PROCEEDINGS: HIGH-ALTITUDE REVEGETATION WORKSHOP NO. 4

Edited by

Charles L. Jackson and Mark A. Schuster
Climax Molybdenum Company

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Edited by

CHARLES L. JACKSON and MARK A. SCHUSTER
Climax Molybdenum Company

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PREFACE

e High-altitude Revegetation Committee through its biennial work- nd annual field tours intends to promote understanding of rehabilitation procedures and materials and natural-resource values and potentials which must be addressed when fragile subalpine and alpine ecosystems are to be modified by activities. Although the theme of the conference is high-altitude revegetation, much information is also applicable or can be adapted to lower-elevation situations.

There was increased attendance and interest at this year's workshop, perhaps in part a response to increased Federal and State reclamation legislation and regulation. With the past history of support and interest from organizers, contributors, and participants, hopefully these workshops can continue to serve as a vital and relevant forum.

Stephen T. Kenny, the immediate past secretary of the High-altitude Revegetation Committee, accepted a position at North Carolina State University in January 1980 to do post-doctoral work. Steve helped in the early planning for the fourth workshop, was a prime mover and proceedings editor in the third workshop, and set out and maintained records on high-altitude grass plots from 1976-79. The committee recognizes Steve's contributions and will miss his conscientious service.

The committee thanks its members who donated their time and effort in the organization and conduct of this year's workshop at Colorado School of Mines at Golden. Special thanks to the workshop hostess, Dr. Beatrice E. Willard of the Industrial Ecology Institute at Colorado School of Mines, and her assistants, Jean Shadwell and Liz Yeates, for their considerable organizational contributions.

All of us participants are indebted to and appreciative of the speakers and their organizations for sharing their information and experience.

Charles L. Jackson

Mark A. Schuster

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Snow, Wind, and Vegetation in the Front Range, Colorado

by

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February, 1980

I. Introduction

I appreciated the invitation to participate in a workshop of persons from many disciplines and professions who are searching for ways and means of revegetating high altitude disturbed lands. You have achieved a remarkable capacity for persistence, doubtless because the potential for preservation of a satisfying environment for human beings is so important an activity. Someone asked me recently just what the "Revegetation Workshop" does. I responded that we are concerned with the business of putting back together the parts of ecosystems broken apart during the process of making essential resources available for technology. In this rebuilding activity, we find that the discipline of ecology provides some helpful tools for the land manager. For example, the ecology of the Front Range provides technical bases for revegetation projects. In the process of conducting research and class field trips in this range during the past 30 years, I have collected volumes of field observations, several files of data, hundreds of photographs, and an abundance of ideas. I would like to share some of these materials with you.

I have been fascinated by the processes which participate in the development and operation of local ecosystems of this dynamic landscape. Today, I shall concentrate on a series of processes and resultant forms involving snow, wind, and vegetation. These will be old stories to many of you but hopefully you may get some new perspective useful in revegetation work.

Figure 1. Heavy snow and little wind in montane stand of ponderosa pine and Douglas fir.

II. Snowstorm Followed by Gentle Wind. Quali.

As a beginning for this survey of ecological processes, we can look at stands on which a storm has dropped several inches of snow and wind is minimal (Figure 1). The results of snow accumulating on branches can be disastrous if the crown of the tree is not symmetrical; irregular accumulation tips trees over and may break the crown. This process was described by Pruitt (1958) who called it Quali, an Eskimo word referring to snow _on_ trees. Pruitt studied the processes in white spruce (_Picea glauca_) stands in interior Alaska where they are common on river terraces. The processes observed were organized in the following cycle: Random breaking off of crowns creates a small opening in the canopy of the stand. Branches around the opening will then grow more vigorously than those on the other side of the tree crowns. In time there will be enough difference in the snow-catching surface of branches and needles to tip the trees surrounding the initial opening into the open area farther and farther; eventually some break or are uprooted, resulting in enlargement of the opening. Spruce does not reproduce well on its own litter in the clearing that has been formed. Willow (_Salix_ spp.), alder (_Alnus_ sp.), birch (_Betula_ sp.) and aspen (_Populus tremuloides_) do reproduce in the openings and form a patch of broad-leaved vegetation. Spruce is able to reproduce under the broad-leaved plants and thereby initiates the reestablishment of spruce as the stand dominant. And thus the cycle of destruction followed by recovery is completed.

III. Snow Storms Followed by Strong Wind.

Another type of snow storm lays a complete snow cover over all the land, except cliffs, but soon after the falling of snow ceases, the wind begins to redistribute the white water; in this process, wind picks bits of snow from the accumulated layer and carries it downwind, often building it into dunes which move across the ground or on old, hard snow surfaces. Eventually the wind loses its transporting capacity and drops its load of snow in a drift behind a boulder or in the lee of a solifluction terrace or just a tuft of grass or other plants.

The eroded surface of snow left when the velocity of the wind decreases to a level at which it is no longer adequate for erosion work, is an interesting pattern of ridges, basins and projecting shelves (Figure 2, 3, and 4).

A. Snow redistribution

During the process of redistribution, three different micro-environments can be observed: a <u>source area</u>, a <u>baffle area</u> and an <u>accumulation area</u>. The source area may be a meadow, an old burn, a shrub stand or a frozen lake. The baffle may be plants or a topographic break which sets the wind to eddying. The processes of redistribution are illustrated in the following examples.

B. Snow drifts and tree stands

Clones of aspen often form groves surrounded by meadows. The clone will tend to spread centrifugally but the process is inhibited to the

Figure 2. Snow dune moving on old snow surface

Figure 3. Snow dune moving on ground

windward by exposure to strong wind, and to the leeward by snow accumulation; the meadow being a source area, the aspen forming a baffle area and the leeward part an accumulation area (Figure 3). As this process proceeds, the grove assumes various forms: Growing to leeward, the development of root suckers is successful only at the periphery of the accumulation site. This produces two legs extending to the leeward of the parent grove, resulting in an overall horseshoe shape. As the growth to leeward continues, the suckers pass by the accumulation area and come together downwind creating a doughnut shaped grove. I have observed many stages in this process in the Front Range. Although it is only theoretical today, it appears likely that a doughnut shaped grove can move along intact as a unit if the external environment of the stand remains constant.

Lodgepole pine, Engelmann spruce and subalpine fir stands often have accumulation areas in which trees are deformed, stunted and attacked by the black felt fungus (*Herpotrichia nigra*) (Figure 4).

C. Tree islands and snow

In the forest-tundra ecotone of the Front Range, there are plants of genera in which most or all other species are trees but these individuals are more like shrubs (Fig. 5). Some of these plants are prostrate, contorted individuals known as "krummholz;" other individuals have multiple leaders which are "flagged" as a result of winter killing of the branches on the lee side of vertical stems. Still other plants are triangular with a sloping windward face of mostly dead twigs and a leeward face of largely live needles, and stems. All of these abnormal

Figure 4. Old snow sculptured by wind

forms are referred to as tree islands since they occur as individuals or clumps in a matrix of herbaceous vegetation (Figure 5). I have published elsewhere a classification of these plant forms (Marr, 1977b).

An interesting question about tree islands has to do with the control of their form: are they special genotypes, genetically different from the "regular" trees, or are they merely environmentally induced forms? In the Front Range, there are tree islands with close similarities to Engelmann spruce, subalpine fir, limber pine, and bristlecone pine. Wardle (1968) interpreted morphological forms he observed to be special genotypes; Grant and Mitton (1977) found chemical differences indicating genetic differences between tree islands and true trees of Engelmann spruce and subalpine fir.

Further support for the genetic difference hypothesis was found by Clausen (1963a, b) in California. The well-known and acknowledged leader in the growth of Rocky Mountain plants, Harry Swift, reported at the 1980 Revegetation Workshop that he has raised hundreds of trees from seed and none of them had the tree island or krummholz form. I don't have any convincing evidence on either side of the debate. The answer requires more facts than are available today.

The counterpart of the accumulation area is the source area. It is snow-free much of the year because wind removes most of the snow soon after each storm. Limber pine (*Pinus flexilis*) and bristlecone pine (*Pinus aristata*) dominate many of these stressful sites. These hardy trees may blow over but continue life supported by a reduced root system. They may grow in both diameter of the trunk and elongation of the crown while stretched out flat on the ground. These pines lack the genetic

Figure 5. Tree islands after redistribution of snow from recent storm

capacity for tip layering (see under tree islands below) or to survive snow burial.

In my early research on the ecotone on Niwot Ridge in the Front Range, I found tree islands growing in sites where it seemed, from overall observations, impossible that a tree seedling could ever have become established in such a severe site (Marr, 1977a). Further research revealed that these plants have a remarkable capacity to move across the landscape; the islands in severe sites must have come from seedlings that started growth in some more congenial microsite to windward, and then migrated to the present position. Such a mobile individual may continue its movement until it encounters some lethal habitat. I have descriptions of many islands with over 5 m of live branches connected to dead branches which extend to the windward of the current island. There is convincing evidence that one of them has moved over 15 m and is still vigorous.

The mechanism for tree island movement is another illustration of the "snow, wind and vegetation" system. Each island is a complex micro-system. The lee face of an island is composed of live branches and needles. The stems are growing an average of approximately 4 cm per year. At some point in time one of these branches, usually but not always close to the ground, ceases to grow out horizontally; instead, it turns upward in its growth and develops a roughly radial symmetry. Some of the branches develop an independent root system but this is not a requirement for the change in growth habit. This process is known as tip layering.

The windward surface of a tree island is a different environment from the protected leeward face. Strong winter winds kill exposed needles and twigs and eventually break them off. The island survives, however, thanks to the existence of the tip layering process and the protection given by the dead branches. The question of whether the death of needles and twigs is mechanical or physiological has not been answered. Since dead needles often stay in place for months, it may be that they are killed by desiccation, the loss of water while twigs are frozen, and needles and twigs are unable to replace lost water by conduction from the frozen twigs.

The leeward branches at any one time are destined to become windward units as their protective windward branches are killed and blown away. These processes produce a variety of tree island forms (Marr, 1977b). The triangular type illustrates the details of the processes: One result of the layering and branch killing is a movement of the island down-wind (Marr, 1978). This movement could potentially continue indefinitely so long as there is a balance in growth and death of branches. However, some islands are prevented from such persistence by the growth of a fungus in the snow and branches in the lee part of the island. This fungus has the remarkable capacity to grow in a medium of water and ice near the freezing temperature of water. Eventually, the fungus penetrates and kills the needles and twigs. In the absence of live leeward branches, layering ceases and windward killing eventually destroys the island.

A spectacular landscape pattern known as Ribbon Forest occurs in localities where snow deposited in the lee of strips of forest which function as baffles also inhibits the development of trees. This alternation of meadow or snow drift with forest is well illustrated in the Buffalo Pass area of the Park Range in northwestern Colorado and at the head of many Front Range valleys such as Forest Canyon in Rocky Mountain National Park and the Brainard Lake Valley of the Indian Peaks area.

D. Patterns of snow and vegetation in alpine tundra

Alpine tundra stands often form a mosaic pattern controlled largely by the pattern of snow redistribution. The most common source areas are kobresia meadow and cushion plant stands. Several species require some degree of snow cover throughout the cold season. Subtle differences in micro-environment segregate stands dominated by one of the following species: Hairgrass (*Deschampsia caespitosa* , Drummond's juncus (*Juncus drummondii*), Parry's clover (*Trifolium parryi*), Sibbaldia (*Sibbaldia procumbens*), and several species of lichens and mosses.

E. Plants of windy sites

Altitudinal transect of species. It is my impression, from many observations, that the Front Range woody species can be arranged in the following sequence on a gradient of increasing severity of wind from bottom to top:

Ground juniper
Woody cinquefoil
Willows
Bristlecone pine
Limber pine
Engelmann spruce
Subalpine fir
Lodgepole pine
Douglas fir
Ponderosa pine

This species list leads to speculation concerning the environment(s) responsible for the pattern. There are numerous theories concerning this tantalizing question (Wardle, 1968). My theory can be expressed in the following manner:

> Beginning in the foothills, reduction in air temperature with rising altitude results in a progressive increase in tree size up to the upper part of the subalpine forest. At still higher elevations temperature is becoming progressively more adverse to tree growth and trees get smaller and smaller. There is some evidence that air temperature does not ever diminish to a level inadequate for the photosynthetic needs of the tree. Instead, soil temperature is the problem. As the soil remains frozen longer and longer, the tree is unable to replace water lost by transpiration and consequently needles die from desiccation.

V. Conclusions.

I have reviewed a few samples of the abundant processes involving snow, wind, and vegetation. I hope some of this information will be helpful in your revegetation efforts. Regardless of what you do with snow in the Front Range, it tends to cause the landscape to be a patchwork. Perhaps our revegetation work should copy that design more frequently than is commonly practiced.

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THE REVEGETATION OF DISTURBED SITES ALONG THE YUKON RIVER TO PRUDHOE BAY HAUL ROAD

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and

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The construction of the Yukon River-Prudhoe Bay Haul Road provides opportunities for observing plant introductions and revegetation of native species along a continuous route from the Alaskan interior to the Arctic Ocean. Although most disturbed sites in subarctic areas exhibit a mixture of introduced weeds and weedy native species, few introduced weeds have been recorded from the Arctic. Whether this difference is due to the lack of opportunities for introduction (the absence of farming, grazing or continuous avenues for overland transport) or because the Arctic environment is too harsh for the persistence of introduced weeds can be addressed now because the Haul Road overcomes the limitations imposed by lack of opportunity.

For the purposes of this paper weeds are defined as introduced, exotic (non-native) species; the element in the native flora that is aggressive, opportunistic and which colonizes disturbed areas is often referred to as "weedy," to distinguish it from the true weeds.

It was anticipated that the opening of the Haul Road would be followed by the northward migration of weeds from their population foci in interior Alaska. What was not fully expected was that the techniques used in revegetation, i.e., the seeding of bare surfaces with exotic grass seeds and the use of organic mulches, would result in the simultaneous introduction of weeds along the entire length of the Haul Road north of the Yukon River. The project on which my student, Susan Kubanis and I have been working for the past three summers is concerned with documenting the occurrence and persistence of introduced weeds, their phenological development, reproductive success and population dynamics. Concomitantly, data are being collected on the invasion of native species into bare and otherwise disturbed areas along the Haul Road. Based on previous observations, our basic hypothesis is that neither weeds nor introduced grasses will persist in disturbed areas along the road north of the Brooks Range and that persistence of these species south of the Brooks Range will be directly related to latitude.

In 1976, preliminary observations were made during a two week reconnaissance of the Haul Road. By that time extensive seeding of road cuts and fills, source areas of rock and gravel and the like had already occurred, and many exotic weeds were recorded from the Yukon River to the foothills section north of the Brooks Range.

The 1976 observations were made at 11 locations along the road, the first 9 south of--and numbers 10 and 11 north of the Brooks Range. While these sites are too few in number and too scattered to show a clear pattern of persistence or the lack of it, the observations are the longest available. At least ten weed species occurred among the 11 sites, 6 species being the largest number at any single site and at the smallest none. At least one species occurred at 10 of the 11 sites. By 1979, all but two of the 11 sites had fewer weed species than had been the case in 1976 (Figure 1).

NUMBER OF SPECIES PER SITE

Site Numbers	0	1	2	3	4	5	6
1	x o						
2		o	x				
3			x		o		
4	o			x			
5				o	x		
6	o	x					
7				o			x
8	o		x				
9	o					x	
10		o		x			
11	o		x				

x = 1976

o = 1979

FIGURE 1. Occurrence of 10 weed species at 11 sites 1976 (x) and 1979 (o) between the Yukon River and Prudhoe Bay, Alaska.

In 1977, 1,326 permanent square meter plots were established along transects at ninety-eight sites along the Haul Road. In 1977, 1978 and 1979, percent cover was estimated for each species and bare ground in each plot. The collection of these basic data was supplemented by extensive plotless observations on occurrence of native and exotic species, their phenology and persistence. About 64 miles of roadsides and 55 access roads and material sites where weeds were not present in 1977 have been surveyed in successive years so that their presence can be noted as they occur.

When these more systematic and extensive observations began in 1977, fifteen weed species were recorded, only six of which occurred north of the Brooks Range. The numbers changed relatively little in 1978, and increased slightly south of the Brooks Range and relatively significantly north of the Range. (Table 1). These data are summarized from all observations made during 1977-1979. All of these observations represent significant range extensions from previously known geographical ranges. The increase in numbers of weed species in 1979 may not represent new introductions. Seed dormancy or incomplete sampling could account for the changes. Although the repeated occurrence of weeds at the same sites south of the Brooks Range implies successful year to year survival, as yet we have no evidence that this has occurred at any site north of the Brooks Range.

Although the cover of individual species of weeds was very high (approaching 100%) in some plots, the average cover value of all weed species (in plots containing weeds) was less than one percent due to the fact that weeds occurred in fewer than 20 percent of all plots. By 1979, the frequency of weeds in plots had dropped to less than 10 percent, a significant reduction. Average cover, however, did not change significantly during this period. These results are somewhat misleading, however, because the seed dispersal patterns of some of the weeds was such that the plants moved out of the areas of the plots into adjacent areas.

SPECIES	1977 SOB	1977 NOB	1978 SOB	1978 NOB	1979 SOB	1979 NOB
Amsinckia spp			X		X	
Arabis hirsuta					X	
Avena sativa	X					
Brassica juncea	X				X	
Camelina sativa	X					
Capsella bursa-pastoris	X	X	X		X	X
Chenopodium album	X	X	X	X	X	X
Crepis tectorum					X	X
Hordeum vulgare	X	X				
Lepidum densiflorum			X		X	
Lepidium perfoliatum			X	X	X	X
Matricaria inodora	X		X		X	X
Matricaria matricarioides	X		X		X	X
Plagiobothrys cognatus	X	X	X		X	X
Plagiobothrys hirtus	X	X	X		X	X
Polygonum aviculare	X	X	X		X	X
Polygonum convolvulus	X		X	X	X	X
Sisymbrium altissimum	X		X		X	
Thlaspi arvense	X		X	X	X	X
Trifolium hybridum	X		X		X	
TOTALS	15	6	14	4	17	11

TABLE 1. The Occurrence of Weeds North and South of the Brooks Range

NATIVE SPECIES

By 1977, 48 native species had invaded disturbed areas along the Haul Road (Table 2). Most of them (31) are weedy in the sense of Griggs (1934), and are frequent invaders of bare sites throughout the North. Most of the rest (10) are species of mature vegetation and can be expected to persist on disturbed sites. By 1979, eleven of the pioneer species and none of the species of later successional stages had disappeared from the plots. As could be expected significant range extensions were recorded for several of the native weedy species most noteworthy of which were *Corydalis sempervirens*, *Senecio pauperculus*, *Hordeum jubatum* and *Chenopodium capitatum*:

TABLE 2. Native species observed in plots--Haul Road 1977-1979.

SPECIES	1977	1978	1979
Achillea borealis	X	X	X
Achillea sibirica	X	X	X
Arctagrostis latifolia	X	X	X
Arctostaphylos sp.	X	X	X
Astragulus alpinus	X	—	X
Betula glandulosa	X	X	X
Betula nana	X	X	X
Betula papyrifera	X	X	X
Brassica juncea	X	—	—
Calamagrostis canadensis	X	X	X
Carex bigelowii	X	X	X
Carex scirpoidea	X	—	—
Chenopodium capitatum	X	X	X
Cornus canadensis	X	X	—
Corydalis sempervirens	X	X	X
Descurainia sophioides	X	X	X
Draba sp.	X	—	—
Dryas octopetala	X	X	X
Empetrum nigrum	X	X	X
Epilobium angustifolium	X	X	X
Epilobium latifolium	X	X	X
Epilobium palustre	X	X	X
Equisetum arvense	X	X	X

Table 2, continued

SPECIES	1977	1978	1979
Equisetum silvaticum	X	X	X
Erigeron acris	X	X	X
Hieracium triste	X	—	—
Hordeum jubatum	X	X	X
Ledum palustre	X	X	X
Luzula parviflora	X	—	—
Oxytropis maydelliana	—	X	X
Petasites frigidus	X	X	X
Picea spp.	X	X	X
Polygonum alaskanum	X	X	—
Polygonum bistorta	X	X	—
Polygonum viviparum	X	—	—
Populus tremuloides	X	X	X
Potentilla norvegica	X	X	X
Rorippa spp.	X	X	X
Rosa acicularis	X	X	X
Rumex acetosa	X	X	X
Salix spp.	X	X	X
Selaginella sp.	—	X	—
Senecio congestus	X	X	X
Senecio pauperculus	X	—	X
Spiraea beauverdiana	X	X	X
Stellaria sp.	X	X	—

Table 2, continued

SPECIES	1977	1978	1979
Taraxacum sp.	X	X	—
Vaccinium uliginosum	X	X	X
Vaccinium vitis-idea	X	X	X
Wilhelmsia physodes	X	X	X

Average cover for native species, while very low is somewhat higher than is that of the weeds, the average cover value per species lying between one and two percent. Average frequency for this group as a whole is around 30%. Neither the average cover value nor the average frequency of occurrence of the native species changed significantly from 1977-1979. Although we have not yet analyzed these data in general average frequency and cover values north of the Brooks Range are lower than those south of the Range.

INTRODUCED GRASSES

During and after the building of the Haul Road attempts were made by the Alyeska Pipeline Service Company to stabilize bare surfaces by sowing them with mixtures of exotic grass seeds (Brown, et al., 1979). Inasmuch as another investigator is concerned with studying the revegetation of roadside cuts and fills, material sites, pipeline work pads and access roadways, we have included only data on the frequency and cover of this group of species as we encountered them in our plots. No attempt was made to identify separate species.

In 1977, grasses occurred in about 83 percent of all plots, and by 1979 their frequency had increased to slightly more than 90 percent. Concomitantly, the cover of the grasses has declined significantly--from an average of about 6% in 1977 to less than 1% in 1979. Inasmuch as the 10 of the 11 grass species used in various mixtures along the Haul Road are exotic, it is our hypothesis that they will not persist in areas north of the Yukon River.

PHENOLOGY

Temperatures are higher, length of growing season longer and precipitation generally greater south of the Brooks Range than north of the Range (Brown, et al., 1979). One can argue that these differences mean less to the native species in each case than to the introduced weeds, i.e., for each phenological event one would expect that native plants should be more advanced than introduced weeds on a given date. And this difference should be most pronounced north of the Brooks Range where the plant environment is more unlike that of the places from which the weeds were introduced, which we assume to be the Alaskan interior.

Figure 2 illustrates the progress of stages in the life cycle of weeds and native plants in the summer of 1978. By June 30, the beginning of our observations, weeds and native species south of the Brooks Range were showing new vegetative growth. Growth of these species north of the range, however, was not obvious until mid-July. Flowers were seen on both weeds and native species SOB by the end of June, while NOB neither group was in flower until mid-July. Fruits were observed on native species at the beginning of July SOB, but weeds in the same areas did not fruit until the week of July 21-27. North of the Brooks Range native species fruited in late July, but the weeds did not begin to mature fruits until two weeks later. Seed dispersal was observed for native

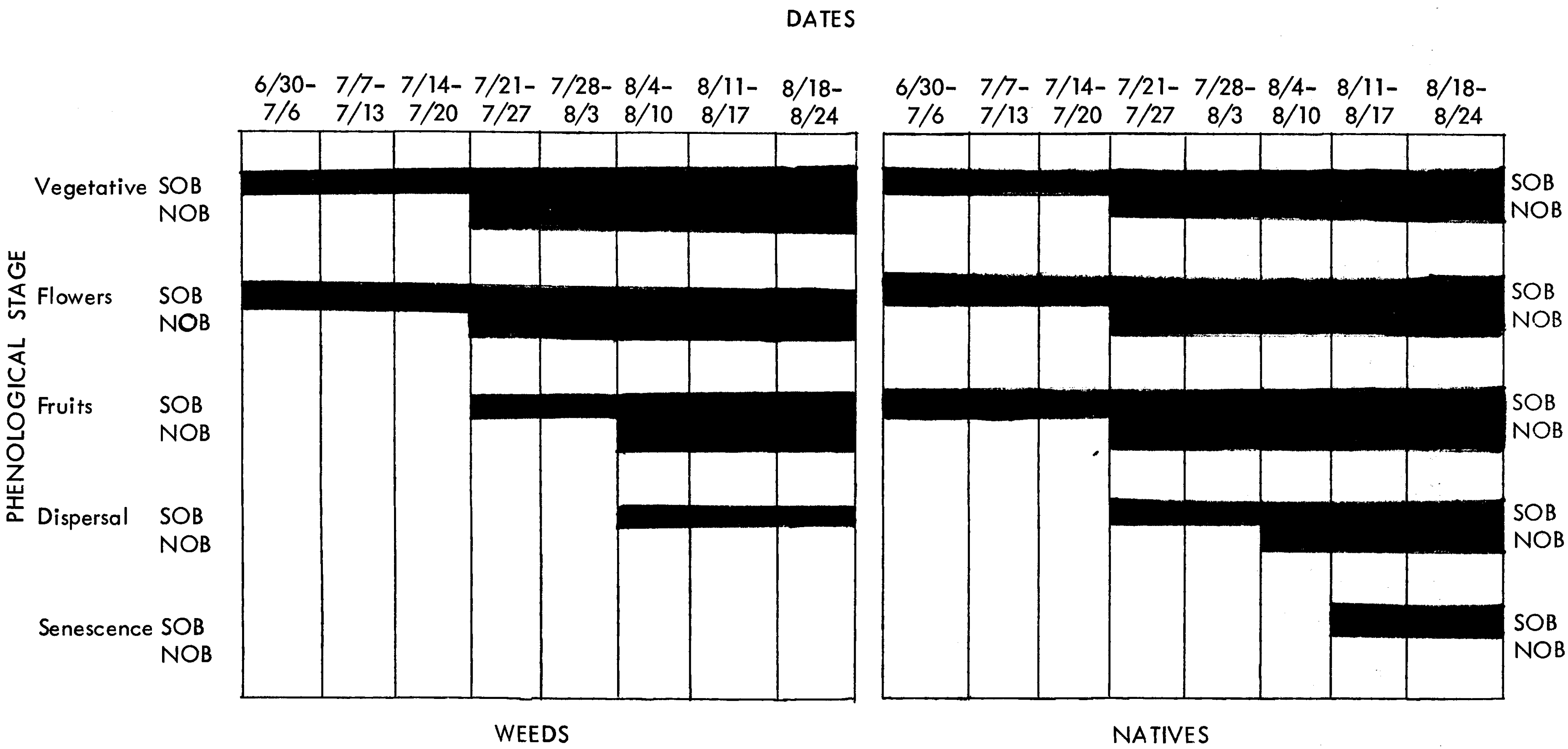

Figure 2. Temporal Range of Phenological Stages of Weeds and Native Species (Summer 1978)

species both NOB and SOB in late July and August, but NOB weeds did not disperse seeds by the beginning of the last week in August in 1978. Our 1979 observations suggest that some weeds did successfully disperse seeds North of the Brooks Range (Table 3). The important point here is that annual species must successfully mature fruits and disperse seeds every year or they do not persist. While the native annual species are able to do this, introduced ones are not adapted to the cooler temperatures north of the Brooks Range.

