	51	141	224	42	1867

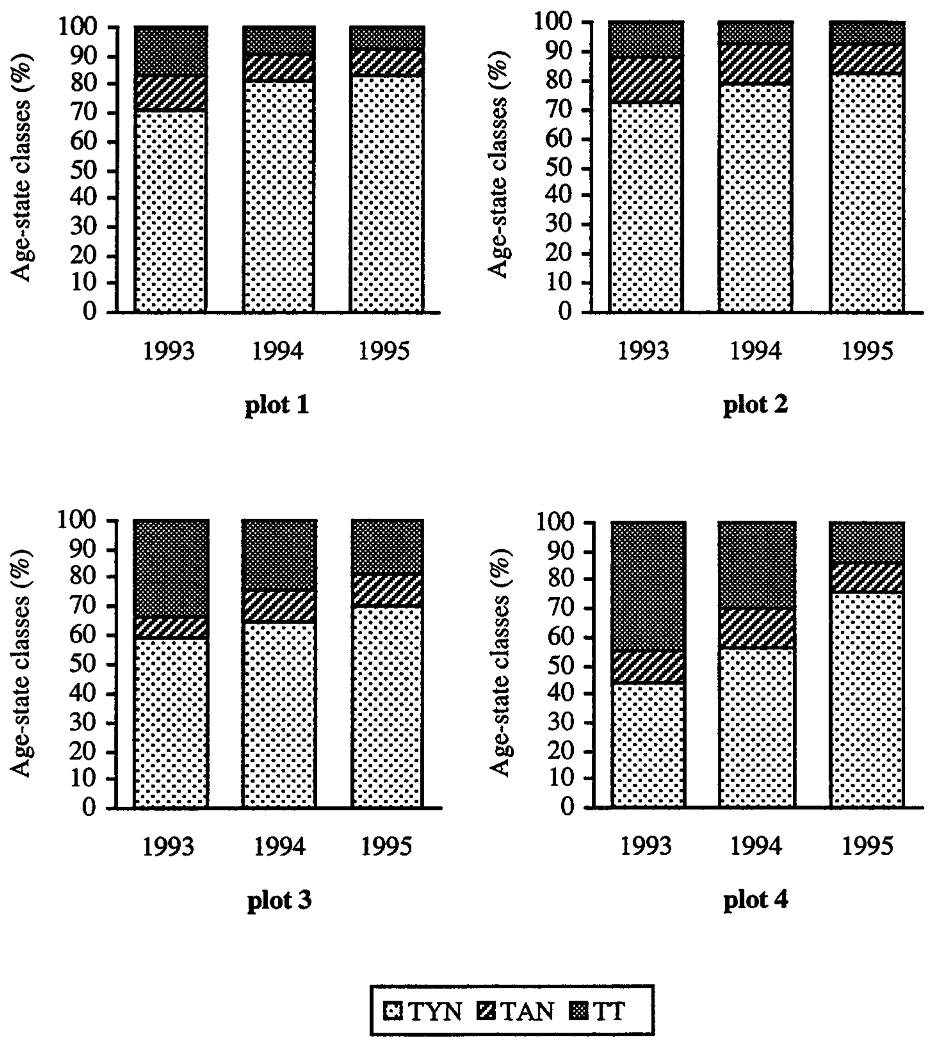

Fig. 2. Age-state structure of the plots studied. The data refer to mid-August controls of the period 1993-95. TYN = total of young newcomers (incl. seedlings and juveniles), TAN = total of adult newcomers (incl. non-reproducing and reproducing individuals), TT = total of transplants (incl. non-reproducing and reproducing individuals).

Transplants

None of the grass species used as transplants was lost, and 88% of all transplant units still survived in 1995. No significant difference was observed in the survival rate of transplants among the four plots (Table 3). The mortality of transplants recorded throughout the three study years was about 5%. The populations of all planted grasses included some juveniles, but transplant offspring was mostly formed by individuals of *Poa alpina* ssp. *vivipara* which reproduces vegetatively through bulbils. Populations of *Agrostis rupestris*, *Helictotrichon versicolor*, *Poa alpina* ssp. *vivipara* and *Trisetum spicatum* also included reproducing newcomers.