TABLE 3. Seed Dispersal North and South of the Brooks Range

SPECIES	OBSERVED DISPERSAL 1978 (to 8/18)		1979 (to 8/26)	
WEEDS:	SOB	NOB	SOB	NOB
Capsella bursa-pastoris	X		X	X
Chenopodium album	X		X	X
Crepis tectorum			X	X
Lepidium densiflorum	X		X	
Lepidium perfoliatum	X		X	X
Matricaria inodora	X		X	X
Matricaria matricarioides	X		X	
Plagiobothrys cognatus	X		X	X
Plagiobothrys hirtus	X		X	X
Polygonum aviculare	X		X	X
Polygonum convolvulus	X		X	
Sisymbrium altissimum	X		X	
Thlaspi arvense	X		X	X
NATIVES:				
Achillea borealis	X		X	X
Achillea sibirica	X		X	
Chenopodium capitatum	X	X	X	X
Corydalis sempervirens	X		X	
Descurainia sophioides	X		X	
Epilobium palustre	X	X	X	X

Table 3, continued

SPECIES:	OBSERVED DISPERSAL 1978 (to 8/18)		1979 (to 8/26)	
NATIVES (con't.):	SOB	NOB	SOB	NOB
Erigeron acris	X		X	
Hordeum jubatum	X	X	X	X
Rorippa spp.	X	X	X	X
Senecio congestus	X	X	X	X

SUMMARY

The range of activities associated with the construction of the Yukon River-Prudhoe Bay Haul Road resulted in the introduction of weeds and exotic grasses at many sites along this 577 km. long corridor. It is believed that the majority of weed introductions occurred as contaminants in the grass seed used in revegetation and in the organic mulches spread in many places along the road. In addition, species of native vegetation are invading the disturbed sites. Although several weed species seem to have become established south of the Brooks Range, as yet we have no evidence that introduced weed populations have become established north of the Range. The climatic differences between these areas are probably responsible for the differential success of the weeds. To some extent this conclusion is supported by plant phenological data.

Revegetation by native species and weeds has been slow, and bare ground still accounts for nearly 75 percent of the area of the plots. We expect that the low recovery rate will continue.

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EDAPHIC FACTORS AND THEIR INFLUENCE IN PATTERNS OF TUNDRA REVEGETATION

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INTRODUCTION

Broadly defined, an edaphic factor is a condition or characteristic (physical, chemical or biological) of the soil or other substrate that influences organisms (Hanson, 1962), macro or micro, plant or animal.

Edaphic factors that influence the establishment and patterns of vegetation under natural conditions are the same ones that must be considered in the managed establishment of vegetation whether that be in a cornfield, on a strip mine spoil bank or on an arctic construction pad. Insofar as the soil itself is concerned these factors include (1) texture, the relative proportion of the various primary and secondary separates (mineral grains), (2) structure, the spatial arrangement of the separates, (3) mineralogic composition of the separates. These factors then, singly or in combination, govern other characters such as infiltration rate or more broadly, hydraulic conductivity, moisture retention, thermal conductivity, ease of root penetration or seed germination and the quantity and availability of nutrient or other ions. These and other soil factors together with those that are climatic and biologic determine the composition and distribution of vegetation on a particular landscape (see Bliss, 1962). Once established the vegetation may, in turn, modify the soil characteristics.

In the paragraphs that follow, the intent is to point out some relationships between soil factors and the natural vegetation patterns on well and poorly drained landscapes in the high subarctic and arctic regions of northern Alaska. These relationships provide a basis on which to judge the course of natural revegetation on disturbed or artificially created sites. They serve also to identify soil factors that may require modification before successful revegetation with non-nature species can occur.

WELL DRAINED SOIL LANDSCAPES

In the natural landscape, in which permafrost is a part, coarse textured soils on positive relief elements seasonally thaw to depths of a meter in Alaskan arctic coastal positions and to 2 meters or more south of the Brooks Range. Because such sites are often related to bedrock outcrops or represent high energy depositional features, e.g., kames, outwash terraces or river bars, the soil materials are commonly coarse textured with relatively small quantities of fines (silts and clays). While infiltration rates may be high, moisture retention commonly is low. The exchange complex, linked especially to the clay fraction, and from which or on to which cations may move is small. It is not uncommon for soils on coarse textured, well drained sites to be composed almost entirely of rock fragments or quartz rich sands and gravels. Under the cold temperatures encountered in these soils the chemical and biochemical processes necessary for weathering, release and/or synthesis of nutrients or other compounds may be extremely slow and commonly is incomplete. A soil composed primarily of quartz under these conditions will release few plant nutrients. In many cases exchangeable cations are measureable only in trace amounts. Plant communities developed on such sites commonly form only incomplete covers and may have a number of xeric components. Lichens are also an important element, especially where soil reaction (pH) is below 5.5. Organic production is low in the relatively warm aerobic surface, and its residence time is short.

Other well drained soils such as those associated with alluvial fans have spatially variable and complex morphologies. Some are simply a box-work of rock below a thin surface horizon of fines while others are a mixture of fines (silts) and cobbles or boulders. Finer textured soil surfaces, once stabilized provide an adequate rooting medium, with the fine materials contributing to moisture retention. The quantity of nutrient ions although small is sufficient to meet the needs of pioneering vegetation that commonly includes *Salix alexensis* which may exist in conjunction with a moss understory and legumes. In time this community is replaced possibly in response to a combination of factors including settlement and compaction of the deposit and the build up of permafrost in response to surface insulation provided by mosses. The latter may render root zone temperatures too cold for *S. alexensis*. In this case *S. alexensis* appears to be replaced by other willows and *Dryas*. This community, when removed from subsequent cycles of alluviation, may persist for thousands of years.

These examples of the relationship among edaphic conditions and vegetation distribution provide natural analogs from which we can understand or anticipate the revegetation of naturally disturbed well drained sites or man-created well drained sites. In the latter case it is often necessary to first recontour the materials in order to increase site stability and to establish the most climatically advantageous aspect. Once this is accomplished, effort can be directed toward creating or enhancing the edaphic factors most favorable for the re-establishment of a natural vegetation pattern or a vegetation composed of introduced species, often with soil requirements very different from those of the natural vegetation. This effort might include steps to reduce pH of the materials, which are commonly neutral to alkaline in reaction and thus encourage lichen establishment or, to add silt and/or silt loam materials to the surface, to provide better rooting medium, slow infiltration, increase moisture retention and to increase the number of exchange sites.

POORLY DRAINED SOIL LANDSCAPES

Within the undisturbed natural realm of tundra soils, and many alpine soils as well, the climatically induced conditions of permafrost and site instability assume important roles in governing soil characteristics. The importance of permafrost lies in the fact that it constitutes an impediment to soil drainage, especially in areas where summer thaw is less than 1 meter, in areas of low relief or in fine textured soils. As a consequence, many tundra and alpine soils have very high moisture contents or are waterlogged and strongly anaerobic. The cold temperatures of these soils during the thawed period restrict significant biological, chemical and biochemical processes to the near surface horizons (upper 20 to 35 cm of the profile). The cold, anaerobic conditions so commonly associated with permafrost soils contribute to the accumulation or retention of organic matter. Site instability, which is commonly the product of short term and seasonal freeze-thaw in saturated or nearly saturated soil materials may severely limit the establishment and maintenance of seedlings.

Even on slopes, the fine texture of the soils, in combination possibly with over consolidation created during the process of ice segregation and thaw, combine to produce saturated soils and favor the accumulation of significant amounts of organic materials. Complex and little understood processes in these soils produce frost boils (or spot medallions) that contribute to the enmixture of organic materials into subsurface horizons. Depending upon the site, frost boils constitute from a few percent to 50% or more of the surface (Johnson *et al*, 1966; Muc and Bliss, 1977) and may affect up to 80% of it (Parkinson, 1978).

Thus a highly complex pattern of soils and vegetation may develop. In the foothills region north of the Brooks Range, *Eriophorum vaginatum*, tussock tundra, develops in which a major component of the vegetation is non-rooted. In the more moderate summer climate south of the Brooks Range black spruce is a common associate of the tussocks or is the dominant vegetation. In the coastal plain area north of the foothills seasonal thaw is generally less than 50 cm and wet sedge meadow dominates. It commonly forms an association with the more xeric plants that occur on the warmer, somewhat better drained rims of the ubiquitous low centered polygons. Soil drainage either on the macro or micro scale appears to be a dominant factor controlling the pattern of vegetation (Webber, 1978). The quantity and distribution of nutrients, at least the cations, does not appear to be a governing factor. Most nutrients suffice for plant needs (as we know them) and generally exceed in abundance the plant's uptake rate (Wielgolaski *et al*, 1975).

Exceptions to this are of course nitrogen and phosphorus. The availability of both elements is severely limited because they are to a large extent tied up in the organic fraction of the soil. This unavailable pool may be of considerable size as a result of slow decomposition rates. Microbial mineralization is severely limited in cold, wet soils and perhaps does not occur at all in some of the wet tundra regions north of the foothills. Phosphorus is also made available through microbial mineralization. In addition the element has a strong affinity to form insoluble compounds with iron and aluminum, both of which are abundant in wet soils. Ongoing research in natural tundra situations by Chapin et al. (1975; 1979) Chapin (1978); P.C. Miller (pers. comm.) suggests that the pattern of rooted tundra vegetation is in adjustment with the available nutrient supply, nitrogen and phosphorus included. This is not to say that a significant response to fertilization (N,P,K) does not occur and result in increased biomass production, flowering and/or tillering or that in time it might not produce changes in the composition of plant communities to which it is applied.

Within the tussock tundra, frost scars represent potential sites for natural revegetation, and have figured prominently in scenarios of tundra vegetation dynamics (Hopkins and Sigafoos, 1951; Johnson et al., 1966; F.S. Chapin III and P.C. Miller, personal comm.). From the standpoint of soils they represent C horizons; that is they are composed of mineral materials showing little evidence of weathering. They are generally low in organic materials although smears, entrapments and enmixtures may be common locally, and weak soil structure can be recognized. The near-surface layers may have a subangular blocky or granular structure during dry periods. Deeper layers have a platy structure induced by ice segregation during freeze up. The entire soil body processes thixotropic qualities in that it may become partly liquified under transitory stress. In some years frost scars may undergo intense heaving, commonly accompanied by the development of needle ice which dislodges young plants. At melt the surface may puddle and upon drying, a crust forms.

Frost scars often represent points of lowered acidity within a generally acid tundra which in addition to increased nutrient availability and warmer soil temperatures (Chapin et al., 1979) make them good sites for seedling establishment. During periods of minimal frost heaving and needle ice development, which may extend over a period of years, the scar surface can become covered with algae and/or seedlings. The vegetation tends to increase site stability and add organic matter.

Soils between frost scars consist of variable thickness or organic materials overlying fine textured mineral soils similar in most respects to the frost scar. They are usually more intensely gleyed reflecting very poor aeration and the presence of reduced iron. The roots of most plants extend only to or slightly below the boundary between the organic and mineral. Oxygenated water moves along this boundary and the organic materials just above it are moderately to highly decomposed and possess a relatively high cation exchange capacity. Bases are supplied by the mineral substrate. Water movement within the mineral subhorizons is very slow and may be at the molecular level. Certain plants such as Eriophorum vaginatum are well adapted to soils with very low oxygen levels. Their roots extend throughout the soil by virtue of aerenchymus tissue and follow the receding seasonal frost down to permafrost. This plant and some others similarly adapted can tap a much larger nutrient pool than plants whose roots are restricted to the aerated near surface. Most if not all of the high croma mottles (oxidized iron) in the mineral sublayers are associated with living or pre-existing roots. The overlying organic horizons by virtue of their high porosities (depending upon the state of decomposition) contain large volumes of water. However, nutrient concentrations and pH are low. Much of the organic material is composed of various mosses, but especially *Sphagnum*, which gain nutrients through air infall and are essentially independent of the mineral soil.

The flat Arctic Coastal Plain is dominated by organic soils or mineral soils with thick organic horizons (Everett and Parkinson, 1977). Over extensive areas the soils are closely related to elements of micro-relief, especially polygonal forms. Soils of wet polygon centers and those of other low areas are composed of partly to little decomposed vegetation such as *Carex* spp. and other water-tolerant plants. The slight elevation (0.5 m) above the general wet surface provided by polygon rims permits drainage, accompanied by biological oxidation as a result of increased soil aeration. The polygon rims then become sites for a variety of plants requiring better drainage, e.g. *Dryas*. Thus an association of soils and vegetation repeats over and over across large areas, Walker *et al*. (in press). Frost scars are much less common on the coastal plain and with the exception of drained lake basins there is little opportunity to study natural revegetation.

It is possible however, to study some trends in natural revegetation in areas where lightning-induced tundra fires have occurred. Changes in soil characteristics as a result of such fires are ambiguous. It is equally uncertain that the changes that are documented have been important in the course of revegetation. Fire, depending upon its intensity removes variable amounts of the organic horizon of soils, i.e., materials below the base of the living vegetation which is consumed. In some cases this may reach 10 to 20 cm (Racine, in prep.; Hall *et al*., 1978). Removal of the material reduces the water storage capacity of the area. The darkened surface may contribute to increased soil temperature (Scotter, 1971) and possibly an increase in microbial activity. Some amount of depression of the permafrost table, i.e., thickening of the active layer, is noted in conjunction with most tundra fires (Racine, in prep.; Hall *et al*., 1978; Wein and Shilts, 1976). In a few cases significant thermokarst has occurred. Most studies in tundra burns have shown an increase in cations, especially calcium and potassium, and in pH. These changes in soil chemical factors appear to be confined to the near-surface soil horizons or layers. It is possible, but not demonstrated, that *Marchantia* which comes in abundantly on many burn sites (as well as fertilized revegetation sites on organic materials) is related to the nutrient release.

Man-induced changes in the characteristics of wet tundra soils commonly involve burial of the vegetation and soils beneath gravel, which results in the production of a coarse textured, well drained substrate where none existed before. The surrounding vegetation community is normally poorly stocked with species capable of exploiting such a site, and in many situations may lack them altogether. Should the gravel addition obstruct surface drainage, ponding results and soils which formerly had limited drainage in near-surface horizons may become anaerobic and in some cases more deeply thawed with an accompanying shift in vegetation. In areas where organic near-surface horizons have been removed and piled, or spread on other surfaces, their drainage and accompanying oxidation may result in a significant loss of nutrients (VanCleve, 1977), a loss of structure, and a decrease in wettability and moisture retention. These factors together with an increased susceptibility to wind erosion and snow abrasion make for an extremely poor seed bed.

Outright removal of the organic surface soil in ice rich, poorly drained tundra results in subsidence proportional to the ice content. Where slope is absent and ponding occurs, soil factors may cease to be a control on the course of revegetation. Where ponding does not occur slump and the transfer of mineral soil and especially the organic surface horizons and their vegetation may, together with vegetative invasion from the surrounding tundra effect the revegetation of the area. The concentration of soil nutrients in such areas probably by surface runoff is also important in establishing a luxuriant growth. This effect was noted by Challinor and Gersper (1975) in vehicle track depressions in the Barrow tundra and observed in undisturbed tundra by Bilgin (1975).

In summary it would appear then that throughout the tundra, soil moisture as it is a function of drainage is the single most important soil factor governing the pattern of natural vegetation and revegetation even in areas where all soils are at or near saturation. The natural vegetation appears to be in adjustment with soil factors. In sites disturbed by man, unnatural revegetation, i.e., the introduction of non-native species usually requires significant alteration of edaphic factors, such as texture, organic matter content and soil nutrients to permit its establishment. And continued application of amendments to maintain it. Ultimately it will be a return to natural soil moisture conditions that will permit a re-establishment of natural species.

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VEGETATION SUCCESSION AND RECOVERY OF OLD OIL WELLS ON THE ALASKAN NORTH SLOPE

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INTRODUCTION

The National Petroleum Reserve - Alaska (NPRA), which covers a large part of the Alaskan North Slope (Fig. 1), was created in 1923 as the Naval Petroleum Reserve No. 4; later it was redesignated and transferred to the Department of Interior (U.S. Navy, 1977). Approximately 36 test wells have been drilled on the North Slope between 1944 and 1953 during the early exploration program (Reed, 1958). The exploration work was reinitiated in 1974 (Fig. 2)

These test well sites may be viewed as long-term experiments in rates and directions of natural recovery of arctic tundra ecosystems. After the initial disturbances, they had not been subject to additional human impact (Brown, 1978). The study of the recovery on these old wells creates a new dimension in vegetation succession studies in the Arctic; although there have been a number of arctic succession studies, none of them were time controlled.

The studies of vegetation and ecosystem recovery at old oil test wells can generate recommendations for the manipulation of revegetation and vegetation recovery at the recent, limited tundra disturbances and test well sites. The conclusions reached at the old test well sites are applicable for the recent sites, although the differences in construction between the old and new test wells have to be taken into account. For example, the Teshekpuk Test Well site on the Arctic Coastal Plain (Fig. 3) exemplifies some of the recent problems: the drill pad, which is five feet high and constructed from local sand, prevents melting of the underlying permafrost, but also cuts off the

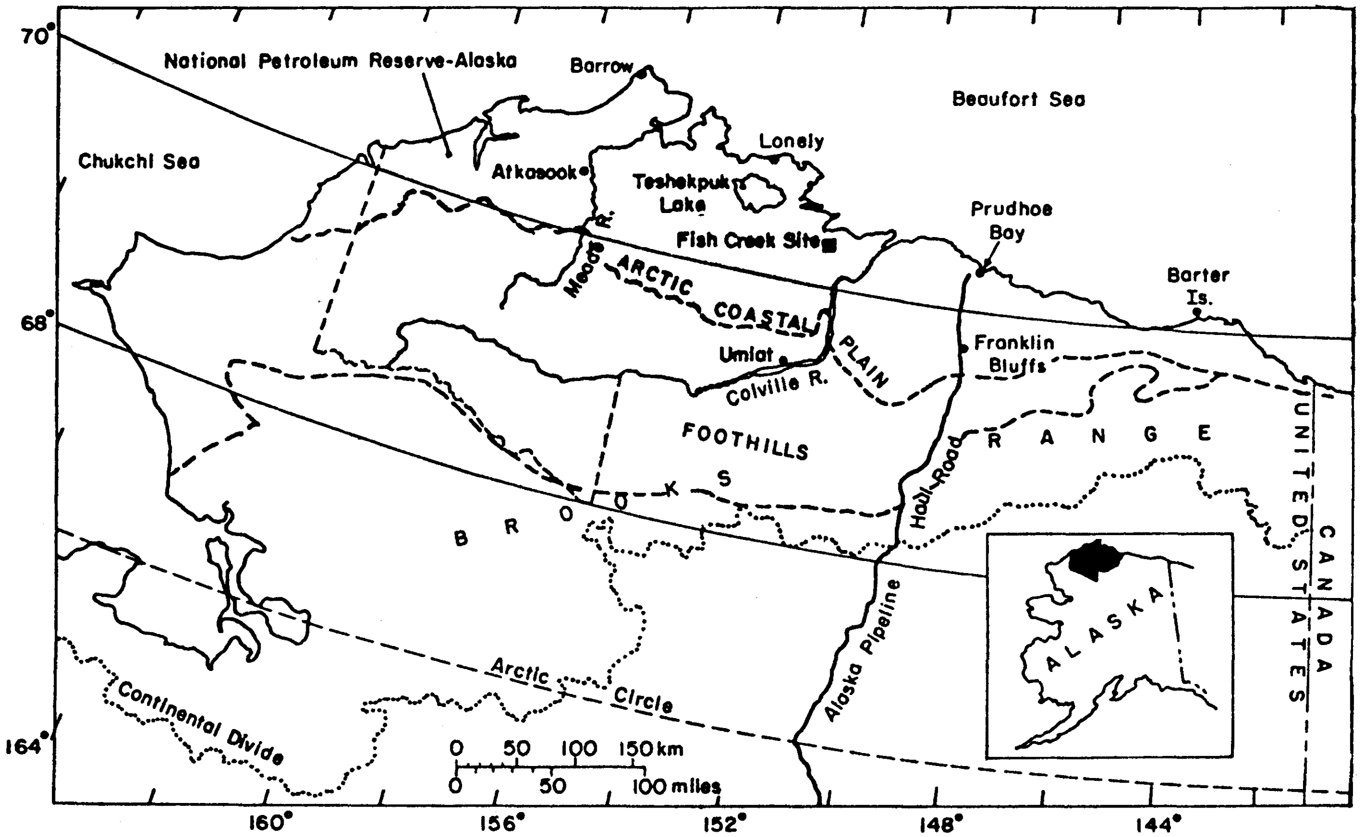


Figure 1: Location map of NPRA and the Fish Creek site. The boundaries of the Arctic Coastal Plain and Foothills Provinces (Wahrhaftig, 1965) are shown. From Lawson et al. (1978).

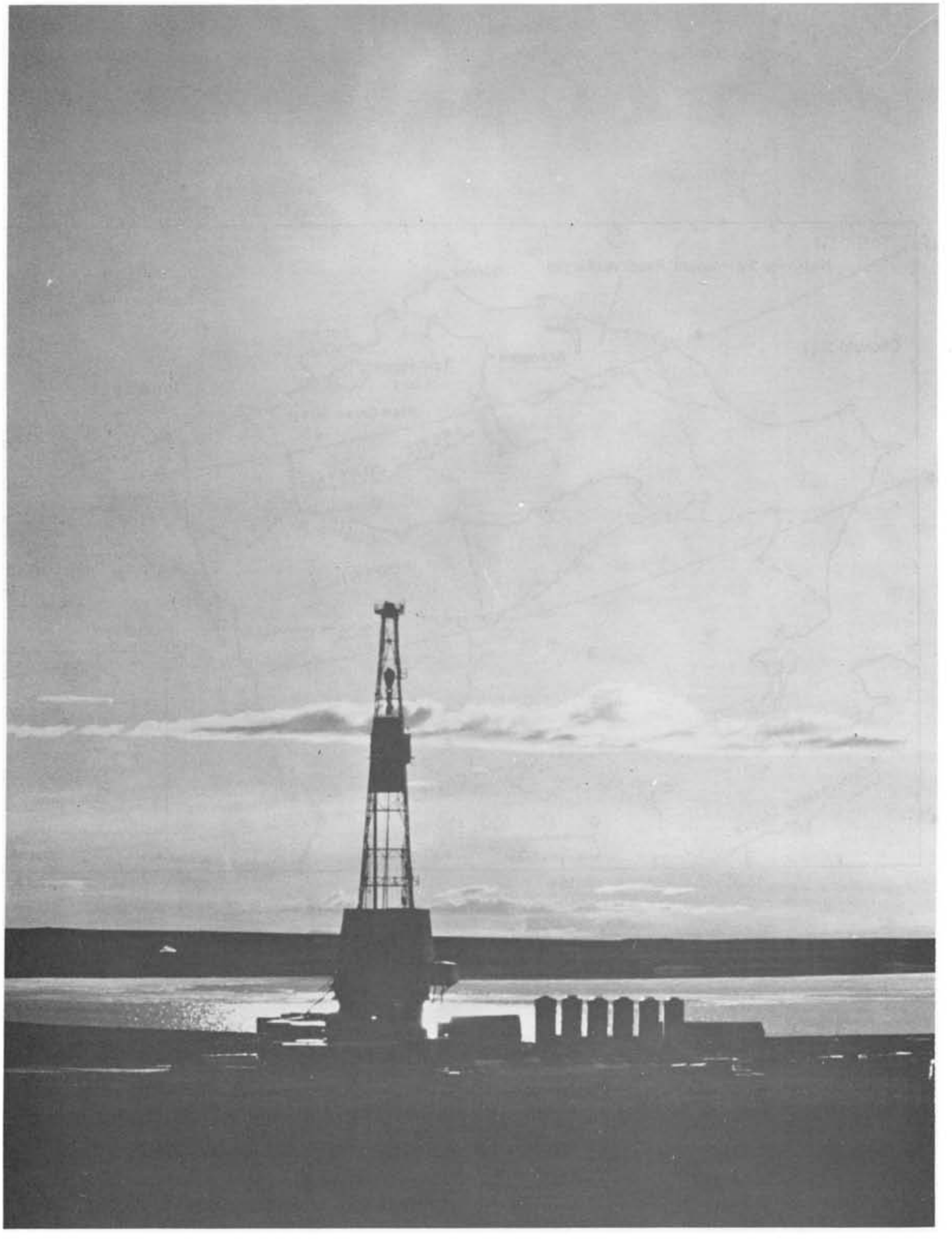


Figure 2: The National Petroleum Reserve - Alaska has been explored for oil and gas between 1944 and 1953 and again since 1974. The Inigok Test Well (pictured) on the Arctic Coastal Plain was drilled in 1978 and all equipment was removed shortly thereafter.

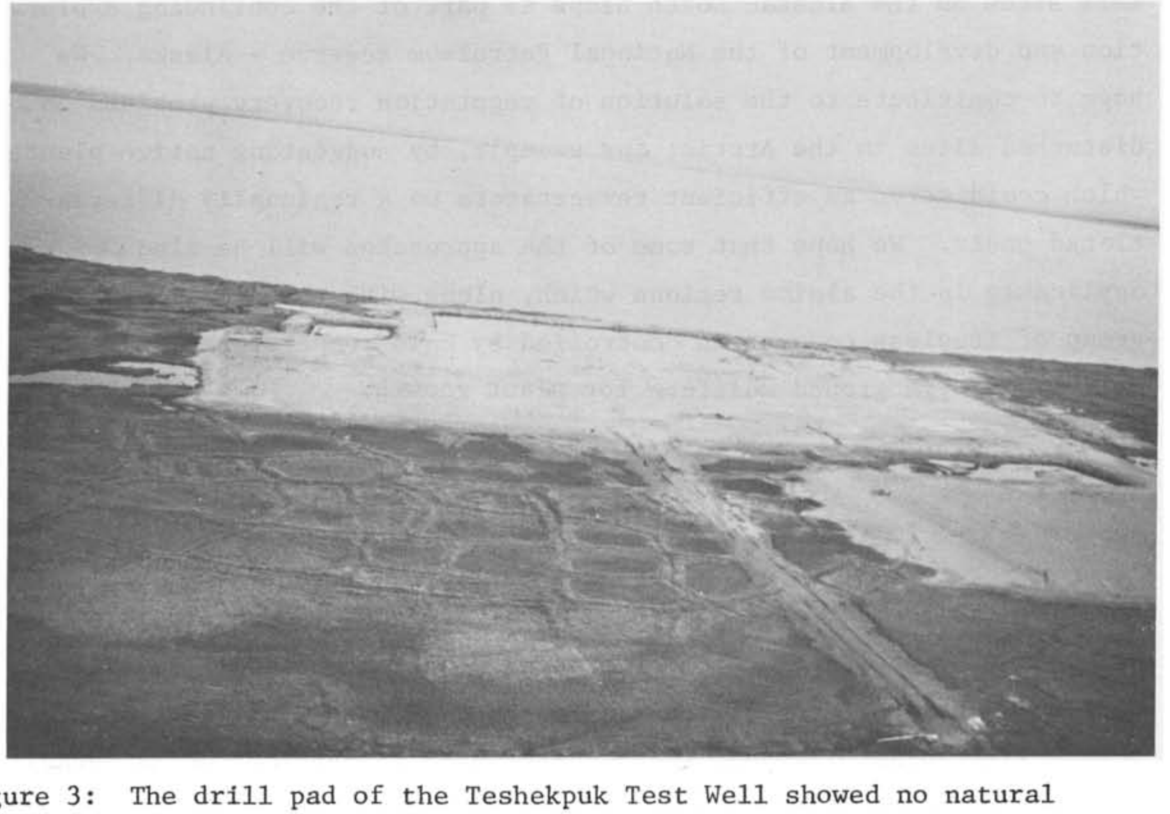


Figure 3: The drill pad of the Teshekpuk Test Well showed no natural revegetation in 1977, two years after abandonment.

supply of ground moisture to the potential revegetators on the surface. This problem can probably be solved by levelling the pad.

Most of the drill pad and other disturbed surfaces remain bare of vegetation at the Inigok Test Well one year after the site abandonment and after the sand and gravel surface of the site has been artificially revegetated (Fig. 4). Germination and growth occur only in places with sufficient moisture; the endurance of the germinating non-native grasses may be very short.

Since 1977, the Plant Ecology Laboratory of the Institute of Arctic and Alpine Research, University of Colorado, has been conducting investigations of natural revegetation and vegetation recovery of the old test well sites on the Alaskan North Slope as part of the continuing exploration and development of the National Petroleum Reserve - Alaska. We hope to contribute to the solution of vegetation recovery problems on disturbed sites in the Arctic; for example, by suggesting native plants which could serve as efficient revegetators on a regionally differentiated basis. We hope that some of the approaches will be also applicable in the alpine regions which, along with the Arctic, form a group of treeless ecosystems controlled by cold temperatures and relatively high ground moisture for plant growth.

ALASKAN NORTH SLOPE

The environment of individual locations on the North Slope is determined by the interaction of several slope-wide gradients. The physiographic provinces of the Alaskan North Slope (Warhaftig, 1965) form a latitudinal sequence which corresponds to the latitudinal gradient of decreasing temperature and increasing severity of climate towards the north. Elevation above the sea level increases gradually towards the south and the Brooks Range; possibly, an east-west gradient of increasing oceanity also exists.

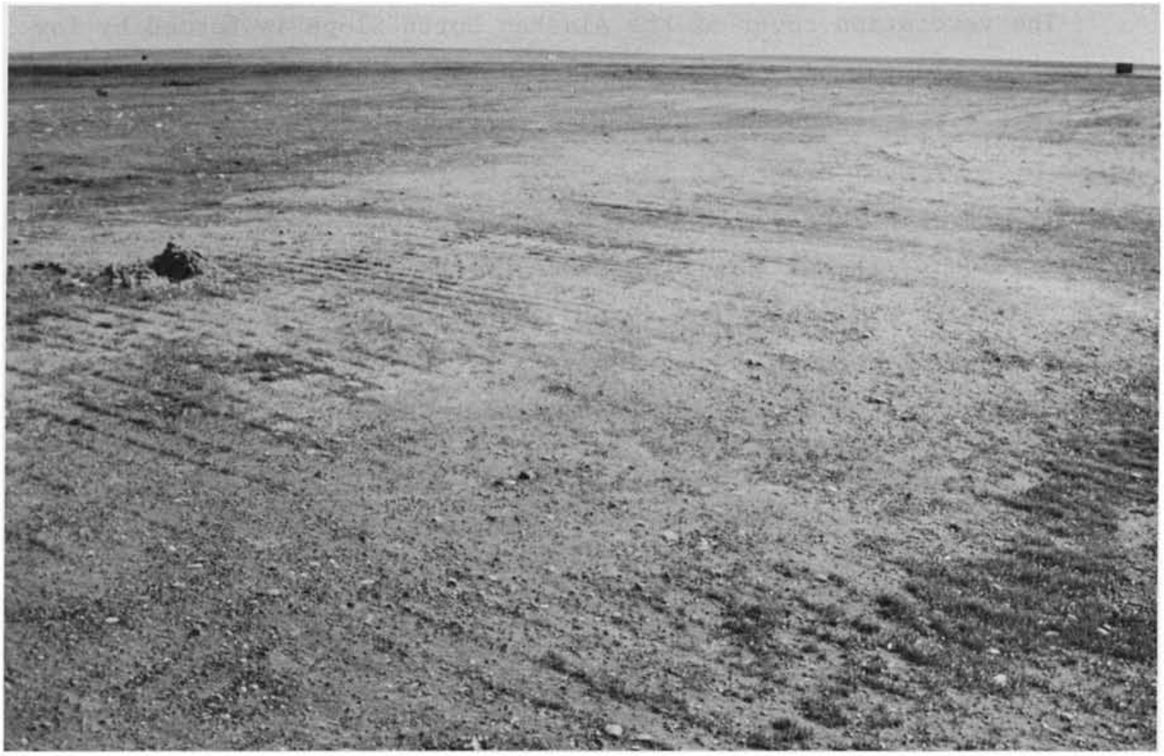


Figure 4: The surface of the Inigok Test Well drill pad in 1979 after experiments with revegetation using a non-native grass seed mixture. Only moist sites show noticeable germination and growth.

The Arctic Coastal Plain is characterized by a high amount of ground moisture; below the shallow surface layer which thaws during the summer lies permanently frozen ground (permafrost). The top soil layer is usually peaty or has a high content of organic matter and insulates the permafrost; Brown et al. (1969) emphasized that elimination or reduction of plant growth will result in increased thaw. When the organic layer is removed, rapid thawing results in the development of water-filled depressions or thermokarst, subsidence, and severe erosion on slopes (e.g., Rickard and Brown, 1974).

The Foothills represent a topographical, elevational, and environmental transition between the Arctic Coastal Plan and the rugged Brooks Range, which has an alpine, continental climate environment.

The vegetation cover of the Alaskan North Slope is formed by low herbaceous plants; bryophytes and lichens and generally low-growing shrubs (e.g., Salix pulchra Cham.) dominate in localized habitats. A large area of mesic surfaces is covered by tussocks of Eriophorum vaginatum L. ssp. spissum (Fern.) Hultén, lowland marshes are dominated by Carex aquatilis Wg. ssp. stans (Drejer) Hultén, and elevated ridges by communities of lichens and dwarf shrubs. Except for small areas on the coast which belong to the high arctic tundra subzone, the Alaskan North Slope belongs to the low arctic tundra subzone of Alexandrova (1970).

APPROACH TO STUDIES OF VEGETATION RECOVERY

Several old test wells and other dated disturbed sites have been investigated on the Alaskan North Slope (Fig. 5). A synthesis of results from all sites should lead to a treatment of natural revegetation, succession, and vegetation recovery on a regional basis and to the development of predictive models of recovery across the North Slope. These should form a basis for a protocol for management and development of the Alaskan arctic tundra.

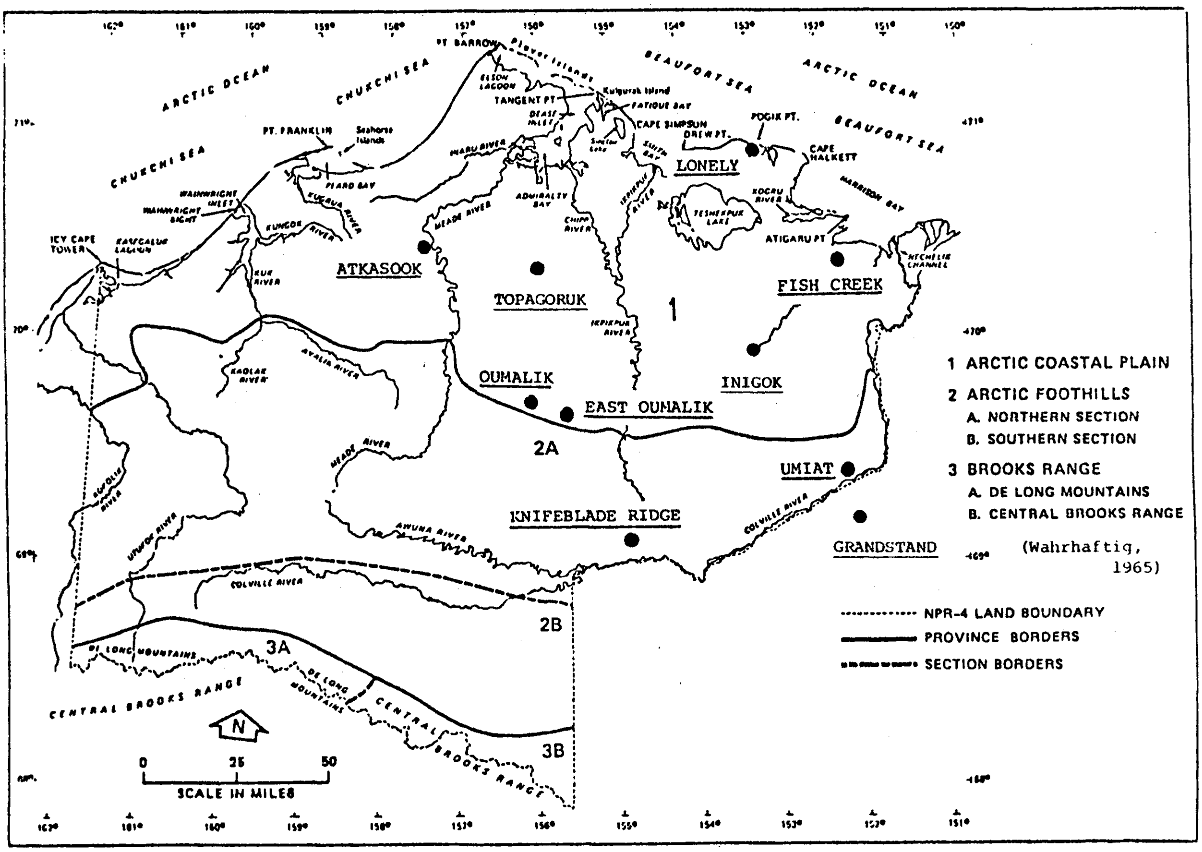


Figure 5: Location map of the test well sites and other disturbed sites which we have been investigating since 1977. The NPRA boundary and the principal physiographic provinces (Wahrhaftig, 1965) are shown. The names of investigated sites are underlined.

Permanent plots at various old test wells are being established, and the plots are being analyzed for vegetation composition. Because the test wells are of similar age, it will be possible to compare the composition of recovering communities in comparable habitats at various sites.

Permanent plots established at recently disturbed sites and in equivalent habitats in undisturbed vegetation will serve as a basis for long-term monitoring of vegetation succession and environmental change.

Our other current studies at the old oil test well sites include correlation of compositional variation of recovering communities to the environmental variation within and between the individual test wells, investigations of the role of protection in the growth of shrubby willows, and the analysis of the causes of more vigorous growth of shrubby willows on disturbed sites than in the surrounding tundra (J.J. Ebersole, in prep.), and monitoring of natural revegetation of new surfaces created by the removal of solid waste by Husky Oil NPR Operations, Inc., Anchorage, Alaska, during the cleanup operations in NPRA.

RESULTS

The investigated, approximately 30-year old test well sites include: Fish Creek No. 1, Topagoruk No. 1, Oumalik, East Oumalik, and Grandstand; other investigated old disturbed sites include: Alligator Road at Umiat, trails and runways at Lonely and Knifeblade Ridge, and a coal mine at Atkasook (Fig. 5).

On the Arctic Ocean Coast, e.g. at Lonely or at Cape Simpson (Fig. 6), the recovering vegetation is dominated mainly by bryophytes and sedges.

The status of the Fish Creek Test Well No. 1 site, located on the Arctic Coastal Plain, was reviewed by an interdisciplinary team in 1977, 28 years after the original disturbance (Lawson et al., 1978). At this site, the surface organic soil layer had been removed (Fig. 7) which triggered possibly still continuing ground subsidence, thermokarst, and

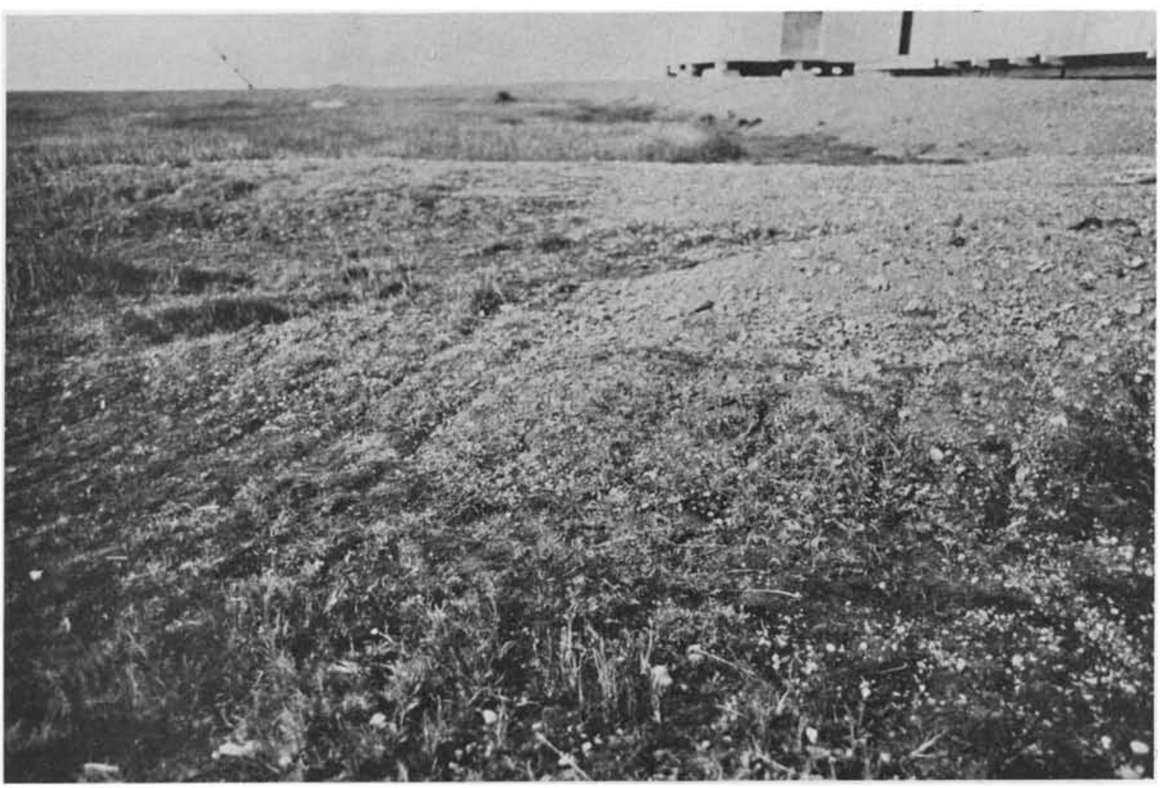


Figure 6: Recent (pictured) and old disturbed sites at Cape Simpson on the Beaufort Sea coast are being naturally revegetated by bryophytes, grasses, and sedges.

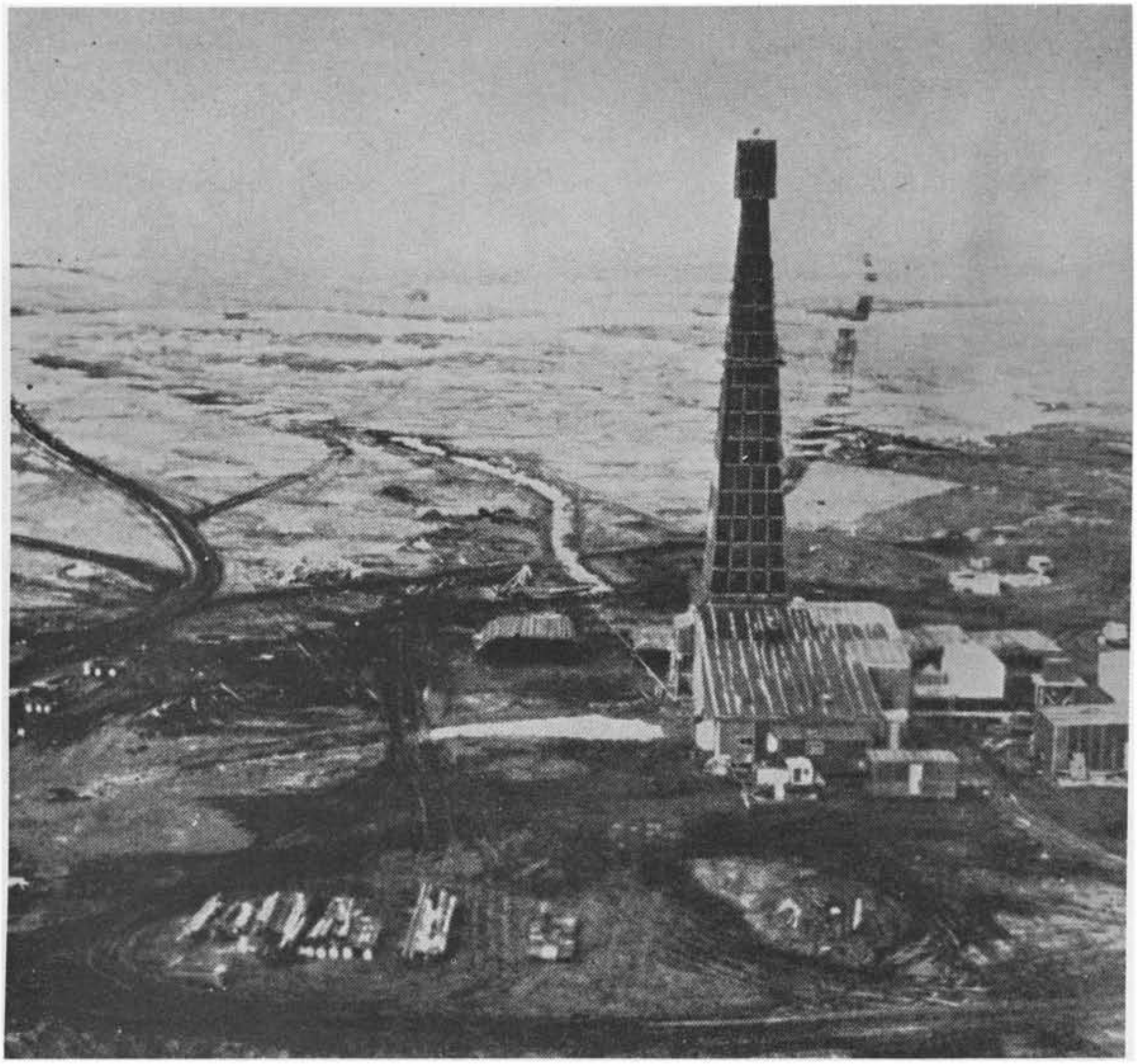


Figure 7: The Fish Creek Test Well No. 1 in 1949. The surface organic soil layer has been removed and much of the surface has been bulldozed. (Photograph provided by U.S. Navy.)

thermal erosion (Fig. 8; Lawson and Brown, 1978a, b). Bare mineral surfaces with adequate moisture were presumably available for colonization at this site following the disturbance. Thirty years after the disturbance, the site is well vegetated; on mesic surfaces, the recovering vegetation is dominated by grasses (Fig. 9) which play only a very minor role in the natural, undisturbed Eriophorum tussock tundra surrounding the site. In the recovering vegetation, shrubby willows (e.g., Salix pulchra Cham.) are infrequent. Only very few sites remain bare after 30 years: both extremes of the moisture gradient, solid waste surfaces, intensive hydrocarbon spill sites, and eroded surfaces (Fig. 10; Komarkova and Webber, 1978).

Very similar site conditions and recovering vegetation exist at the Topagoruk Test Well No. 1 from the same drilling period; this test well is also located on the Arctic Coastal Plain.

At warmer locations in the south (e.g., Alligator Road at Umiat, Grandstand and East Oumalik Test Wells), shrubby willows predominate in the recovering vegetation on mesic disturbed surfaces. An example of a mesic disturbed site in the Foothills is East Oumalik (Figs. 11 and 12), Grandstand Test Well site, which is located on a river terrace, is vegetated almost exclusively by shrubby willows (Figs. 13 and 14).

PLANT GROWTH FORMS IN RECOVERING VEGETATION

Along the north-south latitudinal, topographical, and climatic gradient on the North Slope, the relative roles of principal plant growth forms in natural vegetation change; for example, the role of shrubs increases towards the south, while the role of bryophytes generally increases toward the north. Also, the stature of shrubs, principally shrubby willows, in natural communities decreases along the gradient of decreasing temperature; the near-freezing temperatures at the Arctic Ocean coast are probably near the lower physiological limits for these taxa (Clebsch, 1957; Clebsch and Shanks, 1968; Walker et al., in press).

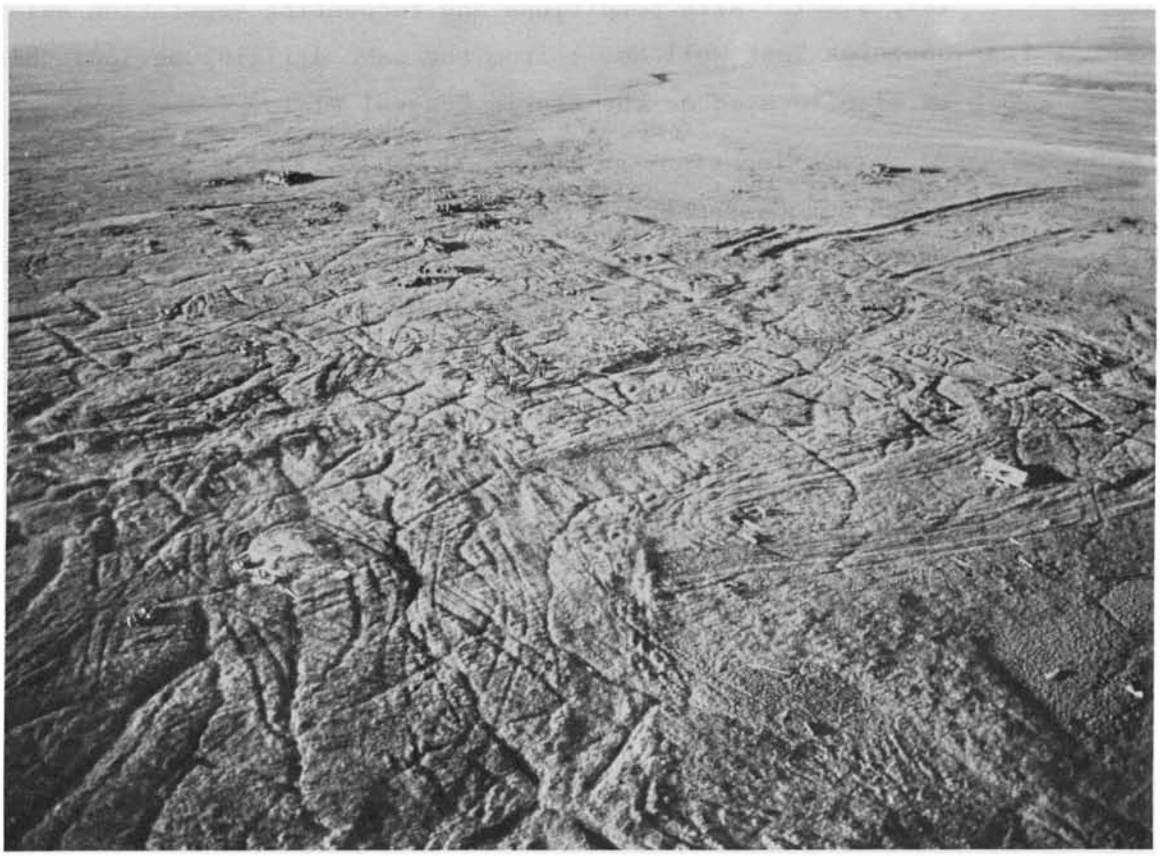


Figure 8: The Fish Creek Test Well No. 1 site on the Arctic Coastal Plain, which was abandoned shortly after the drilling in 1949, during the cleanup in 1979. Thermokarsting in sites of intense surface disturbance is clearly visible. It is uncertain whether thermokarst subsidence is continuing today; at least some ice wedges may be still melting (Lawson and Brown, 1978b).