Table 3. Transplant survival in the studied plots in the monitoring year 1995. ITN = number of transplants used initially in the restoration trials; NLT 1995 = number of live transplants recorded in 1995; S% = survival rate.

Plot	Restoration year	ITN	NLT 1995	S%
1	1985	240	220	91.7
2	1985	240	205	85.4
3	1985	240	215	89.6
4	1986	320	266	83.1

Immigrants

During the monitoring period a continuous increase in alpha diversity (number of species) was registered in all plots (Fig. 3). In 1995, twenty new species were recorded (Table 4) which represented different growth forms and various families. The immigrant populations largely differed from each other in size and age-state structure: some species were probably just immigrated, while the others were already present for several years. The largest populations were those of *Cardamine resedifolia* (4484 individuals) and *Chrysanthemum alpinum* (563 individuals) whose populations represented together 56% of the whole community and 94% of the immigrants. Reproducing individuals were observed in about a half of the immigrant species; most of them belonged to *Cardamine* (591) and *Chrysanthemum* (49).

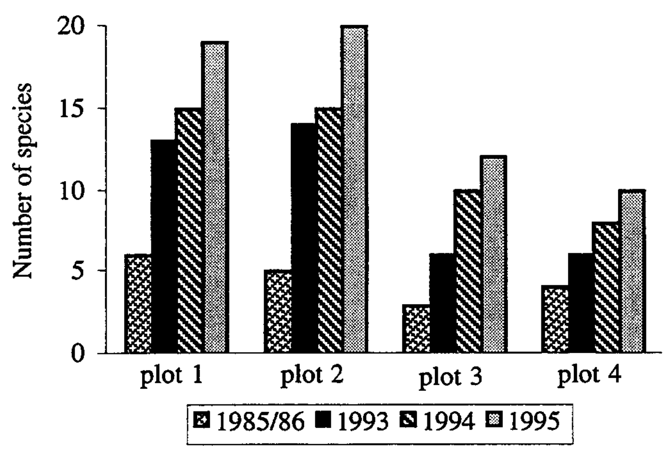

Fig. 3. Increase in alpha diversity in the restored plots. Transplantation dates: autumn 1985 (plots 1 and 2), summer 1985 (plot 3), summer 1986 (plot 4).

The ecological indicator values (Table 4) showed that most of the immigrant species mainly occur in the alpine belt on acidic nutrient-poor soils with variable water content. Three immigrants were indicators of mineral soil (incl. *Cardamine resedifolia*), whereas ten other species (incl. *Chrysanthemum alpinum*) were typical for humus-rich soils. However, in the surroundings of the study area *Chrysanthemum alpinum* was present in different sites such as alpine sedge grassland, scree, and snow-patches.

Table 4. Number of species immigrated in the restored plots: in the left column age-state structure in August 1995, and in the right one the ecological indicator values according to Landolt (1977). F = soil humidity, R = soil alkalinity, N = nutrient status of soil, H = humus content of soil, L = light intensity, T = temperature; other abbreviations as in Table 1.