Figure 9: Recovering regetation and solid waste at the Fish Creek site in 1979. The surface disturbance is almost completely covered by vegetation which is dominated on mesic surfaces by grasses Arctagrostis latifolia (R. Br.) Griseb., A. arundinacea (Trin.) Beal, and Poa arctica R. Br.

Figure 10: Only a very few sites remain bare at Fish Creek after 30 years; for example, this diesel fuel spill on the disturbed surface.

Figure 11: The East Oumalik Test Well in the foothills was drilled and completed in 1950. Greater overall relief and erosion rates and high ground ice content contributed to deep, massive thermokarsting. Thaw is still active 28 years after the initial disturbance (Lawson and Brown, 1978b). This site has been cleaned up in 1979.

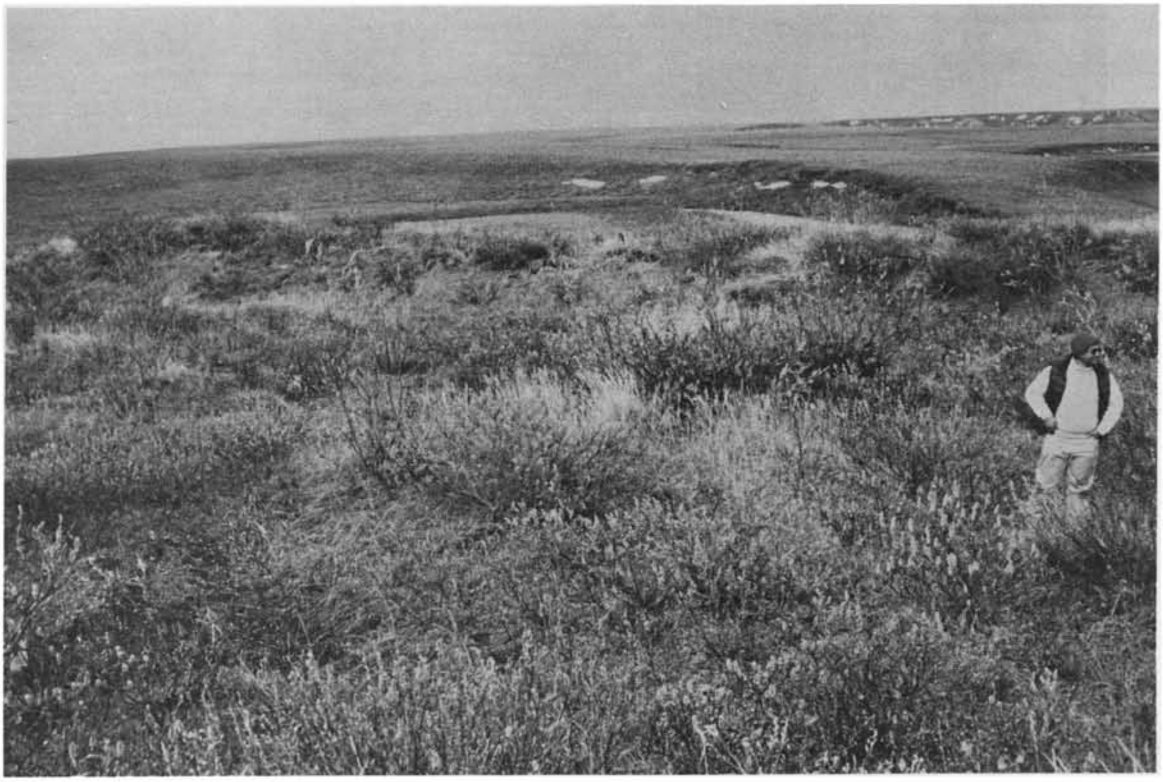


Figure 12: Relatively tall willows, primarily Salix alaxensis (Anderss.) Coville var. alaxensis and S. glauca L. var. glauca grow on the thermokarsted surfaces at the East Oumalik site. The vegetation succession at this site appears to be less advanced than that at the Fish Creek site, where the amount of thermokarsting has been smaller.

Figure 13: The Grandstand Test Well site, which was drilled and abandoned during the first drilling period, during the cleanup in 1979. This is the southernmost site from those investigated. It is located on a terrace of the Chandler River.

Figure 14: Although the natural vegetation of the disturbed river terrace at Grandstand consists only partly of shrubby willows, the recovering vegetation is dominated by Salix alaxensis var. alaxensis.

Parallel gradients, apparently also associated with decreasing temperature and increasing severity of climate towards the north, exist with respect to the role of principal growth forms and the stature of shrubby willows in recovering vegetation at environmentally equivalent, man-disturbed sites of similar age. It appears that some of the native bryophytes, grasses, and shrubby willows, which form only a small percentage of the surrounding natural vegetation, have an advantage over the zonal dominants (sedges and their relatives, dwarf shrubs) in colonization of bare surfaces due to their relatively rapid growth and reproduction.

The changing balance between shrubby willows and grasses along the latitudinal gradient in the recovering vegetation on disturbed sites may be explained by the shifting equilibrium between temperature, precipitation, and the root systems and water economy of these two growth forms (cf. Walter, 1973). At any particular locality where shrubby willows occur, their stature and growth are always considerably greater along streams and on the man-disturbed sites than in the predominant natural vegetation.

It is possible to hypothesize that high nutrient and water availability and low competition from zonal vascular plants enable shrubby willows to capture enough resources to maintain shrubby growth or dominate these environments even under severe arctic climatic conditions. Most probably, with the progress in vegetation recovery with time at these man-disturbed sites, the role of bryophytes, grasses, and shrubby willows in the recovering vegetation, as well as the vigor of the grass and willow growth, will diminish as the availability of nutrients and water decreases along with increasing competition; along streams the disturbance is repeated every year and the conditions favorable for the shrubby willow growth thus maintained.

Tall shrubby willows may persist at the Grandstand site, which is located on a river terrace and where the primary environmental control may be the river rather than the climate.

VEGETATION RECOVERY MODEL

Komárková and Webber (1978) proposed a preliminary model of vegetation recovery after surface disturbance at the Fish Creek Test Well No. 1 site; the model was based on models in Bliss (1970) and Webber and Ives (1978). The intensity of disturbance, amount of ground ice, and site moisture were considered the primary factors influencing the vegetation recovery. Grass-dominated communities, unlike the natural undisturbed vegetation surrounding the site, develop first. Recovery at other disturbed sites at similar latitudes in both North America and Eurasia suggests that on mesic sites with adequate moisture, the recovering vegetation cover is fairly well developed after six years and formed by ruderal native plants which play only a minor role in the undisturbed natural vegetation, and which are characterized by relatively rapid growth and reproduction. After 30 years, the vegetation cover is almost complete, but still formed by the "ruderal" plants; only very few individual plants of taxa which dominate the undisturbed vegetation have been observed in the successional communities at the Fish Creek Site, and there is no sign of replacement of these successional communities by communities resembling the undisturbed vegetation.

Apparently, the development of complex vegetation cover dominated by zonal plants and resembling the undisturbed natural vegetation will take a very long time, probably several thousand years. A climatic change will take place during this recovery time; the succession is thus directional and vegetation different from the original will ultimately develop. Also, the present arctic vegetation may not be in equilibrium with the present climate and represents a relict of a more favorable climate during the mid-Holocene; once disturbed, this present vegetation may be irretrievably lost (Komárková and Webber, 1978; Webber and Ives, 1978).

Models of vegetation recovery after disturbance have to account for complex environmental and vegetation processes and relationships before and after disturbance, as well as for the type, intensity, and frequency of the disturbance. Figure 15 shows some of the environmental changes which have to be considered in succession studies; the new environment and its changes control the direction, rate, and process of succession and vegetation recovery after the disturbance.

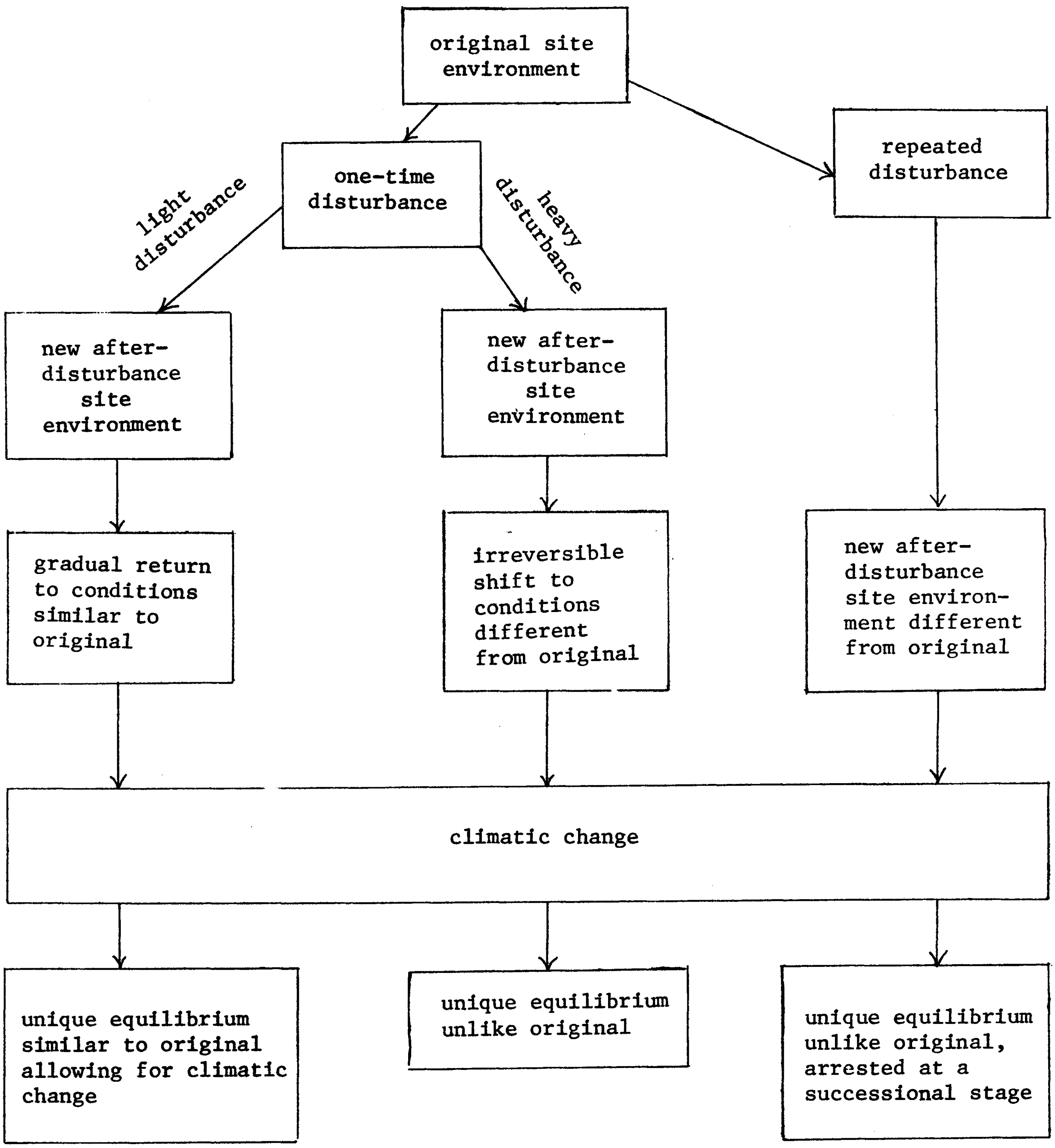
The effects of some of the changes are difficult to isolate. The old test well sites provide an opportunity to study climate-controlled succession on one-time disturbances; the results of studies of succession on sites of repeated disturbances may be more difficult to interpret. It appears that on at least some repeatedly disturbed sites (e.g., in the vicinity of old buildings near the new Atkasook Village; Komárková and Webber, 1980) recovering vegetation persists in the stage of "ruderal" communities due to the repeated disturbance effects. Figure 16 shows the progress of environmental and vegetational changes after a disturbance, based on the diagrams in Komárková and Webber (1978) and Webber et al. (in press).

SUMMARY

Old test oil wells drilled in the National Petroleum Reserve - Alaska on the Alaskan North Slope during the 1944 through 1953 drilling period represent a unique opportunity for time-controlled studies on succession and vegetation recovery on a regional basis. Because the age of these sites is known, the direction, process, and rate of vegetation and ecosystem recovery can be well documented by long-term observations on permanent plots in disturbed and control undisturbed vegetation.

These sites occur across a latitudinal gradient of decreasing temperature and increasing severity of climate from south to north. Along this complex gradient in both undisturbed vegetation and in vegetation recovering from disturbance, the dominance of bryophytes increases and the dominance and stature of shrubs decreases.

Figure 15. Some of the environmental changes with time following a disturbance; these changes determine the outcome of vegetation succession and recovery. Only endpoints of the gradient between light and heavy disturbance are shown.



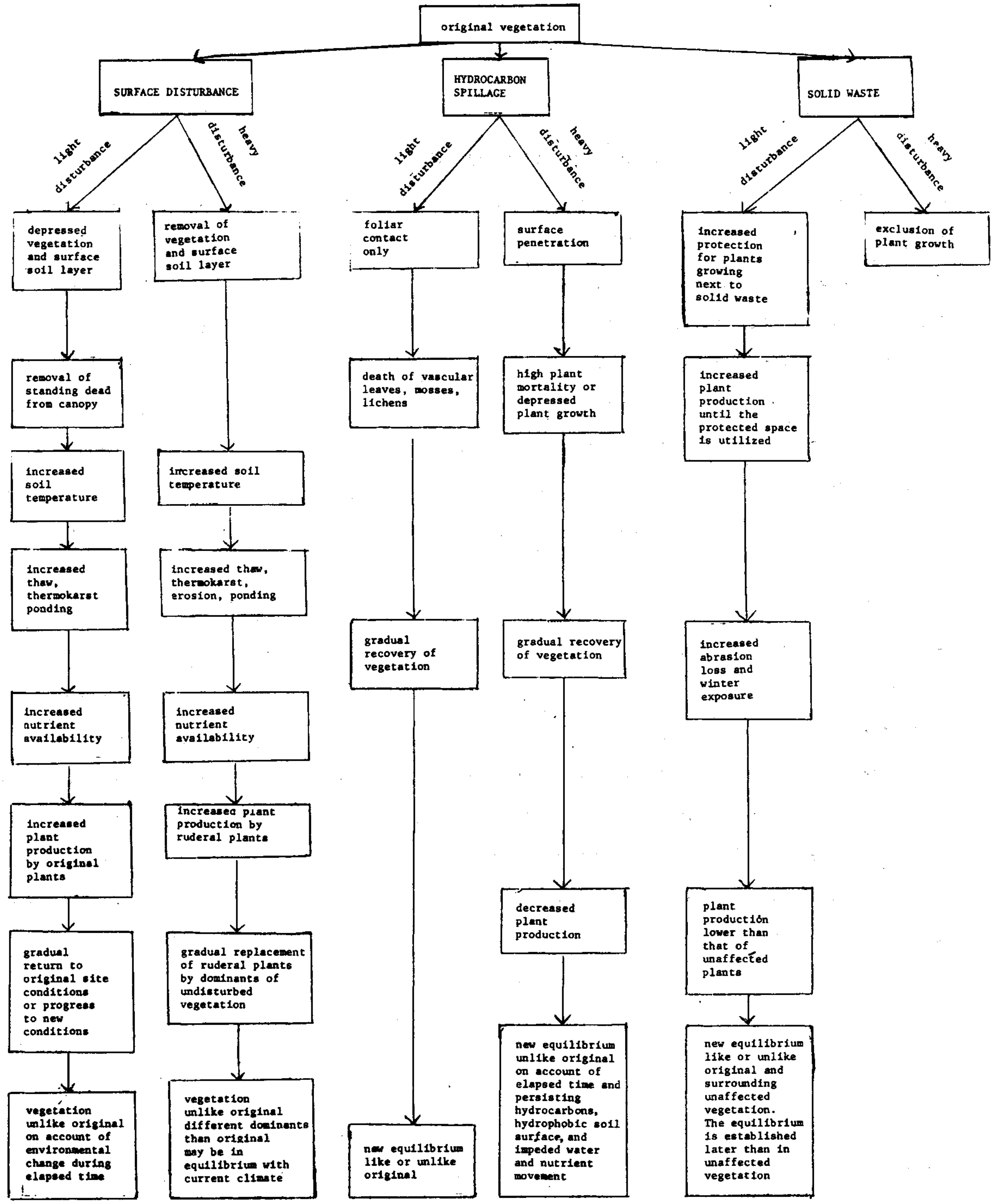


Figure 16. Impact of disturbance with time on mesic tundra at an old test oil well site on the Arctic Coastal Plain. Only endpoints of the gradient between light and heavy disturbance are shown. After Komárková and Webber (1978) and Webber et al. (in press).

Mesic disturbed sites on the Alaskan North Slope show well developed vegetation cover generally six years after the disturbance; 30 years after the disturbance, the vegetation cover is almost complete and formed by "ruderal" plants (predominantly bryophytes, grasses, and shrubby willows) which usually play only a minor role in the undisturbed natural vegetation surrounding the disturbed site. The result of vegetation recovery will be unlike the predisturbance vegetation; the development of complex communities may take several thousand years during which time climatic change will take place. The present vegetation may not be in equilibrium with present climate and may be irretrievably lost if disturbed.

Time-controlled studies of natural succession and vegetation recovery at disturbed sites can provide the basis for a protocol for management and development of the Alaskan arctic tundra. Understanding of natural revegetation and vegetation recovery is particularly important in arctic and alpine regions where standard, artifical revegetation procedures from temperate regions cannot be used on account of low temperatures. The suggested improvement of artificial revegetation in cold regions will include, for example, regional lists of local effective native revegetators.

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PHYSIOLOGY AND LIFE CYCLES OF ARCTIC-ALPINE PLANTS

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INTRODUCTION

Over the past 25 years, a good deal has been learned about arctic and alpine environments, their plant communities and soils that provide mosaic patterns, and the physiology of dominant species. Much of this information is contained in review papers (Billings 1974, Billings and Mooney 1968, Bliss 1962, 1971, Courtin and Mayo 1975, Johnson 1969, Lewis and Callaghan 1975, Tieszen and Wieland 1975) and in recent books that summarize tundra IBP studies (Bliss 1977, Bliss et al. 1980, Tieszen 1978). The objective of this paper is not to further review all of this literature but to discuss plant growth forms and the physiological adaptations of certain species and their potential for success in revegetation.

Arctic and alpine plants are unique in their adaptations to metabolize, grow, and reproduce at low temperatures during a short growing season of 1.5 to 3.5 months. This has resulted in a general "k" selection strategy with very few annuals and short lived perennial species adapted to rapid colonization of disturbed soils. Nearly all species are slow growing, conservative, long lived perennials. In addition, until recently, people have played a rather insignificant role in modifying these landscapes with the consequence, that relatively few weedy species form a part of arctic and alpine floras. The "r" selection strategy of rapid growth, high seed production, and short lived, opportunistic species is very minor.

PLANT GROWTH FORMS AND LIFE CYCLE STRATEGIES

Some of the earliest physiological studies in relation to plant growth form and plant phenology were those of Spomer (1964) for cushion plants, Hadley and Bliss (1964) for graminoids, cushion plants, and dwarf shrubs, and Courtin (1968) for graminoids and cushion plants. These studies within the alpine have been followed by more detailed research of a similar nature in the alpine and the Low and High Arctic during the I.B.P. ecosystem studies.

Cushion and Mat Growth Form

Cushion plants are typical of wind exposed sites with shallow well-drained soils. Representative species include Diapensia lapponica and Loiseleuria procumbens of the New England high mountains, Silene acaulis, Arenaria obtusiloba, Paronychia pulvinata and Trifolium nanum of the Central Rocky Mountain alpine, and Dryas integrifolia and Saxifraga oppositifolia of the High Arctic. These species are characterized by wintergreen or evergreen leaves (Bell 1974, Svoboda 1977), slow growth rates and they are long-lived plants (≃ 50 to 100+ years). The cushion growth form keeps the species within the boundry layer. This results in limited ice and snow cover in winter, reduced effect of wind and abrasion throughout the year, high leaf temperatures, and high leaf resistances to water vapor and CO_2 exchange (Table 1). The result is conservative plants, usually with limited seed germination and seedling establishment capabilities, and low rates of net assimilation.

Table 1. Physiological aspects of cushion plants from alpine and arctic environments. Data are based upon Hadley and Bliss (1965), Bliss (1966), Courtin (1968) for Diapensia and upon Addison, (1977), Mayo et al. (1977), and Svoboda (1977) for Dryas.

Plant form and Physiological aspect	Diapensia	Dryas
Plant age (yr)	20-50+	20-100+
Leaves per shoot per year	5-8	2
Plant production ($g\ m^{-2}$)	75	10-25
Net assimilation (mean rates) ($mg\ CO_2\ g^{-1}h^{-1}$)	1-2	2-3
Carbohydrate reserves	low?	low
Leaf resistance ($sec\ cm^{-1}$)	—	20
Leaf temperature (^{o}C above ambient)		
sun	15	20
shade	8	5

These species are poor candidates for rapid establishment in re-vegetation programs, though in most wind exposed sites with little winter snow cover, they may be the principal species that will survive on a long term basis. Their establishment should be encouraged, though the success rate will be low due to the difficulty of transplanting and seedling survival.

Plants with this growth form are especially well adapted to many areas of the High Arctic (Bliss 1975, 1979a). This is especially true for large areas of polar semi-desert where the soils are well-drained and relatively warm in summer (4 to 7°C at -10cm).

Low Shrubs and Dwarf Shrubs

Plants with this growth form are quite common in low alpine and low arctic environments, but are rare to non-existent in the more severe high altitude and high latitude environments (Bliss 1979a). This group of plants grows where winter snow depth is generally equal to or greater than mean shrub height. These plants are generally conservative in growth and physiological processes. The birch, alder, and willow species are all deciduous leaved, but most of the dwarf or sub-shrubs are evergreen leaved, often growing in acid soils deficient in nutrients (Haag 1974, Bliss 1979b).

Table 2 summarizes growth form and physiological data for shrub species. Although seed production and seed viability may be quite high in the low shrubs (0.5 to 1.5m), seedlings and therefore shrub establishment on bare soil are generally uncommon. As a consequence these species are seldom viewed as pioneering species except the taller Salix species on river gravels and sands. Even here, much of the plant establishment results from stranded sections of sod with rooted shrubs, rather than from seedlings.

Table 2. Physiological aspects of deciduous and evergreen shrubs from alpine and arctic environments. Data are based upon Hadley and Bliss (1964) and Bliss (1966) for alpine species and upon Tieszen and Wieland (1975), Johnson and Tieszen (1976) for arctic species.

Plant form and Physiological aspect	Deciduous shrubs	Evergreen shrubs
Plant age (yr)	20-50?	20-50?
Leaves per shoot per year	10-15	10-15
Net assimilation (maximum rates) ($mg\ CO_2\ g^{-1}h^{-1}$)	35-40	2-14
Leaf resistance ($sec\ cm^{-1}$)	low	high
Carbohydrate reserves	medium	low

Rooting patterns for the dwarf shrub species (heaths) are shallow (≃ 5 to 15 cm) mostly within the peat layer. Roots of the low shrub species, e.g. Salix pulchra, S. glauca, Betula nana are somewhat deeper (20 to 40 cm).

Evergreen shrub species are more conservative than are deciduous species. The former typically grow in soils with a lower pH and therefore lower levels of available ions. The retention of leaves for 2 to 4 yr, even longer in Cassiope tetragona, results in a smaller loss of carbon with leaf fall, generally lower rates of net assimilation, water vapor loss and higher leaf resistances than their deciduous counterparts. These higher leaf resistances, coupled with a thicker cuticle and fewer stomates, result in higher leaf temperatures (Table 2).

Evergreen leaved dwarf shrubs approach the conservativeness of cushion plants in terms of slow growth rates, low levels of carbon loss through leaf and branch fall, and lower rates of net assimilation and transpiration. Deciduous shrub species, by their nature, are not pioneer species in plant succession, and consequently are not ecologically adapted to providing significant cover the first few years. This can be overcome by using rooted shoots, or in some cases only cut shoots inserted into moist soils (Dabbs et al. 1979). Due to their low rates of seed germination (Bliss 1958) evergreen dwarf shrubs have little potential for revegetation. They do however, readily resprout from old shoot bases following fires (Wein and Bliss 1973).

Graminoids-Wet Habitats

Throughout most of the Low Arctic and limited portions of the High Arctic, the graminoid growth form predominates. In alpine environments of North America, graminoids also dominate or co-dominate many landscapes. This group includes species that range from shallow water and wet soils (Arctophila fulva, Dupontia fisheri, Carex aquatilis - C. stans) to those that occupy well-drained soils of wind swept habitats (Carex elynoides, C. nardina). Some species are adapted to late snowmelt sites (Deschampsia caespitosa, Phippsia algida) and others to habitats of moderate snow accumulation (Kobresia bellardii, Carex rupestris, Luzula confusa). Sedges of the Carex bigelowii - C. aquatilis - C. stans complex and Eriophorum vaginatum and E. angustifolium have received the most attention, species of moist to wet habitats.