Species	s	y	nr	r	Total	F	R	N	H	L	T
Cardamine resedifolia	108	3704	81	591	4484	3	2	2	2	4	1
Chrysanthemum alpinum	1	470	43	49	563	3	2	2	4	5	1
Leontodon helveticus	5	107	6	8	126	3	2	2	4	4	1
Senecio carniolicus	6	71	2	3	82	2	1	2	3	5	1
Gnaphalium supinum	0	26	1	7	34	3	2	2	4	4	1
Poa alpina	0	0	4	15	19	3	3	4	3	4	2
Euphrasia minima	0	1	1	6	8	3	2	2	4	4	1
Sesleria coerulea	0	0	0	5	5	2	4	2	3	4	2
Agrostis rupestris	0	1	0	4	5	2	2	2	3	5	1
Anthoxanthum alpinum	0	0	0	4	4	3	3	3	3	4	1
Hieracium alpinum	0	0	3	1	4	3	1	2	4	4	1
Polygonum viviparum	0	3	0	1	4	3	3	2	4	4	1
Salix herbacea	0	3	1	0	4	4	2	2	4	5	1
Taraxacum alpinum	0	2	0	0	2	4	3	4	2	4	1
Arabis alpina	0	0	1	0	1	3	4	2	2	4	1
Doronicum clusii	0	0	1	0	1	3	2	2	3	5	1
Hieracium intybaceum	0	0	1	0	1	2	2	2	3	4	2
Luzula lutea	0	0	1	0	1	2	2	2	4	5	1
Arenaria biflora	0	0	1	0	1	4	2	2	4	4	1
Sibbaldia procumbens	0	1	0	0	1	4	2	3	4	4	1

Cover assessment

In plots 1 and 2 the total vegetation cover was estimated at about 30%, while plots 3 and 4 were characterized by lower values, *i.e.* 18 and 13%, respectively. The data of plots 1-3 were significantly higher than in the control plot (Fig. 4).

The total vegetation cover was principally formed by the canopy of transplants. These corresponded to at least 50% of the value in each plot (Table 5). The role of the immigrants was important only in plot 4; however, mosses and transplant offspring were scarcely represented there.

Table 5. Contribution of different categories to the total plant cover in the restored plots.

Plot	Mosses (%)	Transplants (%)	Transplant offspring (%)	Immigrants (%)
1	6.9	70.9	11.1	11.1
2	18.2	50.0	13.6	18.2
3	9.9	63.0	6.6	20.5
4	2.2	62.7	6.7	28.4