Carex bigelowii was first studied in the Presidential Range, New Hampshire where it grows in soils kept moist by frequent summer rains and nearly constant fog. The combination of limited soil moisture stress, an upright growth form, lower leaf resistance to gas exchange, and high levels of carbohydrate reserves, result in relatively high assimilation rates and plant growth (Bliss 1966, Courtin 1968, Fonda and Bliss 1966, Hadley and Bliss 1964) (Table 3).

Comparable data have resulted from the studies of Carex stans in the High Arctic at 75°N on Devon Island, and of Dupontia fisheri at Barrow, Alaska; the southern edge of the High Arctic. These data show that wetland sedges and grasses possess rapid spring growth due to large carbohydrate reserves (Allessio and Tieszen, 1979, Muc, 1977). They carry over winter a 5 to 10% biomass of green tissue that has high concentrations of nitrogen, phosphorus and potassium even in early spring (Chapin 1978). Dupontia fisheri and Carex aquatilis at Barrow and Carex stans on the Truelove Lowland, Devon Island respond to fertilizer additions. These species grow in nutrient deficient soils, are able to use either ammonium or nitrate ions as nitrogen sources and the levels of nitrogen and phosphorus in normal plant tissues are about twice that of temperate region plants. Using a simulated high arctic environment for three growing seasons, four species including Carex stans grew significantly using <40 nutrient level in a Haagland's solution (Baab and Whitfield 1977). The plant cultures with the least phosphrous were more vigorous than those deficient in nitrogen, suggesting that these species are rather well adapted to growing in these phosphorus deficient soils that are generally calcareous.

Table 3. Physiological aspects of graminoids from wet sites in alpine and arctic environments. Data are based upon Bliss (1966), Hadley and Bliss (1964), Courtin (1968) for an alpine sedge, upon Miller et al. (1978), Tieszen (1978), and Webber (1978 for arctic grasses and upon Addison (1977), Mayo et al. (1977) and Muc (1977) for an arctic sedge.

Plant form and Physiological aspect	Dupontia fisheri Arctic	Carex bigelowii Alpine	C. stans Arctic
Shoot age	3-4	?	5-7
Leaves per shoot per year	5-7	4-8	2-3
Plant production (g m^{-1})	100-120	200-350	150-225
Net assimilation (maximum rates) (mg CO $g^{-1}h^{-1}$)	17	4	19-22
Carbohydrate reserves	high	high	high
Leaf resistance (sec cm^{-1})	5-24	—	16
Leaf water potential (bars)	-12 to -15	—	-4 to -40
Leaf temperature (°C above ambiant)			
sun	—	0.7	5-10
shade	—	1.2	0-2

Wetland sedges and grasses have a large below ground biomass with belowground production 1 to 3x that aboveground (Muc 1977, Dennis et al. 1978, Webber 1978). In the wet soils at Barrow and in comparable habitats in the Canadian Archipelago, the primary roots of Dupontia, Carex aquatilis - C. stans, and Eriphorum vaginatum have a large diameter and this large surface-to-volume ratio is probably of physiological importance in increasing the effectiveness of nutrient absorption (Chapin 1978).

Dupontia, Carex aquatilis and C. stans possess large rhizomes which function for a number of years and serve as the major mechanism of reproduction. The roots of Carex and Dupontia live for 4 to 8 yr, but those of Eriophorum vaginatum and E. angustifolium only one year (Bliss 1956, Billings et al. 1978). Roots of the two Eriophorum species often grow within 1-2 cm of the permafrost table while those of Carex and Dupontia are not found closer to the permafrost than 3 to 13 cm. Roots of these two species are actively growing in soil temperatures of 3 to 13 cm. Roots of these two species are actively growing in soil temperatures of 3 to 6°C; those of Eriophorum often at temperatures of

1 to 2°C. All of these species are well adapted to cold, wet arctic soils.

Net assimilation rates are generally high in these wet site species (Table 3). As a result they put on considerable amounts of shoot and root-rhizome growth each year. It is estimated that in the last one-third of the season, much of the net assimilate is translocated belowground (Tieszen and Wieland 1975). These graminoids and the other arctic plant growth forms are adapted to carrying on near maximum rates of photosynthesis at temperatures of only 3 to 5°C and to reach light saturation and light compensation at relatively low light levels.

Carbohydrates are maintained at high levels throughout the year. Starches are a small component of the total, with oligosaccharides, important in cold hardiness, comprising a high percentage of the total.

These species, growing in saturated soils, seldom are subjected to water stress. As a consequence, leaf resistance to water vapor and CO_2 fluxes are lower than in upland species. This is exemplified by the high rates of net assimilation and plant growth.

Although seed germination is low in species of this group, plants spread rapidly via rhizomes and tillers once established. As a consequence, these species are ideal for rehabilitating wetlands, provided they can be initially established vegetatively.

Graminoids-Moist to Dry Habitats

Some of the most successful tundra plants are the grasses and sedges of uplands. These include Eriophorum vaginatum and Arctagrostis latifolia of the Low Arctic, Alopecurus alpinus and Luzula confusa of the High Arctic and Kobresia bellardii of the Rocky Mountain alpine.

Kobresia bellardii is a widespread species, found in relatively snow-free habitats in many mountain ranges and some arctic regions. This species, and possibly some of the other narrow-leaved sedges of well-drained soils, has a growth strategy very different from the norm (Bell and Bliss 1979). The species has winter-green leaves, leaves that grow slowly in spring and fall under conditions of frozen soil. Many Front Range plants have an extended growing season and possess winter-green leaves (Bell 1974), but Kobresia has the longest season for morphological development (March - late October).

The partially expanded Kobresia leaves have high concentrations of oligosaccharides over winter and the carbohydrate level of roots changes little in fall and spring. This is in sharp contrast with the large annual cycling of carbohydrates in other alpine and arctic graminoids that have been studied (Fonda and Bliss 1966, Muc 1977, Billings and Shaver 1976). The site of carbohydrate storage also varies significantly; rhizome storage in Carex, rhizome and stem bases in Dupontia, stem bases in Eriophorum and winter-green leaves in Kobresia.

The rates of net assimilation are relatively high in Kobresia and Deschampsia caespitosa. This includes higher rates for these species late in the growing season (Caldwell et al. 1978) in the Colorado alpine than occurred in the arctic graminoids late in the season (Mayo et al. 1977, Tieszen 1978).

Since Kobresia grows in sites that have limited snow cover, one might predict its life history strategy would approach that of the cushion plants, slow and limited growth, high leaf resistances, and reduced rates of net assimilation and water loss. Such is not the case for Kobresia grows rapidly in summer, has high rates of net assimilation and does not develop low leaf water potentials (Bell and Bliss 1979, Caldwell et al. 1978).

Kobresia does not survive in fellfields because of mechanical damage to shoots by sand and snow abrasion and low summer soil water potentials. In snow accumulation sites autumn dieback does not occur due to early snows. The unhardened leaf tissues are then killed by winter freezing and leaf elongation is delayed until snowmelt is complete in late June. Those habitats with little winter snowcover appear optional for Kobresia, permitting it to take advantage of early spring conditions for leaf elongation, although sudden cold periods result in dieback.

Although plants of Kobresia are long-lived (≃ 100+yr) the lack of seed production and seedling establishment prevent its use in revegetation at high elevation sites with limited snow cover. Summers with higher temperatures appear necessary for embryo maturation in this species.

Within the Low Arctic, Arctagrostic latifolia appears to be best adapted, of the native species, for revegetation. This species along with the northern boreal forest species Calamagrostis canadensis have been studied intensively (Younkin 1975) for their potential use in rehabilitating old well sites and other surface disturbances in the Mackenzie Delta Region (Younkin 1976).

Both species occur in native low shrub and cottongrass-dwarf shrub tundras, though the plants are small, provide little cover, and produce little seed. With surface disturbance the soils develop a deeper active layer (10 to 20cm), are warmer (3 to 4°C), and plant growth is greatly accelerated (Table 4). Although growth and flowering are stimulated in both species grown on disturbed soils, the results are more dramatic in the arctic species Arctagrostis latifolia.

Seed germination at 5°C was 98% in Arctagrostis and only 20% in Calamagrostis. Increased temperature had little effect on seed germination of Arctagrostis until the temperature increased to 35°C when the rate dropped to zero. At the same temperature 70% of the Calamagrostis seed germinated, clearly a significant difference in their physiological response to temperature. If soil water potential is increased to -6 bars, there is a significant reduction in seed germination (Younkin 1975).

The results of the germination tests and the plant growth studies show that these two grasses are not well adapted to competing with other species in closed tundra communities. They are truly opportunistic species with an "r" strategy, producing very limited numbers of viable seed from plants with little vigor until warmer soils and higher nutrient levels permit a burst of growth.

Table 4. Ecological comparisons of _Calamagrostis canadensis_ and _Arctagrostis latifolia_ in disturbed soils, Mackenzie Delta (Younkin 1975).

Factor	_Calamagrostis_	_Arctagrostis_
Native Habitat	Imperfectly to moderately well-drained soils	Moderately well-drained soils
Natural Flowering	Seldom flowers	Produces seed
Plant vigor	Small, chlorotic clumps	More vigorous green clumps
Plant cover increase on disturbed soils	30 to 80 times	30 to 70 times
Plant clump height (cm)		
Control	17-25	20-40
Disturbed	30-50	70-80
Flowering in Plants (%)		
Control	10	29
Disturbed	35	86
Seed production per head		
Control	Very few	32±33
Disturbed	50	67±10
Seed germination(%)		
5 to 15°C	20-45	95-98
20 to 35°C	70-85	95-0
Net aboveground production		
Control	4 g m^{-2}	4 g m^{-2}
Disturbed	53±4 g m^{-2}	227±16 g m ^{2}

The growth chamber studies show that both cold soils and low soil fertility significantly reduce shoot and root growth (Table 5). Individually these factors reduced growth 50% but combined, growth was reduced 85% compared with fertilized soils at 15°C (Younkin 1975). The addition of nutrients to cold soils increased root and shoot growth to near that of the controls. Soil fertility had a greater effect on leaf length while soil temperature was more influential on tiller development. The root systems of _Arctagrostis_ were consistently larger than those of _Calamagrostis_.

Table 5. Ecological comparisons of <u>Calamagrostis canadensis</u> and <u>Arctagrostis latifolia</u> in undisturbed and disturbed soils, Mackenzie Delta, and under chamber experimentation (Younkin 1975).

Factor	Calamagrostis		Arctagrostis	
Shoot Nutrient Content (%)	Disturbed	Control	Disturbed	Control
N	2.1	1.1	2.9	1.4
P	0.2	0.1	0.2	0.1
Ca	0.3	0.4	0.4	0.4
Effect cold soils and unfertilized soils on shoot and root production (controls 15°C, fertilized) expressed as % reduction in growth		Shoots		
	Unfertilized	-51 to -65%		-59 to 67%
	Cold soils	-51 to 66%		-48 to -49%
		Roots 0 to 8 cm depth		
	Fertilized	-47 to 49%		-46 to -48%
	Cold soils	-41 to -44%		-11 to 14%
		Roots -8 to -14 cm depth		
	Fertilized	-37 to -50%		-49 to 53%
	Cold soils	-92 to -94%		-84 to -86%

Net assimilation rates were measured down to $10 \mu E\ m^{-2}s^{-1}$. At leaf temperatures of 15°C, net assimilation was suppressed only 25% in <u>Arctagrostis</u> with a drop in soil temperature from 11-12° to 3-4°. This again illustrates the significant adaptation of this species to cold soils.

Of the native flora in this area, these two grasses are best adapted to the microenvironmental changes that accompany soil disturbance: 1) seedling establishment (invasion); and 2) growth and development (colonization). Though other species in the Low Arctic have the potential to respond positively to one or the other of these biological responses, only those species that can do both will successfully meet the criteria for revegetation.

Research is currently underway on the life history strategy and ecophysiology of Alopecurus alpinus by Peter Nosko, Phippsia algida and Puccinellia vaginata by Nancy Grulke in the High Arctic. The first two named species hold the greatest promise for revegetation in these northern most lands but their potential use is highly limited due to the lower soil and air temperatures and shorter growing season at 75 to 80°N.

SUMMARY

From this brief review of plant form and function, it is evident that, as in other more temperate environments, graminoids have the greatest potential for early colonization of disturbed soils. Sedges of the genera Carex and Eriophorum are often well equipped to spread via tillers once established, but their low germination rates and even shortness of seed viability (Wein and Maclean 1973) provide real limits to their extensive use.

Once established the cushion plants and even some of the dwarf and low shrub species of Salix and Betula have distinct morphological and physiological attributes for maintaining themselves. The difficulty again is that of establishment and general slow growth. Hormone induced rooting of Salix shoots in wet to moist soils has real potential.

Many, but not all grasses of upland sites have the best combination of characters. They produce abundant seed with high levels of germination. Seedlings establish rapidly and within 2 to 3 yr are capable of providing considerable cover and seed production especially when fertilized in the Low Arctic. The plants grow rapidly, have high photosynthetic rates, but because of lower resistance to gas exchange, are less well adapted to drier soils. These species are often capable of considerable root growth and relatively high rates of net assimilation at low soil temperatures (2 to 4°C).

The early success of seed mixes with mostly northern agronomic grasses rather than native species, by Alyeska Pipeline, will be of interest to many people. The short term success of similar seed mixes in the Mackenzie Delta region has been quite high. Native grasses and forbs are now invading these soils and in many cases replacing the nurse crop of agronomic species. This human induced plant succession to native speices is highly desirable, for in arctic and alpine tundras the native species are physiologically preadapted to long term survival. This is seldom true for the long term success of non-native species introduced into harsh environments.

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RELATIONSHIP OF THE SNOWPACK TO ACID MINE DRAINAGE FROM A WESTERN SURFACE MINE[1]

E. E. Farmer and B. Z. Richardson[2]

INTRODUCTION

To some extent acid drainage water is a problem on many mining areas in the West. All acid mine drainage has essentially the same origin, i.e., the oxidation of sulphide minerals exposed during the mining process. On western mines, acid mine drainage is usually associated with the production and milling of metallic ores under conditions of relatively high average annual precipitation, often half or more of the precipitation falling as snow. Factors that contribute to the severity of the acid problem include the chemical composition of the rock mass being mined, the mineralogy of the sulphide minerals, the method of mining and of solid waste disposal, the climate and physiography of the mine property, and the physical and chemical characteristics of the receiving stream system.

The Blackbird Mine is a copper-cobalt mine at an elevation between 2-2.5 km (6560 to 8200 ft.), about 40 km (25 miles) southwest of Salmon, Idaho. It has been inactive, except for exploratory work, since 1967. The Blackbird consists of both underground workings (12 levels with 8 portals) and an open pit that covers an area of approximately 4-1/2 ha. The general physiography of the area is a rugged succession of high ridges with steep sidehills and deep narrow draws. Most draws are drained by perennial streams, although the smallest draws support streamflow only during periods of active snowmelt, usually May and June.

1/ This research was partially funded by the USDA, Forest Service Surface Environment and Mining (SEAM) program.

2/ The authors are forest hydrologist and research forester, respectively. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah 84401, stationed in Logan, Utah at the Forestry Sciences Laboratory, maintained in cooperation with Utah State University.

Average annual precipitation ranges from about 63 cm at the lowest elevation to 100 cm at the highest elevation with most precipitation falling as snow. At the higher elevations, the April 1st snowpack may have a water equivalent of 50 to 75 cm with snow depths exceeding 250 cm. High sinds are common to the area. High wind velocities, steep slopes, and solar insolation may create large snow-free areas during any winter month, especially on south and southwest aspects.

In general, the rocks of the Blackbird mine are quartzites and metamorphosed Precambrian sediments. Occasional massive intrusions of chalcopyrite, cobaltite, pyrite, and pyrrhotite occur in mineralized lenses; the first two minerals are high-grade ores, the last two are waste sulphide minerals.

For more than 20 years, the Blackbird Mine has been a large contributor of copper and iron ions, sulphuric acid, and erosional products to area streams. These mining by-products have killed all benthic organisms and fish in Blackbird Creek, the major stream leaving the area. Several environmental investigations have been conducted on or near the mine property (Corley, 1967[3/]; Platts, 1967, 1968, 1969, 1970[4/]; Farmer et al., 1976). All reports indicate continuing water and soil problems associated with the oxidation of sulphide minerals.

Although hydrologic information on the Blackbird Creek watershed is scanty, Davis, 1972[5/] drew together information from the Idaho Mining Company and the Salmon National Forest. The flow in Blackbird Creek is not measured on a regular basis (ungaged), however, Davis constructed an average monthly hydrograph of Blackbird Creek by using an adjacent gaged watershed and assuming the same flow rate per unit area on both watersheds. Davis also assembled the available information on the concentration of copper ions in Blackbird Creek, and calculated an average monthly concentration. Unfortunately, the period of record for the copper ion data, 1964-1970, is different from the streamflow data, 1951-1960. However, the relation of streamflow to copper flow proposed by Davis (Fig. 1) indicates that the melt of the snowpack strongly influences the movement of copper ions into Blackbird Creek. Although Davis' data are inconclusive, he also suggested that the concentration of copper ions in Blackbird Creek varies directly with streamflow volumes, i.e., the greater the streamflow, the greater the copper ion

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3/ Corley, D. R. 1967. Biological sampling of Panther Creek above and below the introduction of mining wastes. State of Idaho Fish and Game Dept., Boise, Idaho, unpubl. rep., November 1967.

4/ Platts, W. S. 1967, 1968, 1969, 1970. Water quality studies in the Panther Creek drainage for monitoring aquatic habitat conditions in the Blackbird Creek influence area. Unpubl. Prog. Reps., USDA For. Serv., Salmon N.F., Salmon, Idaho 83467.

5/ Davis, F. T. 1972. Water pollution abatement program for the Blackbird Mine of the Idaho Mining Company. Unpubl. rep., Hazen Research Inc., Golden Colorado for the Idaho Mining Company, Box 514, Cobalt, Idaho 83229.

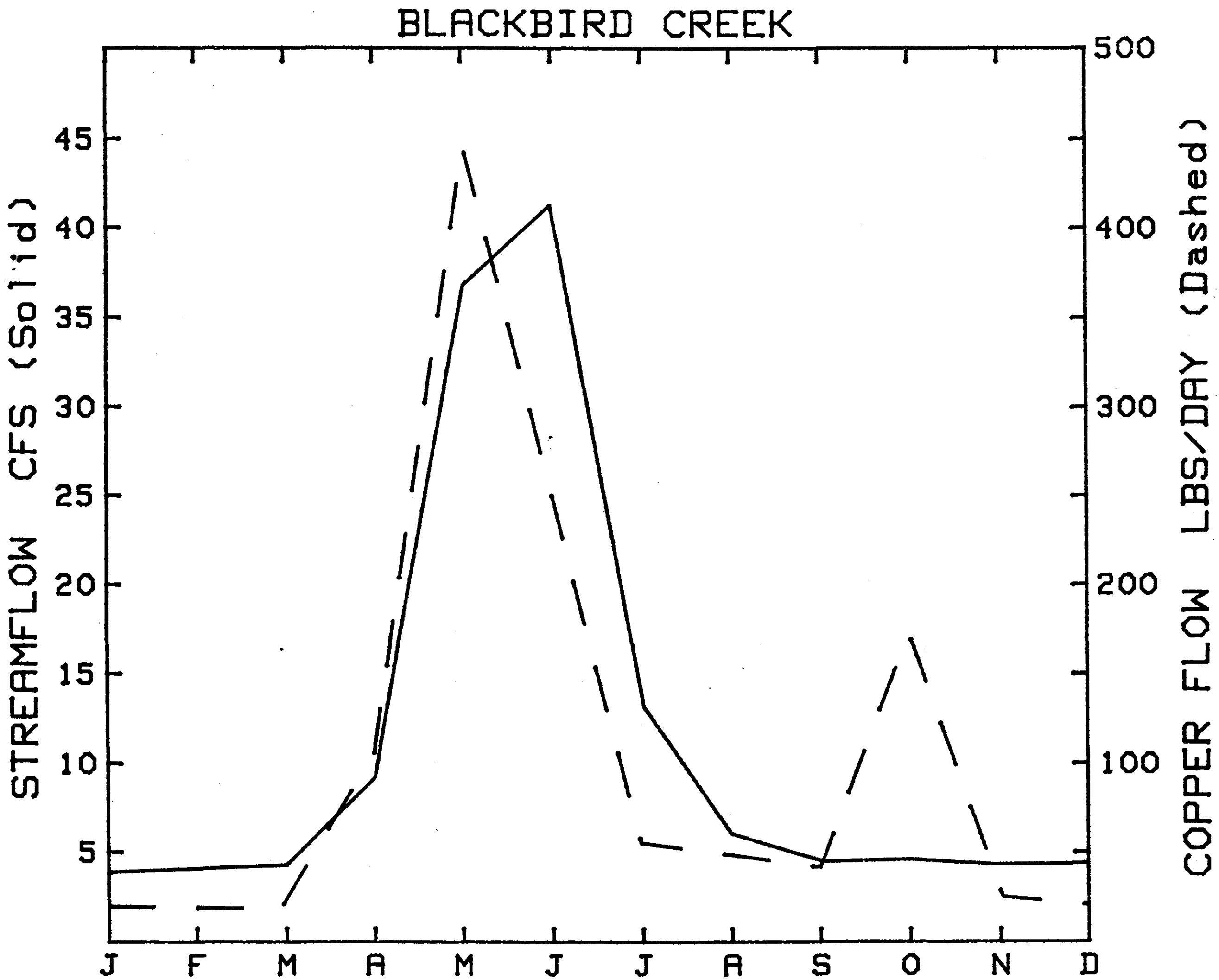

Figure 1. Estimated average monthly streamflow and copper flow in Blackbird Creek. Data from Davis, 1972, footnote 5.

concentration. This was partially corroborated by Williams et al.[6] for two other streams in the area affected by mining, and for flow from one underground tunnel (Table 1).

Table 1. The average flow of water, copper, and iron during low and high streamflow periods, August, 1974 and May, 1975 respectively. Data from Williams, et al., 1975, footnote 6.

Low Streamflow Period

	Flow Gal/Min	Cu ppm	Fe ppm	Cu lbs/day	Fe lbs/day
Meadow Ck.	60	16.3	1.1	12	0.8
6850 Portal	60	8.3	36	6	25.9
Bucktail Ck.	50	400	0.6	240	0.4
	170			258	27.1

High Streamflow Period

	Flow Gal/Min	Cu ppm	Fe ppm	Cu lbs/day	Fe lbs/day
Meadow Ck.	1500	36.7	2.7	661	49
6850 Portal	134	87.9	174.6	142	282
Bucktail Ck.	293	166.6	76.3	586	269
	1927			1389	600

Johannessen and Hendriksen, 1978 demonstrated that the concentration and distribution of pollutants within a snowpack is changed during the early stages of snowmelt. They indicate that 50-80% of the total pollutant load is released with the first 30% of the meltwater. The very first snowmelt factors may contain a pollutant concentration more than five times that of the snowpack.

[6] Williams, D. R., D. B. Trexler, Jr., and D. R. Ralston. 1975. Water resource problems related to mining in the Blackfoot Mining District. Idaho Bureau of Mines and Geology, Univ. of Idaho, Moscow, Idaho.

Timmons and Holt, 1977 studied plant nutrient losses from a native prairie in Minnesota and found that from 63 to 88% of the annual nutrient loss occurred during the spring snowmelt period. They speculated that the nutrients in the snowmelt water did not originate from the soil surface but probably derived from a combination of the leaching of the dormant prairie vegetation and from precipitation itself.

Concentrated flows of calcium in some streams of northern Utah have been related to snowpack melt[7/]. During the spring snowmelt of 1971 a four-fold increase in the calcium concentration of some area streams was noted. The calcium surge occurred just prior to peak streamflow and was bounded on either side by normal concentrations of calcium.

The quality of snowpack water, principally from the Sierra Nevada Mountains of California and the Wasatch Mountains of Utah was studied by Rogers and Feth, 1959. They showed that snow samples that were melted and analyzed in the laboratory often approached the water quality of common distilled water. However, the quality of meltwater only a few tens of feet from the parent snowbank showed large increases in calcium and bicarbonate ions.

All of these findings have implications for the problem of acid mine drainage where snowfall comprises a substantial part of the average annual precipitation. For that condition a large fraction of the annual water yield occurs during spring snowmelt. It also appears that a large fraction of the annual pollutant load occurs during spring snowmelt. The objective of this work was to identify the sources of snowpack contamination and to investigate the relation of pollutant load and concentration with streamflow volume.

This work was done during the period January, 1975 to July, 1976.

METHODS & PROCEDURES

In an effort to identify sources of contaminated surface runoff we decided to sample both in the high and low reaches of the watershed. In the headwater area soil, dust, snow, surface runoff and streamflow was sampled. In the lower portion of the watershed streamflow alone was sampled.

Excepting pH all chemical analysis of soil and water samples were performed by either a commercial laboratory certified by the Utah State Health Department or by the Soil and Water Testing Laboratory of Utah

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7/ Fletcher, J. E. 1975. Personal communication. Utah State University, Logan, Utah 84322.

State University. In every case these laboratories follow accepted analytical procedures[8/]. Measurement of pH was done in the field using a specific ion meter and hydrogen ion electrode against an Ag/AgCl reference electrode.

Snow

Sixty nine (69) snow samples were analyzed, 23 in 1975 and 46 in 1976. Each snow sample was collected as an ice-water matrix, melted and analyzed. Sample locations are indicated on the schematic map of Figure 2 as A(1) through A(4) for 1975 and A(1) through A(7) for 1976.

Snow Water Surface Runoff

In May, 1975 eleven (11) samples of snow water surface runoff were collected; sample locations B(1) through B(4), Fig. 2. In October, 1975 six (6) additional samples were collected at locations B(2), B(3), B(5), B(6), Fig. 2. We do not know the distance between where the snow melted and where the sample was collected. However, the distance from melt to collection was short, probably not more than 60 meters (200 feet).

Snowdust

A considerable surface area of the mine is snowfree during all or part of the winter period. These areas are either very steep (such as the open-pit walls) or areas exposed to the full force of the wind along ridges, saddles, or windward slopes. The combination of high wind velocities, steep topography, little or no vegetative cover, and solar insolation produces an ephemeral snow cover; these areas are dust source areas.

Snowdust samples were collected from the surface of ripe spring snowpacks during May of 1975 and 1976, (location A(1), Fig. 2). About 1000 square feet, (95 square meters), of the snowpack surface was scraped to obtain a sample of snow and dust. Most of the meltwater was decanted off and the dust sample was air-dried. Elemental analyses were done by atomic absorption methods and neutron activation analysis[9/].

The size distribution of the air-dry material was obtained by wet-sieving through screens with openings of 1.65, 1.00, 0.83, 0.42, 0.18, and 0.06 mm.

Topsoil, Subsoil, Spoil

In order to put the elemental analyses of the snowdust material into the appropriate perspective, samples of topsoil, subsoil, and spoil were

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[8/] Specific information on methods employed for the analysis of soil and water samples is available from the authors.

[9/] Neutron activation analyses were performed at the National Engineering Reactor Laboratory, DOE, near Idaho Falls, Idaho.

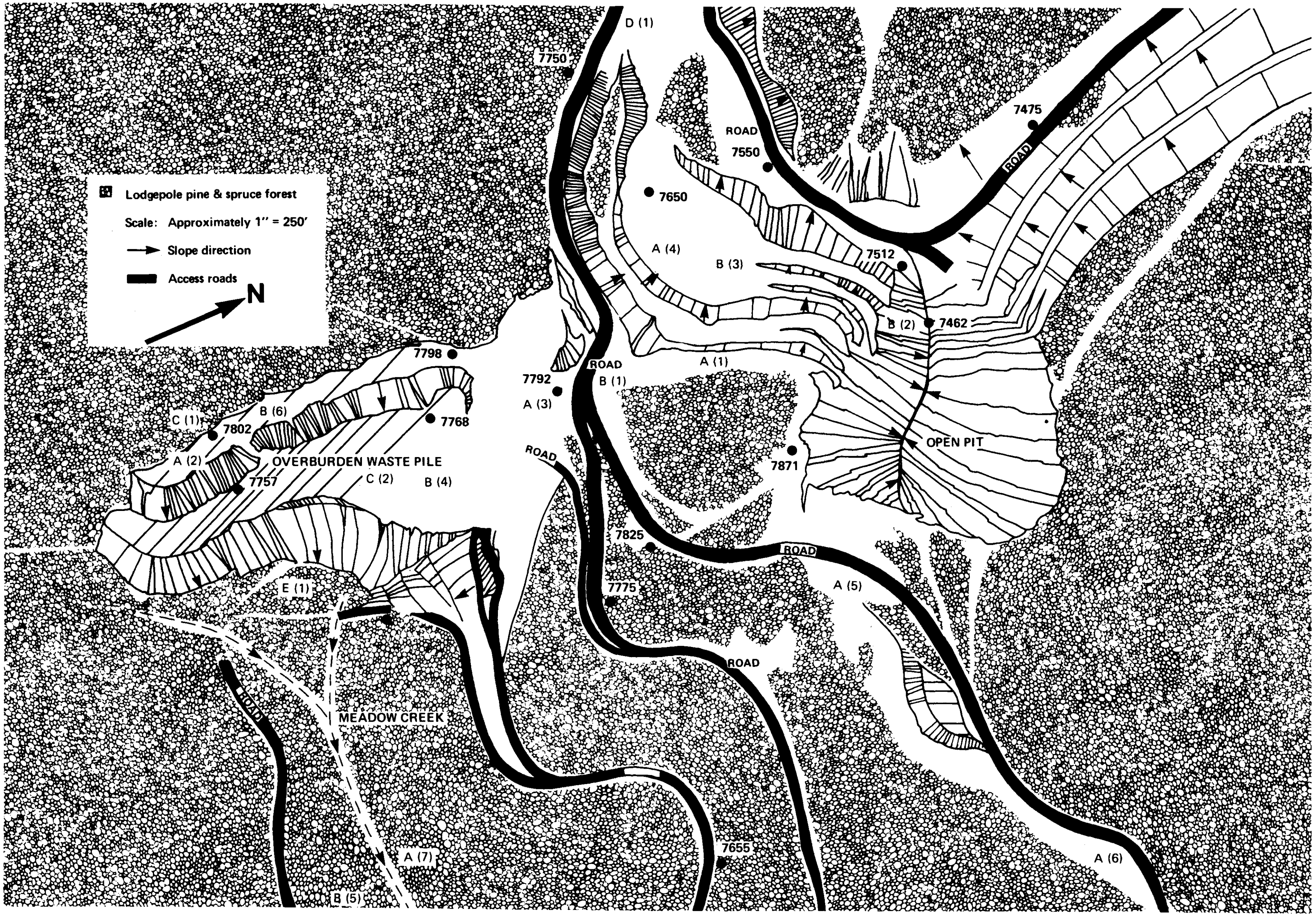

Figure 2. Schematic map of the headwater area of Blackbird Creek and the Blackbird Mine. Arrows indicate the downslope direction. Elevation is indicated at the solid dots, feet.

also collected 6 inches (15 cm) deep and 8 feet (2.5 m) deep, respectively, under an undisturbed Lodgepole pine-Engelmann spruce forest (location C(1), Fig. 2). The spoil sample taken from the surface centimeter, (location C(2), Fig. 2).

Streamflow

Streamflow volumes and chemical constitutents were sampled during the spring and summer of 1976. Sampling in Meadow Creek (location A(7), Fig. 2) is indicative of the influence of mining in the upper reaches of the Blackbird Creek watershed and is not influenced by flows emanating from underground workings.

Streamflow volumes and water samples were also taken in the main Blackbird Creek at a point about 6400 feet (1950 m) below the Meadow Creek sampling point. This sampling station is located just below the main gate of the mine property. Water quality is influenced by both mining wastes stored on the surface (but not mine tailings) and flows emanating from underground workings.

RESULTS & DISCUSSION

Snow

Multiple dust layers are incorporated within the snowpack, Figure 3 (location A(1), Fig. 2). Analysis of the samples shown in Figure 3 clearly indicate that these dust layers are adversely influencing the water quality of the snowpack, Table 2A. The snowpit in Figure 3 and analyses in Table 2A were made in May, 1975. One year later, a snowpit dug in the same location was deeper but was somewhat less contaminated, Table 2B. These differences from 1975 to 1976 are probably natural variations due to yearly wind and weather differences.

On the Blackbird Mine all snowpacks located on sulphide mineral wastes and which have, or have had, free water in the base of the pack, show a yellow discoloration in the bottom six inches of snow. This discoloration is due to the absorption of acid pollution products from the spoil surface Table 3. The yellow discoloration varies in hue and intensity depending upon the nature and concentration of absorbed pollutants. The depth of absorbed pollutants probably depends on the physical characteristics of the snow-ice matrix; however, chemical potentials and gradients may also be involved. Contamination of the base of the snowpack is another means of increasing the concentration of snowmelt surface runoff.

The snow base contamination is probably controlled by three factors: (1) diurnal temperature changes and the presence of free water in the snowpack, (2) the pore size distribution in the snow matrix at the snow-ground interface (constantly changing), and (3) the rate that acid products are removed from the snow matrix by leaching.

Table 2. Analysis of snow meltwater from snowpits, 1975-76. Sample locations are in inches above the ground.

A-1975

Sample location, in.	Snow description	pH	Conductivity µmhos/cm	Acidity mg/l	Concentration ppm SO_4	Cu	Fe
0	dirty	3.79	138	84	36.8	8.4	0.7
1	dirty	3.93	53	23	6.8	2.4	1.4
7	dirty	4.14	26	17	2.9	0.5	3.4
14	dirty	4.22	15	6	0	0.1	2.1
21	clean	5.53	8	4	0	0	1.0
31	dirty	4.89	11	5	0.3	0	2.7

B-1976

Sample location, in.	Snow description	pH	Conductivity µmhos/cm	Acidity mg/l	Concentration ppm SO_4	Cu	Fe
0	dirty	5.4	7		5	.1	.1
13	dirty	7.1	202		9	.1	.2
24	clean	6.3	11		1	.1	.1
29	dirty	5.9	7		2	0	.1
38	clean	5.6	3		3	0	0
51	dirty	6.1	9		1	0	.1
69	clean	7.0	61		2	.1	.1
78	dirty	5.9	. 15		4	.1	0

Yellow snow discoloration was not found in dry snowpacks. However, yellow ice layers have been found in the base of snowpacks. These ice layers are due to the diurnal melt cycle; refreezing of snowpack free-water containing dissolved acidification products.

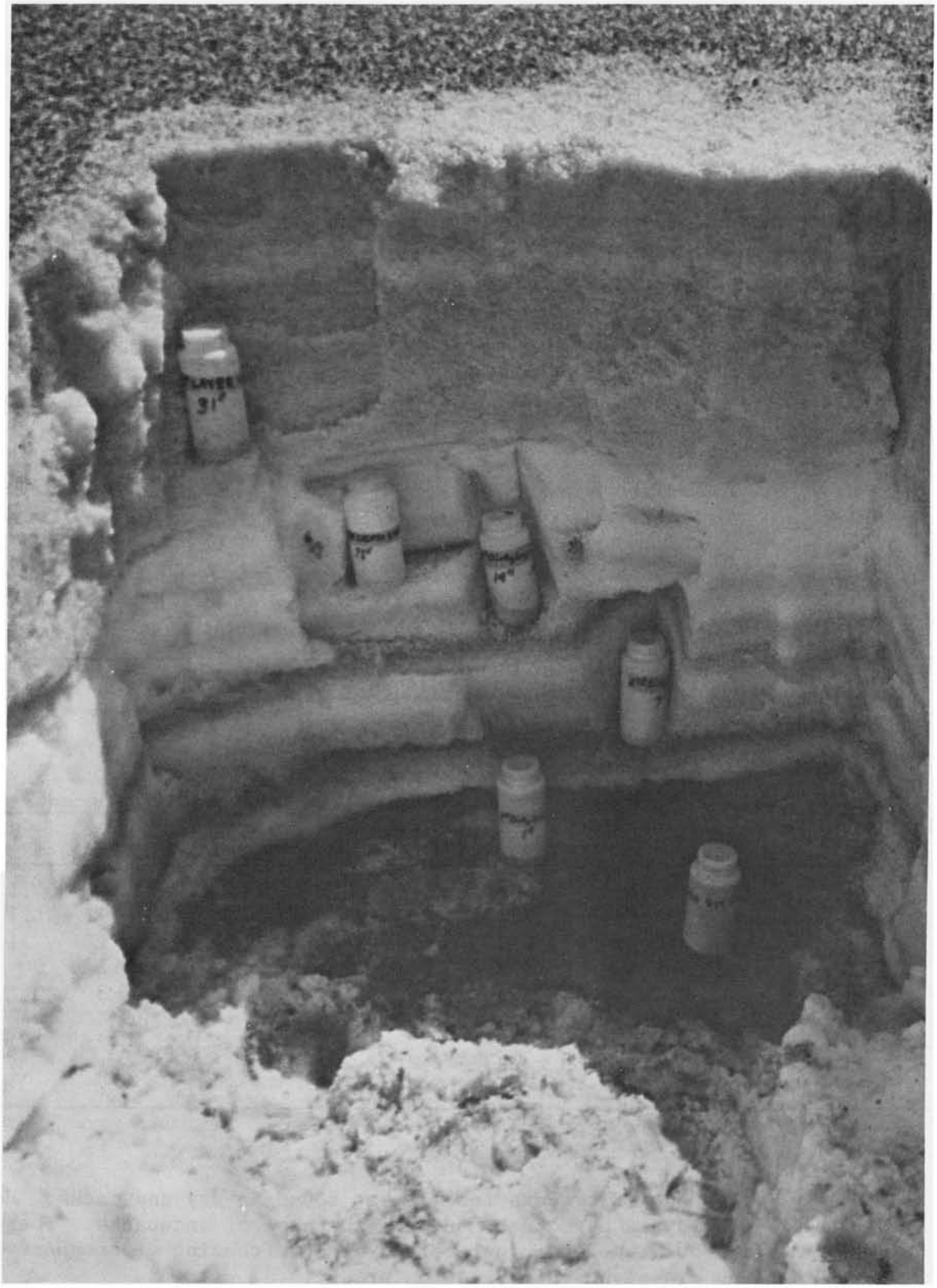

Figure 3. A snowpit 50 inches deep shows distinct layering caused by dust deposits. Sample bottles are located at 0, 1, 7, 14, 21 and 31 inches above the ground, May, 1975.

Table 3. Snowmelt water analyses on the Blackbird Mine, spring, 1975. All samples taken at the snow-ground interface on sulphide mineral wastes.

pH	Conductivity µmhos/cm	Acidity mg/1	Concentration ppm SO_4	Cu	Fe
5.75	8	5	3.1	0	4.4
5.88	308	62	2.2	3.1	2.3
4.66	200	45	125	22.1	0
4.93	7	5	0	0	0.7
4.67	25	8	12.3	0.8	0
2.86	680	451	NA	10.8	23.4

In addition to sampling clean or dirty layers within the snowpack, and at the base of the snowpack, integrated snowpack samples were obtained in May, 1976. This is a sample down through the entire snowpack, integrating the clean and dirty layers. Thirty-eight (38) samples were taken. Locations as shown in Figure 2 as E(1), C(2), B(6), A(3), A(1), D(1), A(5), and A(6). At the time of sampling the snowpack was ripe and wet. In fact, well over half of the snowpack had already melted. The snowpack was contaminated, Table 4. However, there is no clear trend in the contamination. Samples located on bare mining wastes near known dust sources are not much more contaminated than samples on undisturbed forest land. More samples and a formal experimental design could begin to define the relation between mining disturbance and snowpack contamination. To date, this has not been done.

Snow Water Surface Runoff

Snow meltwater on mining disturbances such as those in this study are triply contaminated, (1) pollutants, from whatever source, are believed to be concentrated initially on the surface of the snow crystals and are probably further concentrated during alternate freezing and melting of the snowpack, (2) pollutants are concentrated in the ice-water matrix at the base of the snowpack by absorption from the ground surface, and (3) water soluble pollutants are dissolved in the surface runoff water as it makes its way toward stream courses. Therefore runoff are highly contaminated, Table 5.

Snowdust

Elemental analysis results of the snowdust samples collected from spring snowpacks in 1975 and 1976 leave little doubt that dust from mining wastes and from open-pit walls are a source of snow meltwater contamination, Table 6. A 50-50 water extract with the snowdust gave a pH of 4.7 and 4.9 for 1975 and 1976 respectively.

Table 4. Results of analyses on meltwater from snow samples over the depth of the snowpack. These results are typical of the whole data set.

pH	Conductivity µmhos/cm	Concentration ppm Cu	Fe
4.5	26	0	.15
4.2	3.5	0	<.1
4.8	5.1	.2	.3
5.2	3.5	0	<.1
5.1	2.4	<.1	<.1
5.4	2.5	.1	.1
5.3	2.5	0	.1
5.3	12.4	.1	.5
5.3	4.4	<.1	.4
5.1	28.6	1.8	.35

Since the snowpack is at a temperature no greater than $0^{o}C$, it is unlikely that snowdust is a significant direct source of acid production within the snowpack. Oxidation of sulphides is a temperature dependent chemical process. However, any water soluble products on the dust surface can be dissolved and transmitted within the snowpack by capillary action. This is probably the primary mechanism by which sulphide mineral dusts degrade snowpack water quality.

After the snowpack has melted and these dusts are deposited upon the soil surface, the dust provides readily reactive material for further acidification.

The snowdust material is coarser than expected for a windblown deposit, Figure 4. Of course the maximum particle size is dependent upon maximum wind velocities and may vary from year to year. However, the small particles are probably more important than the large particles. About 34 percent of the sample was less than 60 microns in size. Sixty microns and less is roughly the silt and clay size particles.

Topsoil, Subsoil, Spoil

Elemental analysis results for undisturbed topsoil and subsoil are presented in Table 7. A comparison of tables 6 and 7 reveals that snowdust has a higher concentration of most of the listed elements than either topsoil or subsoil. Snowdust is not an innocuous material; it has greater concentrations of arsenic, cobalt, copper, iron, lead, and nickel than either of the soil materials.

Table 5. Analysis results of surface runoff water from snowmelt. The May samples represent a period of rapid spring snowmelt. The October samples resulted from the first snowfall of the season.

pH	Conductivity µmhos/cm	Acidity mg/l	Concentration ppm SO_4	Cu	Fe
		---May, 1976---			
4.93	7	5	0	0	0.7
4.67	25	8	12.3	.8	0
5.50	49	10	29	4.3	0
5.91	43	10	29	3.6	0
4.63	154	55	115	12.8	3.4
3.92	1,584	901	2,267	315	3.3
4.64	150	30	96	12.5	0
4.50	123	25	77	7.3	0
5.11	30	5	19	2.1	0
4.83	32	5	19	0.5	0.5
4.78	186	3	134	13.8	0
		---October 1975---			
2.25	7,130	26,700	12,900	442	2,665
2.20	9,270	36,300	19,300	595	3,940
6.24*	1,551	52	120	0	0.7
4.29	100	85	30	3.2	0.4
5.76	23	74	4	0	0.2
3.52	165	---	55	6.4	5.5

* Surface runoff from freshly limed topsoil.

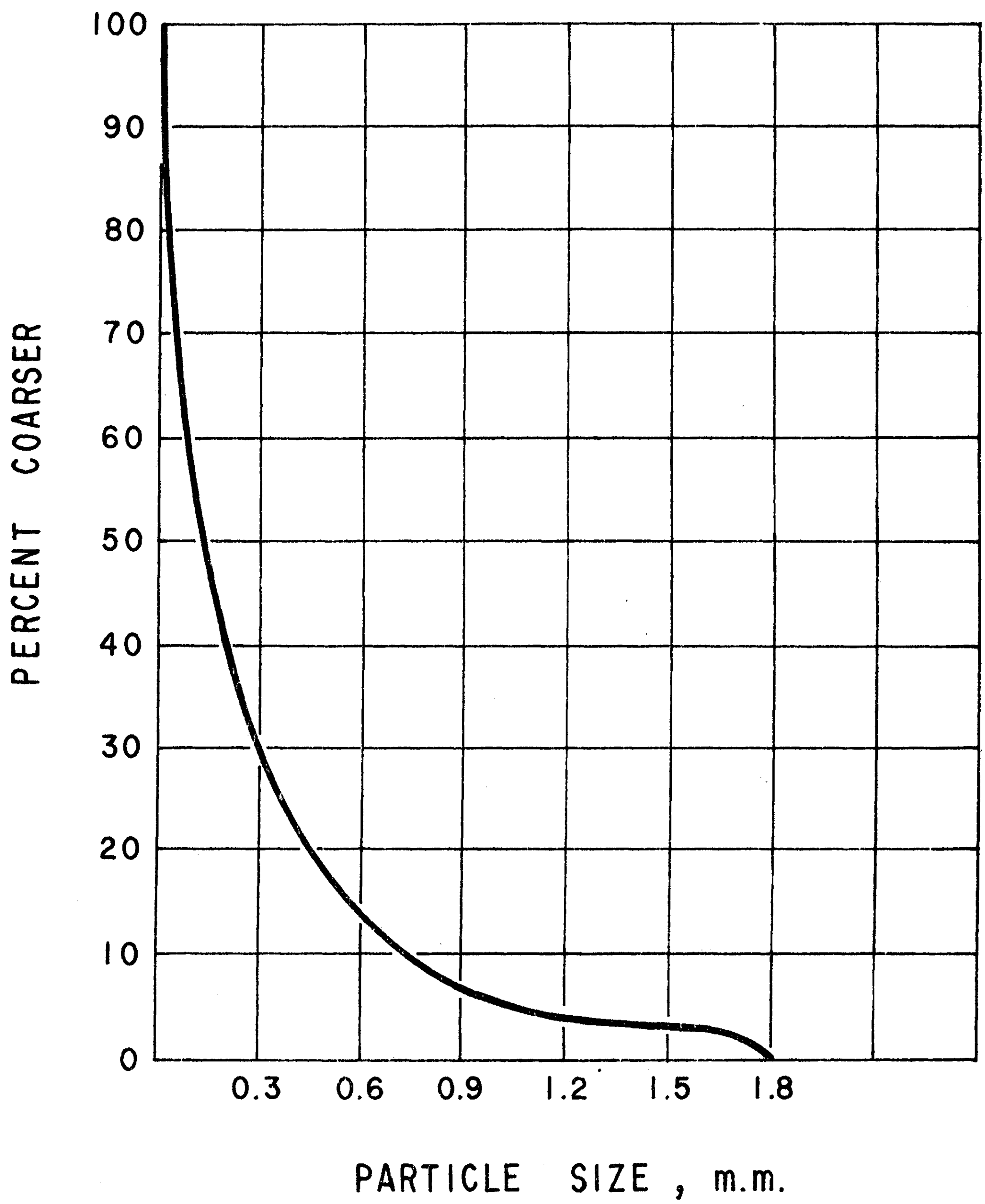

Figure 4. Particle size distribution of the 1975 snowdust material.

Table 6. Elemental analysis results on dust samples collected from spring snowpacks, 1975 and 1976.

Element ppm	Snowdust 1975	Snowdust 1975
Aluminum	17,000	55,000
Arsenic	1,941	105
Calcium	6,367	6
Cobalt	505	900
Copper	5,157	5,350
Iron	118,000	92,700
Lead	116	1
Magnesium	35,100	4,110
Nickel	67	21
Sulfur	416	51
Zinc	122	19

Table 7. Elemental analysis results for undisturbed forest topsoil (6 inches deep), forest subsoil (8 feet deep), and waste overburden.

Element ppm	Topsoil	Subsoil	Overburden
Aluminum	59,000	12,300	18,600
Arsenic	10	8	183
Calcium	114	140	0
Cobalt	122	142	123
Copper	1,268	1,441	7,710
Iron	62,500	70,100	100,300
Lead	1	1	1
Magnesium	2,540	3,280	3,970
Nickel	17	18	26
Sulfur	84	65	73
Zinc	41	20	27

Streamflow

Meadow Creek.

Meadow Creek is an ephemeral mountain stream. It usually dries up in late summer and regains its flow during the spring snowmelt. A large overburden waste pile is located in the very headwaters of the watershed, Figure 2.

In the spring of 1976 several measurements on Meadow Creek were initiated on a semi-regular basis, streamflow, copper concentration, and iron concentration, Figure 5, and electrical conductivity and pH, Figure 6.

As in the manner suggested by Davis (Figure 1) the maximum concentrations of both copper and iron precede peak streamflow volumes. The peak concentration of iron precedes peak streamflow by almost 45 days, the maximum copper concentration precedes peak streamflow by 12 days. However, note that the copper concentration curve is bimodal; the first peak came almost 35 days before peak streamflow. We feel that the absolute timing, in days, between copper or iron concentration and peak streamflow is less important than the relative timing, i.e.; the fact that both copper and iron concentrations peak several weeks to a month or more before peak streamflow is crucial. This is strong evidence that the early melting of the snowpack is closely tied to translocation of acid pollution products to live stream channels, probably aided by the mechanisms suggested by Johannessen and Hendriksen, 1978. The streamflow volume generated during peak snowmelt does dilute the metallic ion water. The dilution effect is not so apparent on stream pH. However, pH is on a logarithmic scale; the hydrogen ion concentration is reduced about 2½ times during peak streamflow.

Blackbird Creek.

Blackbird Creek at this sampling location is a perennial stream. There are multiple pollution sources above the sampling station including both point flows from underground workings and diffuse pollution sources from mining waste piles. There are no fish or benthic organisms in the stream.

The relation between streamflow, metallic ion concentrations, conductivity, and stream pH, Figures 7 and 8, are similar to those already mentioned for Meadow Creek. Peak concentrations of copper and iron precede peak streamflow by about 30 days. Conductivity is lowered and pH is increased by dilution, but the effect is short-lived.

The most important point here is the relatively long period of time from peak metallic ion concentrations to peak streamflow.