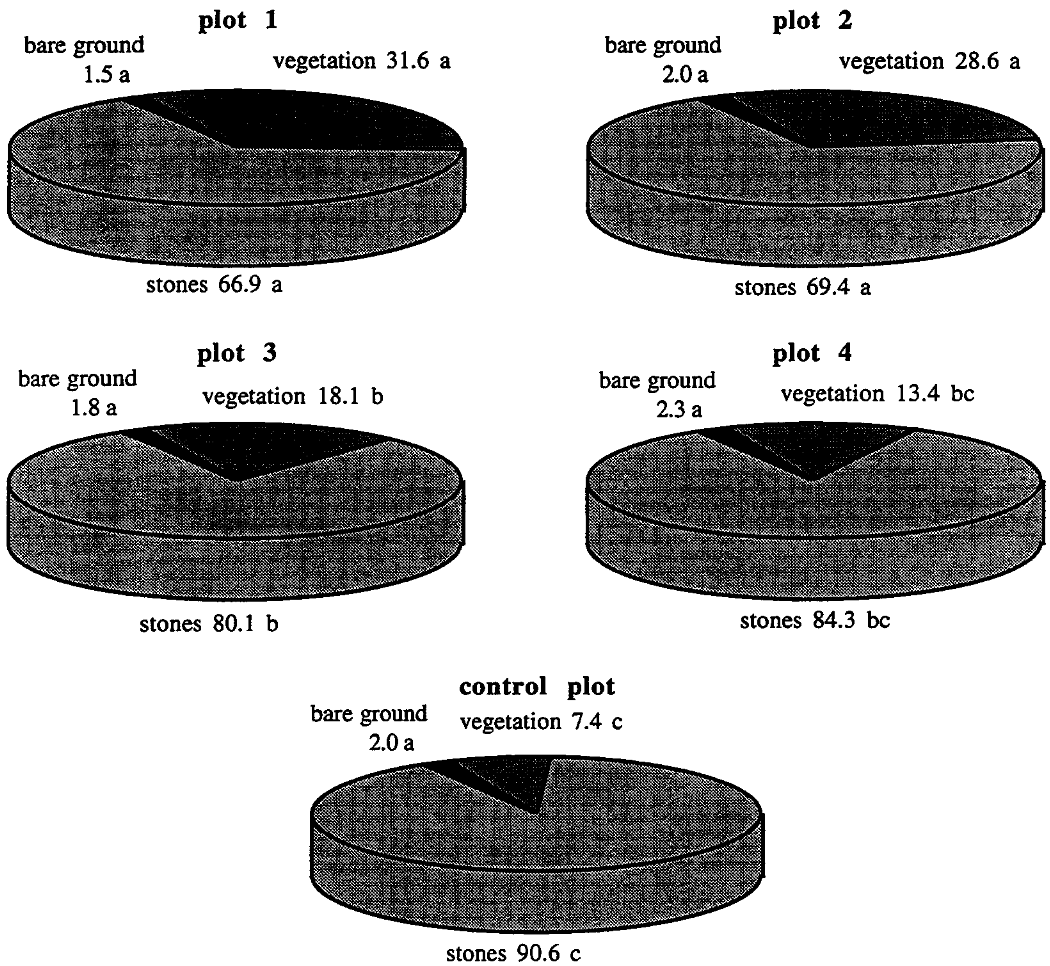

Fig. 4. Cover (%) of single plots in summer 1995. Significant differences between corresponding categories among plots are indicated by different letters (Fisher's LSD test, $p < 0.05$).

DISCUSSION

During the survey the plots showed a clear increase in alpha diversity (number of species) and delta diversity (age-state classes; see Urbanska 1995 b). The vegetation was characterized by a frequent occurrence of juveniles (78%), and the total vegetation cover was significantly higher than on the unrestored ski run. This development was due to survival, growth, and reproduction of transplants as well as to diaspore immigration from the surroundings. Immigrants originated either from nearby intact vegetation (alpine sedge grassland, snowbeds) or from neighbouring restoration plots. More than half individuals registered in the restored plots were of *Cardamine resedifolia* or *Chrysanthemum alpinum*. The rejuvenation process was principally due to these immigrants rather than to transplant offspring. On the contrary, transplants constituted 3/5 of the total vegetation cover in the restored area whereas mosses, transplant offspring, and immigrants represented together the remainder.

Transplants and immigrants contributed thus to post-restoration development of plant cover in a different way. Transplants apparently allocated more resources and energy to clonal growth and vegetative reproduction (in the case of *Poa alpina* ssp. *vivipara*) rather than to reproduction by seed. However, in 1995 offspring of all planted grasses included many juveniles, and reproducing newcomers originated from seeds were already present in populations of *Agrostis rupestris*, *Helictotrichon versicolor* and *Trisetum spicatum*.

Several alpine grasses show clonal growth accompanied by self-fragmentation (Wilhalm 1996) and also reproduce successfully by seed. However, the reproductive success may often be prevented by the harsh climate and short vegetation period which may lead *e.g.* to destruction of flowers, lack of pollination, or incomplete seed development (Landolt 1992). Herbivory may also reduce the probability of reproduction by seed (Abrahamson 1980). In the restoration plots herbivory was registered for some transplants whose flowers, leaves, and even roots were eaten, especially by cattle and marmots.

The most successful immigrants were characterized by large resource allocation to reproduction by seed. The numerous individuals of *Cardamine resedifolia* and *Chrysanthemum alpinum* suggest that these species usually produce many seeds. Since seedlings of alpine plants suffer high mortality, the number of diaspores which immigrated in the restored plots must have been very high. A previous study in the same research area already revealed the success of *Chrysanthemum alpinum* in the colonization process on machine-graded alpine ski runs and estimated its production of fertile seeds at 30-36% (Pazeller 1990). The numerical supremacy of *Cardamine resedifolia* in the plot communities could be related to the fact that individuals of this species may already be able to reproduce during the second growth season, whereas onset of flowering in most alpine plants occurs 3 to 4 years from establishment. Immigrant diaspores in the studied plots were apparently brought by wind, while in restoration trials of other ecosystems birds were recognized as the predominant dispersers (Robinson and Handel 1993). Species recruitment from a seed bank or as a result of clonal growth of individuals that survived below ground was not possible, due to the poor soil characteristics after grading (Flüeler 1992). The importance of dispersal of seeds for development of plant cover has been reported in previous restoration trials of our research group (Hasler 1992, Tschurr 1992, Urbanska 1995 a, b) and also in many other areas *e.g.* in the industrial waste heaps of north-west England (Ash *et al.* 1994).