Acid Mine Drainage from Diffuse Sources

The data accumulated so far on snowpack quality, sources of snowpack contamination, snow meltwater contamination, and streamflow contamination,

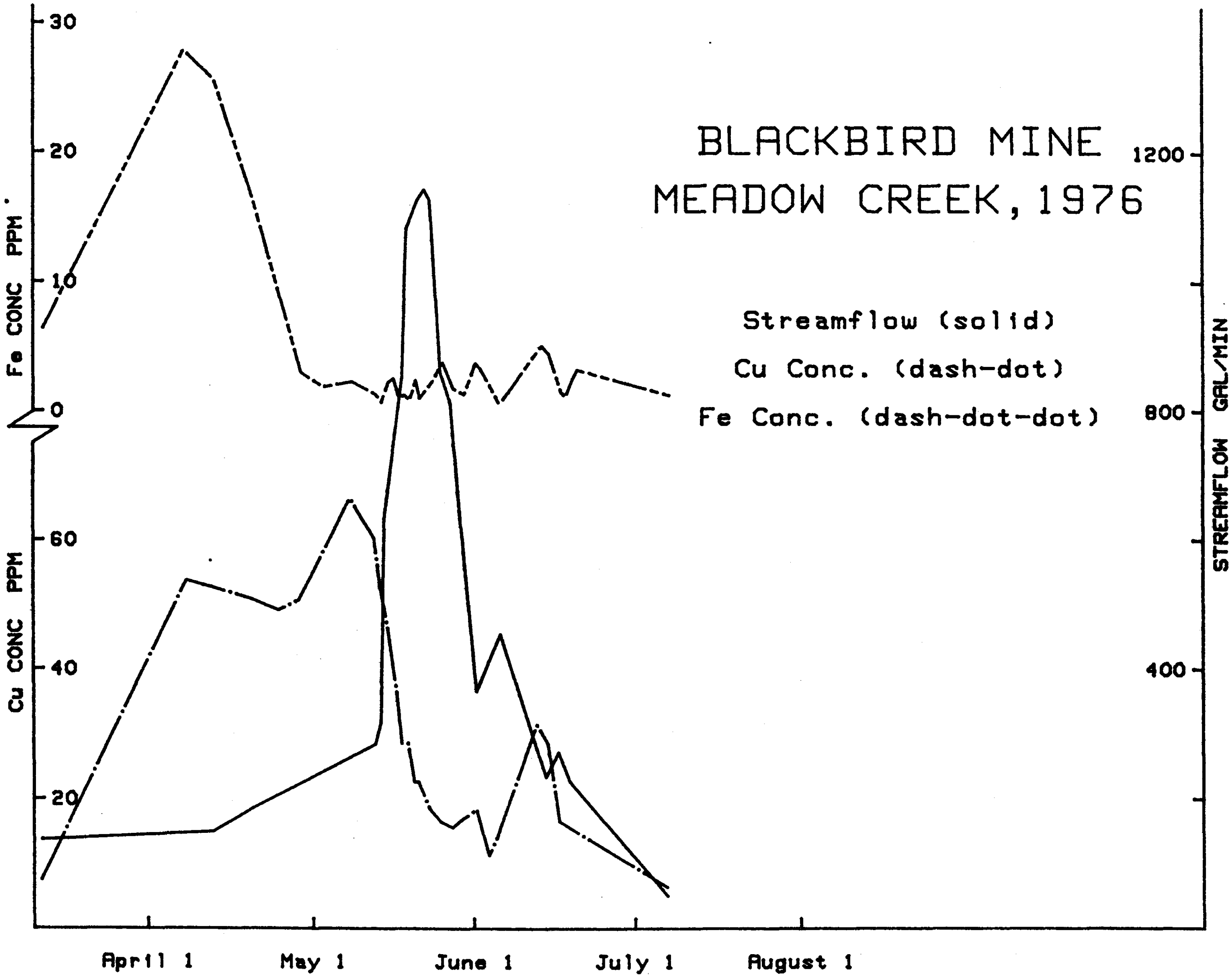

Figure 5. Streamflow volumes, copper and iron concentrations in Meadow Creek during the spring and summer of 1976.

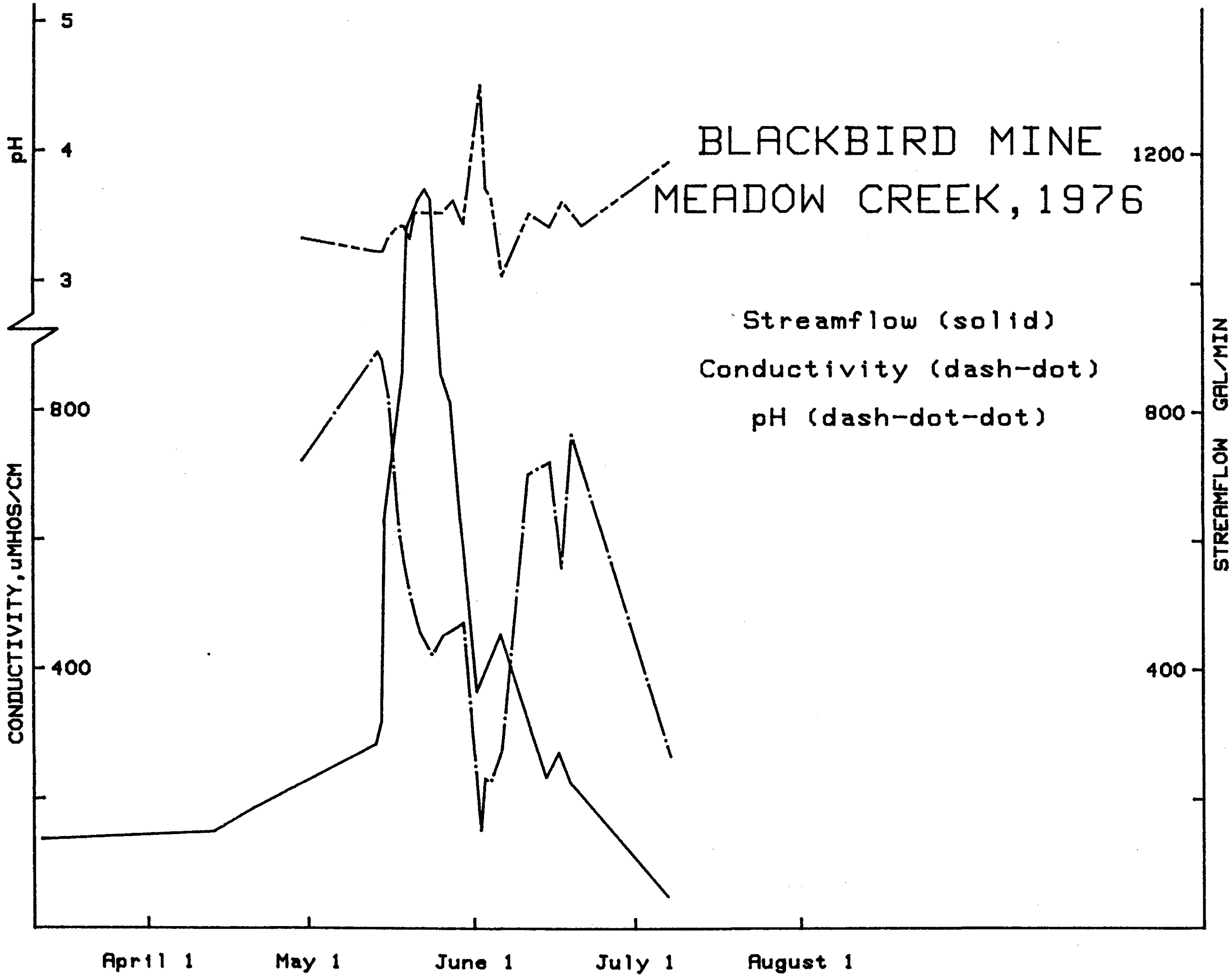

Figure 6. Streamflow volumes, electrical conductivity, and stream pH in Meadow Creek during the spring and summer of 1976.

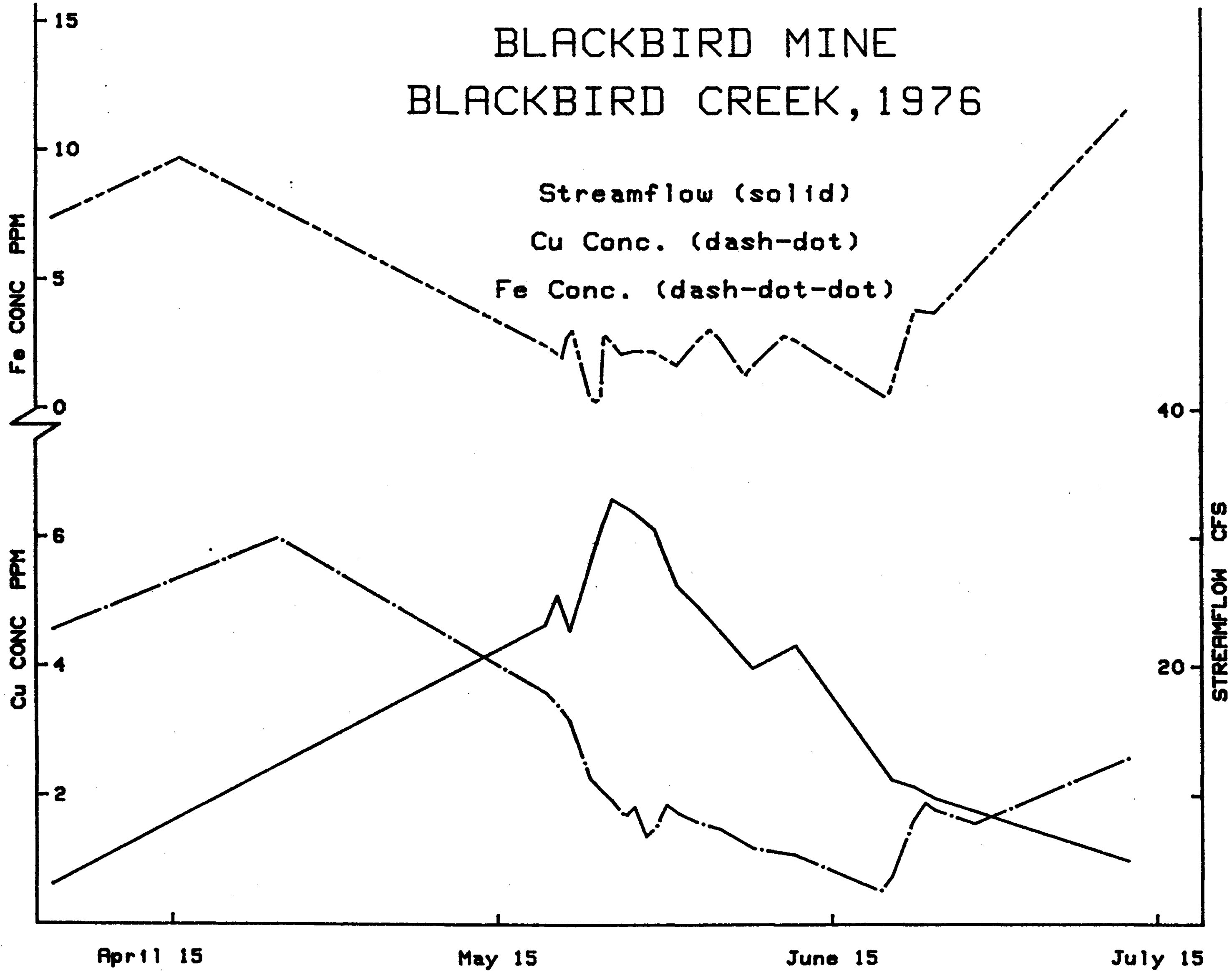

Figure 7. Streamflow volumes, copper and iron concentrations in Blackbird Creek during the spring and summer of 1976.

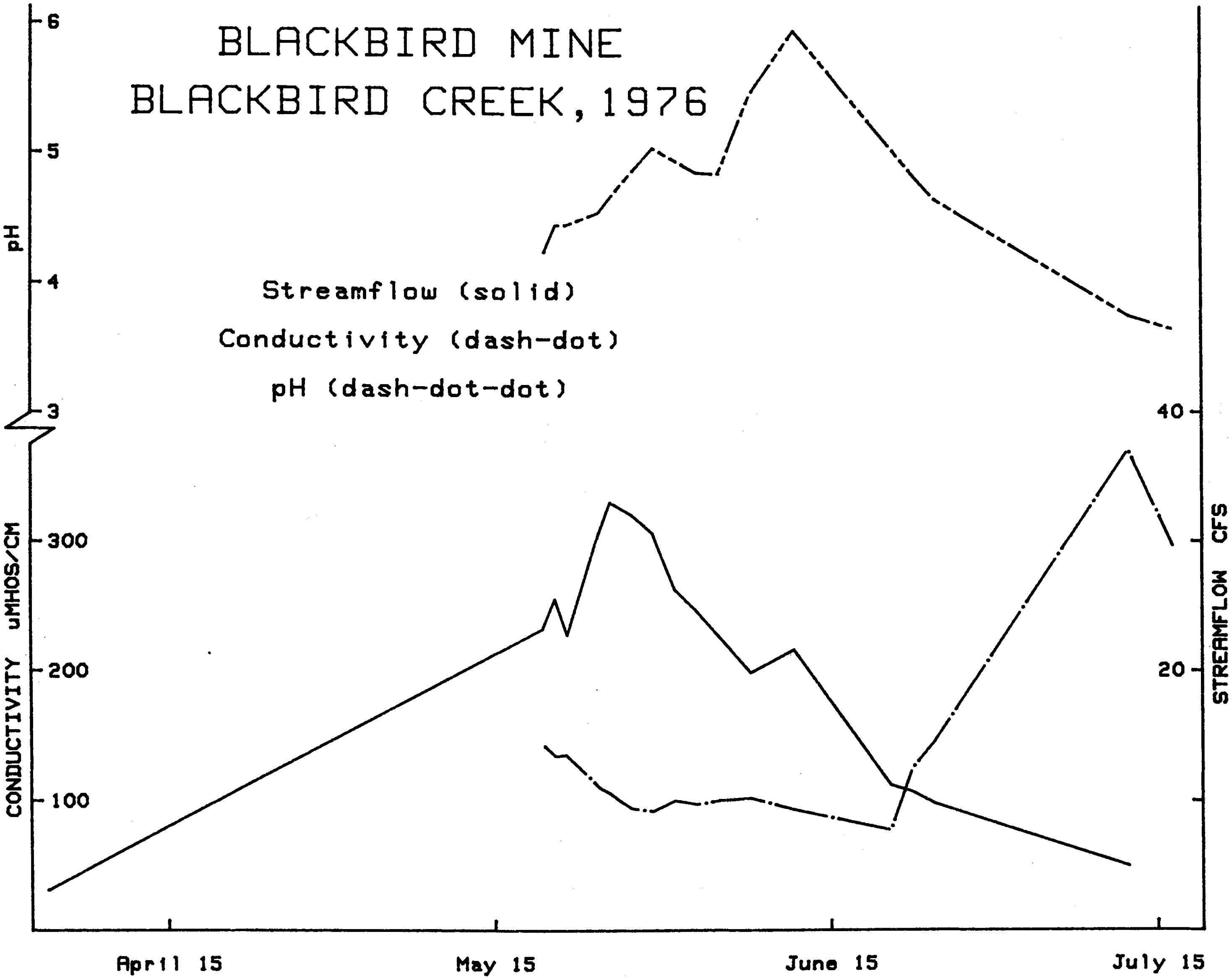

Figure 8. Streamflow volumes, electrical conductivity, and stream pH in Blackbird Creek during the spring and summer of 1976.

all lend evidence to the thesis that acid mine drainage from diffuse sources at high elevations in the western United States is directly related to the snowpack. The snowpack acts as both a pollution sink (dust and absorption of oxidation products) and as a translocation agent for moving contaminants to streams.

We conceived the acid cycle to be completed in three phases. The first phase is the active oxidation of sulphide minerals during the warm season. The rate of oxidation approximately doubles for each 10°C rise in temperature. Oxidation products tend to accumulate in the soil and spoil during this period. The soil pH is lowered which increases the solubility of most metals. Contaminants in the soil-water solution increase.

The second phase starts with the fall and/or winter snowpack accumulation. During this period dust is incorporated within the snowpack. Pollutants probably concentrate on the surfaces of ice crystals. Any free water excess within the snowpack promotes absorption of contaminants from the ground surface. During the snowmelt process snowdust within the snowpack is gradually brought to the surface. This decreases snow albedo and increases the melt rate.

The third phase of the acid cycle involves the translocation of contaminants to the stream course. Early in the snowmelt period, several weeks before peak streamflow, the flush-out of contaminants greatly increases the metallic ion concentration of streamflow. The flush-out phenomena is closely associated with the triply contaminated surface runoff waters already discussed. Later on in the melt of the snowpack the flush-out is essentially completed and streamflow quality shows some improvement due to the dilution effect.

Snowmelt removes the oxidation products from the site of their reaction and prepares the way for the renewal of the acid cycle with the first onset of warm weather.

CONCLUSIONS

1. If a snowpack accumulates on untreated acid mining wastes it becomes both a pollution sink and a translocation agent for AMD.

2. Snow meltwater is triply contaminated:

   a) contaminants probably concentrate on the surface of ice crystals
   b) contaminants are absorbed into the snowpack base from the ground surface
   c) surface runoff water picks up soluble oxidation products on its way to stream courses.

3. Dust production on sulphide minerals is not innocuous. It contributes water soluble oxidation products directly to runoff and provides reactive material for further oxidation.

Given the three conclusions just stated how can we minimize the adverse effects?

I. Dust production on the mine should be, from whatever source, severely curtailed. Every mine operating on sulphide minerals should develop a dust control plan.

II. Contact of the snowpack with untreated mining wastes should be minimized. An untried treatment is the surface application of lime.

III. Erosion of soil/spoil surfaces by water or wind, which exposes additional sulphides to oxidation, should be checked.

IV. Although it has never been quantitatively demonstrated on an operational basis, the establishment and maintenance of a heavy vegetative cover on mining wastes is the best alternative for mitigating diffuse AMD sources.

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RECLAMATION OF ACID-PRODUCING SPOILS ON A WESTERN SURFACE MINE

Bland Z. Richardson[1/]

The Blackbird Mine is a copper-cobalt mine in the heart of the Salmon National Forest about 25 miles (40 km) southeast of Salmon, Idaho. Elevation of the mine ranges between 6,600 and 8,200 feet (2 012 and 2 500 m). The area is a succession of rugged high ridges with steep hillsides and deep, narrow draws, most of which are drained by perennial streams. Rocks in the area are mostly quartzites and metamorphosed Precambrian sediments. Minerals mined as high grade ores are chalcopyrite and cobaltite. Pyrite and pyrrhotite occur with the ore and are waste sulphide minerals.

During the mine's intermittent operation since 1893, spoil material containing pyritic and sulphide minerals was dumped on the sides of steep slopes. As these spoil materials were exposed to the atmosphere, they oxidized and produced sulfuric and other acids. These acids dissolved heavy metal ions, making the overburden material quite toxic.

Average annual precipitation ranges from about 22 to 35 inches (0.56 to 0.89 m). Dominant vegetation in the area is the lodgepole pine-huckleberry (*Pinus contorta-Vaccinium spp.*) type. Important understory species are Oregon grape (*Berberis repens*), spiraea (*Spiraea* spp.), and pinegrass (*Calamagrostis rubescens*).

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Each year the Blackbird Mine contributes tons of toxic metal ions into Blackbird and Panther Creeks which drain into the Idaho Primitive Area via the Salmon River. These toxicants have killed streamside vegetation and benthic organisms in the streams, and have eliminated anadromous fish all the way from the mine to the Salmon River, some 25 miles away. Elimination of the salmon and steelhead alone has resulted in an estimated annual loss of over $1.5 million according to an economic analysis by the Salmon National Forest.

RESEARCH

Research began in 1972 on a selected drainage within the mined area where spoil dumps had been bare for 18 years and where laboratory tests showed no measured biological activity (Farmer and others, 1976). The research was designed to determine methods by which vegetation could be established on bare mine spoils having a pH as low as 2.8 and which were contributing toxic materials to streams.

When the research began, it was not clear just how toxic materials were entering streams within the watershed. Some believed the major cause was leaching through the mine dumps; others believed it was the result of the surface erosion caused by spring runoff from snowmelts. During the early springs of 1973, 1974, and 1975, the author dug snow pits and collected water and snow samples in an effort to determine the exact mechanism. In spring 1975, it was determined that reactive fractions of the sulphide minerals, which high winds were blowing from snow-free dumps, were entering the snowpack. This resulted in metal ions going into solution during snowmelt and subsequently entering streams through surface runoff (Farmer and Richardson 1980). Thus, the major source of stream contamination was now identified. The only practical preventive measure was to establish vegetation on the surface of dumps to prevent exposure of the overburden material to erosion by wind and water.

In fall 1975, all the best results of previous research and technology were applied to demonstration areas covering 11 acres (4.45 ha). An additional 2.5 acres (1 ha) was planted in 1976. These areas were large enough to demonstrate how reclamation could be accomplished on an operational scale and at the same time significantly reduce toxic runoff. The best combination of treatments and methods included: (1) proper liming, (2) topsoiling, (3) fertilizing, and (4) seeding with a mixture of native and introduced species. Straw mulching was used to prevent movement of spoils and seed by wind and water. In a cooperative effort, the Hanna Mining Company graded the demonstration areas to reshape the dumps and contour slopes.

METHODS AND TECHNIQUES

Liming

Results of previous research indicated that lime requirements for the Blackbird Mine spoils differed substantially from those calculated by using a modified SMP buffer method (Shoemaker and others, 1961). Although a university laboratory determined the original lime requirements, reacidification began within 2 years after lime was first applied. Other methods of analyzing spoils did not result in recommendations greatly different from those made by the university. In order to determine more realistically the lime requirements of these sulphide minerals, oxidation rates of the pyrites needed to be reconsidered and evaluated (Sorensen and others, 1979; Sorensen and others, 1980). The rate of oxidation of pyritic material is related to its shape and size--the finer the material the more rapid the oxidation. First, the proportion of finer particles was measured. Then the portion of the larger material that was expected to weather into small particles within the next 10 years, was combined with the fine material in order to estimate the total percent of the spoil expected to oxidize within the next 10 years (Sorensen and others, 1980). The original lime requirement was estimated at about 1.4 tons/acre/foot, but the requirement estimated by using the method just described was closer to 20 tons/acre/foot!

Ground limestone ($CaCO_3$) was used as the liming agent. It is soluble in a weak acid but is highly insoluble in water. The limestone particles varied in size from 200 mesh to 3/8 inch diameter. These two properties (water insolubility and varied particle size) could make the limestone very effective over the long term. (We expect the treatment to be effective for at least 10 years.) The lime was applied to the spoil area at the rate of 15 tons per acre and was mixed to a depth of about 21 inches by ripping. After the spoils were topsoiled, 5 additional tons per acre were applied.

Ripping

Ripping is an important technique in reclaiming spoils. However, it is necessary that the spoil be dry enough and the standards close enough to completely shatter spoil material that became packed during placement. Ripping (1) provides soil aeration, (2) reduces compaction, (3) improves retention and movement of moisture, (4) allows better root penetration and improved tilth (soil structure), and (5) controls erosion through contour tillage. The combination of these beneficial effects results in increased production of vegetation (see discussion later in this paper). Ripping is also an effective method for incorporating soil amendments deep into the soil profile. The demonstration area at Blackbird was ripped to a depth of 14 inches with standards of 14-inch centers. Ripping was done on the contour and when soil was dry enough to insure fracturing.

Topsoiling

Earlier research data from plots at Blackbird indicate that topsoiling significantly improved both establishment and production of grass (Farmer and others, 1976). Topsoil adds organic matter, tilth, and fertility to sterile spoils. After ripping, the entire area was covered with a layer of 8 inches of topsoil from a 5-acre forested area nearby. This topsoil was removed in a manner that left sufficient organic soil for revegetating the 5-acre area. Lime was then applied to the topsoil at the rate of 5 tons per acre and mixed into the topsoil by ripping.

Fertilizing

Proper fertilizing improves grass yields threefold under certain conditions (Richardson and Farmer 1980a) and aids both emergence and establishment of grass on acid spoils. Routinely, soil samples were taken and analyzed in order to properly determine fertilizer requirements. Fertilizer was applied at the rate of 520 pounds per acre, giving 83 pounds available nitrogen, 83 pounds available phosphorus, and 83 pounds available potassium Seventy percent of the nitrogen was in the form of ammonia (NH_4) and 30 percent was nitrate (NO_3). Fertilizer was incorporated into the topsoil with lime. An S-tine cultivator harrow thoroughly mixed the fertilizer into the soil, broke up large dirt clods, and produced a uniform seedbed.

Seeding

Natural topography divides the demonstration site into six working areas that vary in size, aspect, and slope; these characteristics and the seed mixture used on each are shown below (see photo page 112).

Area number	Acres	Slope	Aspect (facing)	Seed mixture
1	3.6	Flat to gentle	South	Mix #1
2	1.3	Flat to gentle	East	Alpine mix
3	2.8	Gentle	Southeast	Mixes #1 and #2 plus western yarrow
4	1.1	Nearly flat	Northeast	Mixes #1 and #2 plus white clover
5	2.5	Gentle	Northeast	Mix #2, without pubescent wheatgrass but with western wheatgrass, hairgrass, and western yarrow added
6	2.3	Steep	North	Mix #1

The Alpine mixture planted in area 2 is a standard mix available from the Northrup, King, and Company in Boise, Idaho[2/]. Seed for the hairgrass and western yarrow planted in area 5 had been collected by hand and were added to mix #2 without further treatment.

Content of the seed mixtures mentioned above is shown in Table 1. Each mix contained both native and introduced species, as this combination proved the best on the 1972 research plots (Farmer and others, 1976). The introduced species establish quickly, add organic matter to the soil, and generally make the microsite more hospitable. Results on Blackbird Mine research plots show that when cultural treatments such as ferilizer are discontinued, the native grasses compete successfully with the introduced species and thereby contribute greatly to the final success of rehabilitation. The species chosen for these mixes had already demonstrated greatest adaptability on the research plots. Some other species were added that I believed would complement the mixture and compete successfully. For example, some plants show greater tolerance to aluminum in acid spoils than do other plants.

All seed mixtures were applied at the rate of some 38 pounds per acre by a Brillion grass seeder (also called a "seeder packer"). The front rollers of the seeder prepare a firm, even seedbed, breaking up clods, closing air spaces, and creating furrows for the seed. The seedbox precisely meters seed into the well-prepared seedbed. Rear rollers split the shallow ridges formed by the front rollers and firm the soil around the seeds. The seedbed preparation and complete "planting" done by the machine ensure maximum germination.

Mulching

Mulching proved not to be a significant treatment at Blackbird. Previous research showed that it did not improve emergence over that in nonmulched plots. However, proper application of mulch does control wind and water erosion and contributes to water conservation (Aldon, 1979; Richardson and others, 1979b). A Fynn[2/] strawblower applied mulch to the demonstration area at the rate of 2,000 pounds per acre. The straw was crimped into the soil by a mechanical crimper to prevent movement of the straw, seed, and soil by winds and water.

[2/] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement of approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

Table 1. Seed mixtures used on demonstration areas at Blackbird Mine, 1972.