The Curlex® mats protected the transplants and trapped diaspores during the first years after restoration (see also Schütz 1988, Hasler 1992, Tschurr 1992). Secondary safe-sites were apparently provided by transplants themselves: seedlings and juveniles often occurred within clonal structures of the transplants or in their immediate vicinity, frequently under the canopy. These observations are similar to previous results obtained in limestone grassland (*cf.* Ryser 1993).

Some immigrant species, *e.g. Chrysanthemum alpinum* and *Leontodeon helveticus*, may be classified as late seral dominants *sensu* Chambers *et al.* (1984) which can also colonize disturbed alpine sites with appropriate edaphic and topographic characteristics. Biological degradation of Curlex® mats and litter of transplants probably provided conditions suitable for plants occurring in sites with more developed soil. However, soil nutrient status in our trial plots remains to be studied.

CONCLUSIONS

- Transplantation of grass species is an effective small-scale method to restore disturbed sites above the timberline.
- Some species contribute to post-restoration development of plant cover mainly through reproduction by seed while the others mostly increase cover via clonal growth.
- A mid-term demographic monitoring of single populations and whole vegetation is a useful measure to assess the restoration success.

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Ectomycorrhizae in Alpine Restoration: Soil Aggregation & Plant Development

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Introduction: Degraded alpine sites are strongly attacked by erosion processes, seriously aggravating the situation. Restoration efforts, even with autochthonous plant material often fail, due to the highly instable and barren soil. Successful plant development and establishment needs a certain nutrient availability, which again requires a minimum of soil stability. Microorganisms play a key role in soil aggregation with fungal mycelia as probably most effective contributors. Among them, it is the mycorrhizal fungus that provides a direct link between soil aggregation and its host plants.

Soil: Ectomycorrhizal fungi are particularly responsible for creating microaggregates, but are also involved in the architecture of the macroaggregate structure. Their hyphae contribute in both, physical and chemical binding mechanisms. Quality and size distribution of aggregates affect a soil's pore size distribution. Together, these properties constitute what is termed soil structure. They influence soil physical, chemical and biological processes, and are essential for plant establishment, by enabling nutrients, shelter, and water and oxygen supply.

Plant: Ectomycorrhizal fungi are associated with the daily functioning of plants through different processes, such as nutrient uptake, water relations, and protection against parasitic attacks. It is a well known fact, that ectomycorrhizae enhance plant growth.The increase in density and branching of the root system is of particular interest for restoration purposes. Not least, the better nutrient and water supply strengthen plant health, which again increases the resistance against detrimental influences.

Conclusions: A major goal of restoration should be to create conditions that favour the development of stable soil aggregates, thereby facilitating the rebuilding of a nutrient reserve. Ectomycorrhizal fungi are responsible for initial aggregative functions, in order to protect and stabilize organic residues within the soil, and for the link between the nutrient pools and the roots of the host plants.
The application of ectomycorrhizal mycelia in alpine restoration may therefore contribute a considerable part to the establishment of self sustaining "restoration communities".

Restoration of alpine ski runs by volunteer teenagers - a lesson in environmental education*

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Introduction

Communication and education are essential to restoring degraded landscape because only in this way the community support may be expected. Restoration work done by teenagers represents an important educational opportunity since the future decision-makers are then directly confronted with the problem of human-induced environmental damage.

In 1990, a small-scale restoration of a ski run was undertaken in surroundings of Davos (Grisons, NE Swiss Alps). The restoration site was located on N slope of Jakobshorn (ca. 2350 m. a.s.l., siliceous substratum). This restoration was done by a high-school class and their teacher as a „Pro Juventute“ action. Five years later both the educational value of the restoration work and development of plants in the restored plots were assessed.

Methods

Plant development in the restored plots was studied with help of demographic monitoring (fixed-point system). Two levels of diversity were assessed: (a) species richness, and (b) range of age-state classes in whole plots, and also in selected populations. The didactic value of the action was assessed in interview with the teacher and placed in an appropriate frame of reference by literature study.

Results

Demographic monitoring revealed that in comparison to the controls, the restored plots were characterized by a significantly higher total number of plants and species (Table 1); the full range of age-state classes observed in the plots indicated a dynamic development of the plant cover. *Trifolium thalii* introduced as transplant species qualified as an excellent restoration material. *Gnaphalium supinum* was the best-performing immigrant species.

Table 1. Increase in species number between 1990 and 1995.

Year	Restored plot 1	Restored plot 2	Control
1990	13 (transplants)	13 (transplants)	no data
1994	22	18	12
1995	23	20	15

* Contents of the poster presented at the Workshop

The educational value of the restoration work done by the teenagers corresponded exactly to the principles of environmental education (Table 2).

Table 2. Environmental education tenets and the restoration work of the teenage volunteers in the alpine.

Tenet	Experience of the volunteers
Environmental education is based on the actual work ("learning by doing")	The actual work included e.g., planting, laying out the geotextiles
Environmental education includes a direct confrontation with the learning object	The teenagers were directly confronted with the site destruction
Environmental education includes outdoor experience	The teenagers did their work in the alpine
Environmental damage must be perceived as a problem directly concerning the persons involved in the learning process	The teenagers perceived the damage themselves and became thus directly involved
"Repair" of environment must be understood in this context as acting one's own interest to improve the life quality	The teenagers were involved, their restoration work qualified thus automatically as done in their own interest
Environmental education should seize the individual's way of thinking about the environmental problems and open the mind to reflections	By visiting the destroyed alpine site and actively participating in restoration, the teenagers had the opportunity for reflections. These may be encouraged later on by the teacher or (most desirably) to be the individual's own initiative
Environmental education should give opportunity for learning and acting	The opportunity to learn and to act was provided by the appropriate teaching prior to the restoration and then by the actual restoration work

Conclusions

- The restoration of alpine ski runs by teenage volunteers represents a valuable form of environmental education fulfilling the didactic and pedagogic objectives.

- It also shows that a successsful small-scale restoration does not necessarely require special skills provided that the ecological principles are followed.

Small-scale restoration of a construction site in the alpine: Pilatus Kulm, Switzerland*

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Jakob Eschmann, Alpine Nursery, Emmen

Introduction

The restoration site (ca. 300 m^2) is located at ca. 2050 m. a. s. l. in the summit area of the Pilatus, Central Swiss Alps, Canton of Obwalden. The substratum is limestone and base-rich schists. The site was destroyed by construction of sewer pipeline (1988-89) and military installations (1992-93).

Pilatus is easily accessible by a cogwheel train and attracts many tourists; it is a nature reserve well-known for its rich flora and fauna. Restoration was thus commissioned by the Pilatus Train Company and the Federal Airforce Office. The goals were to provide:

- suitable place for visitors and starting point for hand-glider flyers
- attractive plant cover
- slope stabilization
- visual improvement of the summit area landscape.

The restoration work was initiated in 1990, interrupted for the period 1992-1993, and taken up again in 1994. The assessment was done in 1994.

Methods

Topsoil was amended with 0.5 m layer of rendzina mixed with limestone gravel; 10 cm humus layer was added later. Alpine plants from the area were used for seed and clonal transplant production at nursery. Transplants were established in 1990-1991; in 1994, alpine grass mixture was hand-seeded (300 g/m^2). The site was covered with jute and watered in summer.

* Contents of the poster presented at the Workshop

Problems and conflicts of interest

Many problems were encountered:

- Visitors and hand-glider flyers had to be given free access to the site despite the ongoing restoration (!), which had to be interrupted for two years on account of the military construction works.
- Clients and tourists expected full recovery already within one year.
- The employes of the train company viewed restoration with mistrust because it involved neither high-technology nor extensive use of machines.
- Wildlife (*Ibex ibex*) damaged the site by grazing and trampling.

Results

Over 80% of transplants survived the four-year period. On the whole, plant cover increased up to 40% on the slope and up to 80% on tilted borders. The seeded grasses produced loose cover within five weeks. Vegetation developed after restoration was species-rich. Among the best performers were *Arabis alpina, Deschampsia caespitosa, Doronicum grandiflorum, Festuca rubra, Hutchinsia alpina, Lotus alpinus, Myosotis alpestris, Poa alpina, Trifolium badium, T. thalii.*

Conclusions

- Restoration in the alpine is labour- and thus cost-intensive but quite possible.
- Soil attributes are major limiting factors.
- A timely restoration saves much trouble and money but damage should be avoided in the first place.

Spontaneous colonization of restored downhill ski runs above the timberline*

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Introduction

Restoration trials carried out on machine-graded alpine ski runs included reintroduction of native species in form of pre-grown clonal transplants. Safe site conditions were provided with use of biodegradable wood-fiber Excelsior mats (Urbanska 1994, 1995a, b, Urbanska in press). It was hypothesized that these covers should function in a twofold way:

(i) they should protect the transplants from environmental hazards

(ii) they should enhance spontaneous immigration of further species by trapping trapping the diaspores and providing safe sites for recruitment.

The usefulness of biodegradable mats in promoting spontaneous immigration of plant species into restoration plots was tested with age-state-oriented mapping of populations. The present paper deals with two plots respectively aged of six and seven years.

Material and methods

The plots were situated at Strela mountain (NE Swiss Alps, Canton of Grisons, in the surroundings of Davos). The mother-rock in this area is dolomite, the elevation of ca. 2400 m. a. s. l. corresponds well to the alpine vegetation belt. The plots were set up on machine-graded downhill ski run, used by many skiers throughtout the winter season and extensively maintained by track machines.

The "fixed-point" monitoring included demographic protocols. Immigrant populations were classified as to age-state classes and mapped with help of light-metal frame of 1 x 1 m subdivided into 100 quadrats of 10 x 10 cm each. The data gathered in this way permitted to assess the following parameters:

- number of the immigrant species
- number of age-state classes
- respective areas of immigrant populations within the restored plots.

There was virtually no immigration on non-restored ski run.

Results and comments

The very successful immigration in restoration plots (Fig. 1) was clearly recognizable in a distinct increase in species number and the corresponding increase in the number of plant families they represented (Table 1). Identified immigrant species formed a considerable component of the whole plot community: they represented 40% of the total plant number in the plot installed in 1987 and 37.4% in the plot installed one year later (Table 2).

* Paper based on poster presented at the Workshop

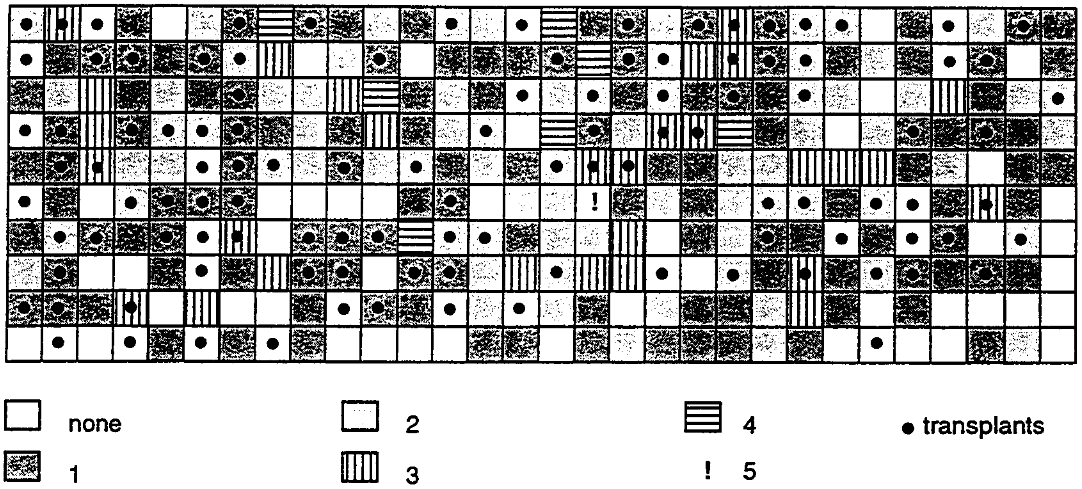

Fig. 1. Plot AH 1987 at Strela: Small scale-distribution of species (number of species per 10 cm x 10 cm square) within the total plot area of 3 m^2.

Table 1. Plots at Strela: increase in number of plant species and families after restoration. ISN = intitial species number; IFN = initial number of families. SN 1994 = number of species registered in summer 1994; FN 1994 = number of families registered in 1994.

Plot code and restoration year	ISN	IFN	SN 1994	FN 1994
AH 1987	6	3	25	15
AH 1988	8	4	24	14

Table 2. Plots at Strela: Group contribution to the whole plot community registered in summer 1994. TRANSP = transplants; TRO = transplant offspring; IMM = immigrants; NID = non-identified newcomers, either immigrants or transplant offspring.

Plot code and restoration year	TRANSP	TRO	IMM	NID	TOTAL*
AG 1987	117	551	472	40	1180
AH 1988	188	665	574	108	1535

* initial number of plants at the beginning of the trial was
188 transplants in plot AH 1987
240 transplants in plot AH 1988

Some species clearly immigrated from neighbouring intact vegetation, whereas the others apparently originated from other restoration plots installed nearby. The respective differences in size, area and age-state structure of immigrant populations (Table 3) suggest that some of them are older and include several generations whereas many others result from more recent immigration episodes.

Table 3. Identified immigrant species grouped according to their population size.

Code	1-10 plants	11-50 plants	51-100 plants	101 and more plants
AH 1987	8	8	1	2
FT 1989	14	0	2	0

Conclusions

- A sucessful colonization represents the outcome of two separate processes viz. (i) diaspore ability to reach a site and (ii) ability to become established (Ash, Gemmel & Bradshaw 1994, Green 1983). The colonization process begins with diaspore deposition.

- Development of immigrant populations in the restoration plots above the timberline indicates that diaspores of many species are aparently able to reach the sites but fail to establish if safe site conditions are not provided

- Restoration above the timberline should by all means include providing of safe site conditions because both the diaspore entrapment as well as the actual germination and recruitment have to be enhanced.

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PARTICIPANT LIST

We were pleased to have a total of 215 participants at the Twelfth High Altitude Revegetation Conference. Representatives from two foreign countries, as well as from 18 states 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 Alaska were present.

For all of you that came, thank you for your participation in the conference. Make plans for attending in 1998. The High Altitude Revegetation Conference will be held in February or March, 1998 in Fort Collins, Colorado. Pass the word to your colleagues, so that the 1998 conference will be a great success.

Warren R. Keammerer
Editor

Table 1. Geographical distribution of participants at the Twelfth High Altitude Revegetation Conference.

Geographic Entity	Number of Participants	Percent of Total Participants
CANADA		
British Columbia	1	0.47
SWITZERLAND	3	1.40
UNITED STATES		
Alaska	1	0.47
Arizona	4	1.86
California	3	1.40
Colorado	146	67.91
Maryland	1	0.47
Minnesota	2	0.93
Montana	9	4.19
Nebraska	1	1.47
Nevada	6	2.79
New Mexico	4	1.86
Ohio	1	0.47
Oregon	1	1.47
South Dakota	1	0.47
Tennessee	1	0.47
Texas	2	0.93
Utah	9	4.19
Washington	1	0.47
Wyoming	18	8.37
Total	215	100.00

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