Mix #1	Mix #2	Alpine Mix
Orchardgrass (*Dactylis glomerata*)	Alta tall fescue (*Festuca arundinacea*)	Kentucky bluegrass (*Poa pratensis*)
Timothy (*Phleum pratense*)	Orchardgrass (*Dactylis glomerata*)	Timothy (*Phleum pratense*)
Smooth brome (*Bromus inermis*)	Smooth brome (*Bromus inermis*)	Chewings red fescue (*Festuca rubra* var. *commuta*)
Creeping foxtail (*Alopecurus arundinaceus*)	Creeping foxtail (*Alopecurus arundinaceus*)	Creeping red fescue (*Festuca rubra*)
Crested wheatgrass (*Agropyron cristatum*)	Clover (Alsike) (*Trifolium hybridum*)	Meadow foxtail (*Alopecurus pratensis*)
Intermediate wheatgrass (*A. intermedium*)	Timothy (*Phleum pratense*)	Smooth brome (Manchar) (*Bromus inermis*)
Western wheatgrass (*A. smithii*)	Crested wheatgrass (*Agropyron cristatum*)	White clover (*Trifolium repens*)
Pubescent wheatgrass (*A. intermedium* var. *trichophorum*)	Pubescent wheatgrass (*A. intermedium* var. *trichophorum*)	
Kentucky bluegrass (*Poa pratensis*)	Medium red clover (*Trifolium pratense*)	
Hairgrass (*Deschampsia caespitosa*)		
Idaho redtop (*Agrostis idahoensis*)		

DATA COLLECTION AND RESULTS, 1978 and 1979

In 1978 grass production was estimated on demonstration areas 1, 2, 3, and 4 using a double sampling method. Estimates were made using a Neal capacitance meter, Model 18-1000[2] (Neal and Neal 1973), which was calibrated by clipping, drying, and weighing grass produced on one out of every five or six plots. A linear regression curve was run to correlate the meter readings with the measured dry weights. In 1979 we measured all six areas by the same method. Both years we scanned the areas to get an ocular estimate of their species composition and to see what species were dominant.

Species Composition

The species growing on the demonstration areas in 1978 and 1979 are listed in table 2. The differences in results of assessment between 1978 and 1979 are believed to be due to differences in sampling dates and climatic conditions: 1978 sampling was done earlier in a wetter year, while 1979 sampling was done later in a drier year.

Production

During these two growing seasons, weather conditions were quite varied. Total precipitation for 1978 was 13 percent greater than the 4-year (1975-1979) average, and other growing conditions were generally favorable. However, in 1979 the total precipitation was 22 percent less than the 4-year average, and growing conditions were unusually severe. Production of grass in 1978 and 1979 is shown by the following tabulation.

Area number	Acres	Production (lbs/acre) 1978	Production (lbs/acre) 1979
1	3.6	1,100	1,031
2	1.3	1,094	893
3	2.8	2,859	1,224
4	1.1	656	374
5	2.5	---	918
6	2.3	---	1.172
Weighted average		1,603	1,007

Table 2. Species composition on demonstration areas at Blackbird Mine, 1978 and 1979.

Seed Mix	Species 1978	Species 1979
Mix #1 (Note: western yarrow not planted in these areas)	*Intermediate wheatgrass Wheatgrass Crested wheatgrass *Smooth brome *Timothy *Bluegrass *Orchardgrass	*Intermediate wheatgrass *Pubescent wheatgrass Crested wheatgrass *Smooth brome *Timothy Kentucky bluegrass Orchardgrass Redtop Western yarrow
Alpine mix		*Smooth brome *Timothy *Red fescue White clover
Mixes #1 and #2 plus western yarrow	*Smooth brome Intermediate wheatgrass *Pubescent wheatgrass Crested wheatgrass Kentucky bluegrass Meadow foxtail *Western yarrow	*Smooth brome Intermediate wheatgrass *Pubescent wheatgrass Crested wheatgrass Kentucky bluegrass Timothy Orchardgrass *Western yarrow
Mixes #1 and #2 plus white clover	Smooth brome *Wheatgrass *Timothy *Orchardgrass Hairgrass	*Smooth brome *Timothy *Kentucky bluegrass *Clover Hairgrass
Mixes #1 and #2 plus white clover	White clover	Fescue Western yarrow

* Dominant

Note: Intermediate and pubescent wheatgrasses are of the same species. They are highly promiscuous and, as a result, offspring are produced that have characteristics of both.

Although grass yields for both years are generally acceptable, production in 1978 was substantially greater than in 1979, as the individual data and the weighted averages show. Such variations are expected because of the differences in precipitation and other seasonal climatic factors (Sampson 1952; Vallentine 1971).

In 1978, representative samples (that is, whole plants) of various grass species were taken out of ripping marks and from the strip between ripping marks. The total biomass ratio of nonripped to ripped was measured at 1:2. The ratio of below-ground biomass (nonripped to ripped) was 1:2.4, while the ratio of "litter" (nonripped to ripped) was 1:1.6. The ratio of aboveground current year's growth (nonripped to ripped) was 1:2.4. Thus, the production of grass plants that benefited directly from the ripping was twice as much as that of the other grass plants.

The same study showed that shoot-to-root ratios for all samples were between 1:4.6 and 1:4.7. Therefore, if aboveground production is estimated to be 2,000 pounds per acre, root production can be estimated at 9,400 pounds per acre.

Blackbird Mine *spoils*--for that matter, many other surface mine spoils--are seriously lacking in organic matter, a primary constituent of any *soil*. Organic matter is essential to the fertility and good physical and chemical properties of a soil. It improves the cation exchange capacity (directly related to fertility), soil aggregation and tilth, efficiency of use of water, and adds essential elemental nutrients through biological decomposition, oxidation, and reduction. Rapid establishment of grass stands, including production of biomass both above and below ground, should be a primary goal of all mine spoil reclamation. Only plants that contain chlorophyll can produce organic matter from inorganic elements and sunlight; this is why they are highly instrumental in forming new fertile soil: "soil from spoil" (Richardson and others, 1979a).

As sterile spoils are converted to fertile soils, one would expect that native seed from adjacent forests would begin to germinate and grow in the more favorable site. We have in fact found this occurring. The 1978 and 1979 data from the 1972 research plots show that invasion of native species (primarily conifers, native forbs, and grasses) is occurring on the topsoil plots (Richardson and Farmer 1979). On the demonstration areas, hairgrass (*Deschampsia caespitosa*) and Idaho redtop (*Agrostis idahoensis*), both native grasses, and penstemon (*Penstemon fruticosus*) and yarrow (*Achillea millefolium*), native forbs, were found even in areas where these species had never been planted previously.

CONCLUSIONS

Continued assessment must be done for a number of years in order to evaluate the final success or failure of the demonstration areas. However, several valid conclusions may be drawn from data collected to date.

1. The "new" method for determining lime requirements for acid spoils (Sorensen and others, 1980) has proved satisfactory thus far. By the summer of 1979 there were no indications of reacidification.

2. Ripping greatly improves soil aeration, moisture retention and movement, and tilth. It promotes better root penetration and reduces compaction; this, in turn, results in increased grass vigor.

3. Several species of native grasses, forbs, and legumes (especially white clover) appear well adapted for use in reclaiming acidic spoils.

4. Methods and techniques are available for establishing plant cover adequate to insure protection from erosion by wind and water on acid mine spoils.

5. Recognizing that organic matter is the single most important constituent for soils, maximum *production* of organic matter (plant biomass) by selecting suitable plant species and using fertilizer appears to be one of the most important factors in early establishment and longevity of vegetative cover. It could be much more important than introducing organic soil amendments (mulches) into the surface few inches of the spoil (Richardson and Farmer 1980b). Results on Blackbird Mine research plots show that when cultural treatments such as fertilizing are discontinued, the native grasses and forbs compete successfully with the introduced species, thereby contributing greatly to the final success of the rehabilitation effort.

6. Actual longevity of the revegetation project is not known. While it is essential that yearly monitoring be continued, there is every indication to date that natural succession is taking place and is due to the improved quality of the spoil.

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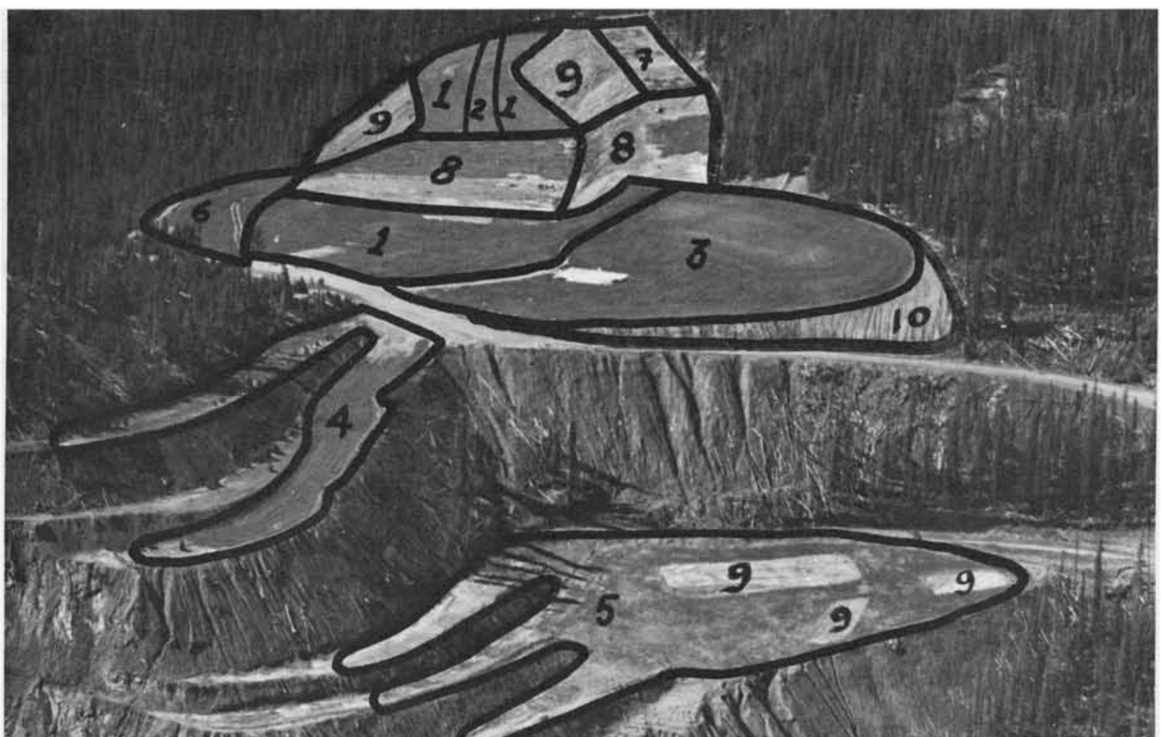

(see text page 104)

REVEGETATION-RESTORATION FOR THE TRANS-ALASKA PIPELINE SYSTEM

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In the mid twentieth century it became apparent to both the American people and the American policy makers that a national charter was required to insure proper management of a quality environment. To meet this need the National Environmental Policy Act of 1969 was passed by Congress and became public law.

In 1968, just prior to this landmark legislation, oil was discovered on the North Slope of Alaska. Research within the industry pointed to a large diameter pipeline as the most practical and economical method of transporting this huge reserve of crude oil to an ice-free port and then on by ship to markets in the southern contiguous states. Because of the protracted litigation surrounding the pipeline project, Congress felt it necessary in 1973 to pass an authorization act to insure timely construction.

In the intervening years between oil strike and construction approval, intensive research was being conducted on methods for minimizing the project's potential impact on the arctic and subarctic environments. Manifested in the "Agreement and Grant of Right-of-Way for the Trans-Alaska Pipeline" are the environmental stipulations that outline Alyeska's responsibility to rehabilitate, revegetate or otherwise restore any damage that results from construction, operation or termination of the pipeline system.

Revegetation is an intergral part of Alyeska's rehabilitation effort. By the time the first barrel of oil entered the pipeline in June of 1977 our revegetation program was in full swing and nearing the 50% completion mark. This last January the one billionth barrel of oil was transported from Prudhoe Bay to Valdez and the revegetation of all construction disturbed lands was complete with a total of nearly 18,000 acres restored.

Geographical Facts

For revegetation purposes the 800 mile pipeline traverses four ecologically and geographically distinct zones in Alaska. The "Arctic Tundra" zone of Alaska's North Slope covers approximately 130 miles of the right-of-way with lowland (wet) and the foothill (moist) tundra habitat types. The lowland tundra type is characterized by its sedge (Carex spp.) communities, a lack of topographical relief and the presence of large volumes of standing water during the summer. The foothill tundra consists of tussock forming plant communities and shows the characteristic polygonal patterns of the subsurface ice wedges. In both these areas continuous permafrost can be found near the surface. These areas were seeded with Alyeska seed mix 1A (North Slope) at a rate of 46 pounds per acre. (See Table I)

TABLE I

ALYESKA SEED MIXTURES

	1A North Slope	2A Brooks Range	3A Interior	4A Alpine
Arctared Fescue	11	4		4
Nugget Blue	11	9	5	
Redtop	1	3		
Boreal Red Fescue	9	9	9	5
Durar Fescue		9	5	
Arctic Grass	1			
Climax Timothy		4	2	
Meadow Foxtail		10	6	11
Manchar Brome			9	2
Sydsport Blue				13
Annual Rye	13	12	7	7
Rate per acre in pounds	46	60	40	42

The "Alpine" zone of the pipeline right-of-way covers approximately 160 miles and is found in the Alaska Range. This area is characterized by the high barren ridges, a mat vegetation and the dwarf shrubs associated with the river valleys. Alyeska seed mix 4A was used at a rate of 42 pounds per acre. (See Table I)

The "Brooks Range" zone was singled out as a separate entity for our revegetation purposes and includes some 100 miles. This area encompasses the higher elevation foothills both north and south of the Continental Divide crossed by the pipeline at Atigun Pass. Alyeska seed mix 2A was used exclusively in this area at a rate of 60 pounds per acre. (See Table I)

The remainder of the 410 pipeline miles were consolidated under the designation of "Interior". In fact, this zone was really two separate geographical areas but similar enough for our extensive revegetation purposes.

The interior of Alaska, from the upper Koyukuk River valley north of the Arctic Circle to the northern foothills of the Alaska Range is crossed by approximately 300 miles of the Alyeska pipeline. This area is best characterized by the boreal forest composed of white and black spruce, paper birch and aspen.

The southern 110 mile portion of the pipeline ranges in habitat types from the boreal forest to the coastal coniferous forests composed of Sitka spruce and hemlocks.

These two areas were both seeded at a rate of 40 pounds per acre with Alyeska seed mix 3A (Interior). (See Table I)

Alyeska, after a 15,000 sample soil fertility investigation, partitioned the pipeline right-of-way into three main areas for its specialized fertilizers. (See Table II)

Mix III (14-7-21) and Mix IV (13-14-17) were used in various localities south of the Yukon River at a rate of 600 pounds per acre. In general, Mix III was used in conjunction with the "Interior" seed mix while Mix IV was used with the "Alpine" seed mix. Mix V (10-15-14) was used for all areas north of the Yukon River at a rate of 650 pounds per acre.

Three other fertilizers were designed for special applications. Mix I (10-32-10) and Mix II (15-20-15) were designed for maintenance use at 300 pounds per acre or as additional phosphate sources on cut and fill slopes at 365 and 584 pounds per acre respectively. Monoammonium phosphate (13-52-0) was also approved as an additional phosphate source at 225 pounds per acre.

All the fertilizer mixes were sulpher-urea coated to enhance a time release mechanism and Mixes III, IV and V contained a predetermined amount of micronutrients. (See Table II)

Revegetation Procedures and Techniques

The Alyeska restoration program is a three stage process. Stage EC-1 was the initial erosion control effort during the construction phase of the

TABLE II

ALYESKA FERTILIZER MIXTURES

Mix	Rate/ Acre	N	P_2O_5	K_2O	S	Mg	Cu	An	B	Mo
I	(300)	10	32	10						
II	(300)	15	20	15						
III	(600)	14	7	21	8.5	4.25	.33	.56	.14	.0250
IV	(600)	13	14	17	5.2	4.2	.36	.58	.14	.0250
V	(650)	10	15	14	5.0	3.6	.36	.48	.12	.0230
Special	(225)	13	52	0						

project. It applied only to those disturbed areas where immediate attention was required to prevent soil erosion and/or where further disturbances were not planned. Necessarily this was the least active stage of the overall revegetation effort as most sites remained in use throughout the construction phase of the project. The majority of the EC-1 effort was spent revegetating cut and fill slopes associated with both the pipeline right-of-way and the 358 mile North Slope Haul Road that parallels the pipeline from the Yukon River to Prudhoe Bay. This phase of the restoration program extended over two years and included a revegetated area of approximately 2,000 acres.

Stage EC-2 was the major revegetation effort of the project. All construction disturbed sites were final graded and all remaining erosion control, revegetation and rehabilitation took place at this time. This phase also covered two years but was much more extensive than the previous stage. In all, over 16,000 acres were revegetated during EC-2.

Alyeska is now in Stage EC-3 which is the maintenance program for the previously revegetated sites as required for proper erosion control.

The techniques utilized in our revegetation efforts are fairly standard to the farming community and most highway departments. Initially, the disturbed sites were final graded and scarified to a depth of four inches as a seedbed surface preparation. On saturated sites, or those with a high percentage of fine soils and organics (spoil disposal sites), scarification was not required. In most cases the scarification was accomplished with a disc harrow or a Caterpillar 14G motor grader with a ripper/ scarifier attachment. Both the final grading and the scarifying were performed using the natural contours of the site as much as possible. This enhanced not only the natural drainage pattern of the site but its aesthetic appearance as well.

Although a specification existed which allowed "temporary" seeding (15-30 pounds per acre of annual rye) for erosion control purposes most all seed distribution came under the heading of permanent. The permanent seed mixes (See Table I) are combinations of perennials and an annual that would meet both short term erosion control and long term restoration needs.

Because of the limitations on the northern growing season seeding "windows" were established to take advantage of the optimum conditions. All of the geographical seeding zones along the pipeline were allowed by specification to start the revegetation effort as soon as practicable after spring breakup. From the upper Koyukuk River Valley at Coldfoot to the Beaufort Sea (approximately 230 miles) the seeding "window" closed on July 15. South of Coldfoot the "window" closed on August 1. The net effect of this is two seeding seasons, one of approximately 45 days for the northern third and one of approximately 80 days for the southern two-thirds of the pipeline.

Because of the extensive acreages involved, a third seeding "window" was developed. An option existed to seed dormantly after the first killing frost and to continue until crusted snow was in excess of two inches. For our revegetation purposes the first killing frost was defined as a continuous twelve hour period of 32°F (0°C). This could occur north of the Brooks Range anytime after mid-August and might not occur south of the Chugach Range until after mid-October.

Various seed application procedures were utilized. In Stage EC-1 hand seeders, hydroseeders and small ground driven mechanical spreaders were used. The areas to be restored in this phase were relatively small and widely spaced.

In EC-2, which included the majority of the revegetation acreage, hand seeders, hydroseeders, both large and small ground driven spreaders, air impellar spreaders, helicopters and fixed-wing aircraft were used.

Fixed-wing application proved to be the most economical and productive provided proper landing and loading sites were available. North of the Yukon River we took advantage of the Haul Road's proximity and used it both as airstrip and load site. The plane was able to land, load and take-off in five or six minutes without any long road closures. Using a Cessna AgTruck costs were about $125 per acre.

Because flying conditions in Alaska are unpredictable we flew shifts during the day and under the midnight sun.

Other than inclement flying weather the biggest obstacle to aerial distribution of seed was crosswinds in excess of five miles per hour. This was especially true with the seeding of the 85-100 foot wide pipeline workpad.

During the inclement weather or high crosswinds seed distribution was from ground driven mechanical spreaders. Although all types of common bulk spreaders were used, from the overall versatility standpoint a small four-wheel drive diesel tractor with a power take-off spinner type spreader proved to be the best for us. Being four-wheel drive this tractor was able to negotiate steep cut slopes, wet or saturated sites and more important to Alyeska ... both sides of the above ground pipeline. Seed application in this method cost approximately $270 per acre.

The hydroseeders were used for all cut slopes and hard-to-reach places. It was not used for vast areas because its labor-intensive nature boosted costs to $450 per acre. Likewise, the efficient, but costly helicopters were used only sparingly.

Fertilizer distribution techniques were similar to seeding with two major exceptions. Hydrofertilization was not allowed as the time-release mechanism was destroyed by the hydroseeder agitation and in certain times of the year liquid fertilizer of these types could prove harmful to the existing vegetation. Large bulk spreaders of the five ton capacity were employed as much as possible. Bulk spreading cost approximately $630 per acre.

Aerial fertilization could be successfully accomplished in crosswinds up to ten miles per hour and was employed when weather permitted. This method could be accomplished for approximately $350 per acre.

To finish all revegetated areas except those that had been hydroseeded a tine harrow or drag was applied to the site following the natural contours. This aided in lessening the effects of seed redistribution by wind which we suspect is a major contributor to a lack of success in some arctic revegetation efforts.

Mulching was employed on certain special sites and with the hydroseeding program. Wood cellulose fiber was used in our hydroseeders at approximately 1500 pounds per acre. Straw and excelsior were used when revegetation was in areas of thermal erosion. Straw at 3000 pounds per acre was tacked with the mechanical crimp method, tack netting or polyvinyl acetate.

Because of the extensive acreages we were dealing with, watering was neither feasible nor attempted.

One other type of revegetation bears mentioning. Due to a request from the regulatory agencies, Alyeska has undertaken a project to investigate the feasibility of reintroducing over one million willow plants (Salix spp.) on 890 acres of possible wildlife habitat north of the Brooks Range. Currently, we are in our third year of a three year contracted research project and expect their recommendations in early 1981.

Revegetation of Terrestrial Oil Spill

In February of 1978 an incident of sabotage on the pipeline resulted in a golf ball sized hole in an above ground section of pipe near Fairbanks. Approximately 16,000 barrels of 50°F crude oil escaped into the environment.

The area of discharge was within the drainage of a small tributary of the Chena River. The existing vegetation was boreal forest on muskeg and there was an 18 inch snowpack. The ambient air temperature was near $0^{o}F$. The total area affected was limited to 2.1 acres because of quick action by the response crews and winter conditions.

The containment and recovery process started immediately as did the pipeline repair. The repairs were completed and the pipeline was functioning normally in less than 24 hours. The recovery process took sixty-three days and culminated with the recovered crude oil being reinjected into the pipeline system.

The residual crude left after recovery operations was burned in mid-April of that same year. In an attempt to recover more crude a portion of the spill site was disked and reburned.

After breakup the entire area was fertilized by hand with Alyeska Mix I (10-32-10) at a rate of 1000 pounds per acre. No seeding was attempted but natural recovery and reinvasion of the local flora covered 50% of the spill site by the end of the first growing season.

During breakup of 1979 some residual crude was recovered and after snowmelt water was drained from the site using inclined culverts the entire area was refertilized. Along with Alyeska fertilizer Mix IV (13-14-17) at 600 pounds per acre the spill site was seeded with our "Interior" mix at a rate of 40 pounds per acre. The results were a close to 100% grass cover of the site.

In the future we will continue to recover any residual crude oil each spring and, for 1980 at least, refertilize the entire site to promote further recovery of the native species.

Revegetation Maintenance Programs

Throughout the estimated thirty year life of the pipeline Alyeska will maintain a responsibility to control erosion through revegetation. In 1980, scheduled field programs include 642 acres of revegetation and 1,115 acres of remedial fertilization. Both seed and fertilizer will be applied with bulk spreaders and other ground-driven spreading apparatus.

In addition, "spot" revegetation will follow on any redisturbance of the restored acreages. "Spot" revegetation is an intergral part of our field activities as most of our maintenance crews routinely carry seed, fertilizer and hand-operated spreaders.

We take pride in our restoration efforts and will continue to strive for negligible soil losses through our revegetation program.

AN ASSESSMENT OF REVEGETATION TECHNIQUES FOR ALPINE DISTURBANCES

Ray W. Brown and Robert S. Johnston[1/]

The immediate goal of revegetation is to provide protection and surface stability to disturbances. Esthetic appeal and site productivity are also important considerations in most instances. Techniques such as shaping and contouring the site, fertilizing, mulching, and seeding and planting are used to accomplish these objectives. These techniques alter the extreme conditions of the disturbed land so the edaphic and microclimatic factors are commensurate with the physiological tolerance limits of plants adaptable to that region. The primary hydrologic objective is to reduce runoff and erosion while providing for the movement of water. Establishing protective plant cover is usually the principal means of achieving this hydrologic objective, while simultaneously providing esthetic appeal and site productivity.

The longer range goals of revegetation are often not as well defined. In the mountainous regions of the West, where management options are limited, long-range goals of revegetation usually focus on restoring disturbed land with self-sustaining vegetative cover that provides site stability. Various legislation and regulation have recently attempted to define these goals with specifics, but often they are unrealistic because they conflict with basic ecological principles of plant succession and environmental limitations. One extreme philosophy, that people can improve nature, supposes the pompous attitude that if we legislate or desire a state of nature, we can make it happen. But the alpine zone, for example, will not be made to produce more than environmental conditions can support without a tremendous artificial investment of resources.

On the other extreme is the "organic" approach, preaching that only natural processes should be tolerated. While the most expedient revege-

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tation techniques use the natural forces of plant succession to advantage, some levels of cultural treatments can markedly enhance revegetation. The rather sluggish nature of plant succession, even when supplied by an abundant natural seed supply (Howard 1978), will most often not achieve the socially-imposed standards of revegetation. This is particularly true in the alpine zone where environmental conditions approach the limits of vascular plant adaptability.

Economic constraints are often used to justify applying only minimal revegetation efforts to achieve short-range goals. The theory that "nature will then take over" and somehow magically return the site to a climax condition is often not realized. Natural plant succession studies on severe disturbances at high elevations show that the time scale standards of humans and of nature may not be compatible. Plant cover that meets immediate goals does not necessarily indicate a priori link to long-range goals. The level and intensity of site treatment needed to surpass initial stand establishment may substantially exceed minimal prescriptions. Selecting a long-range target for revegetation, and then matching it with appropriate cultural practices, is an imposing challenge.

Revegetation research on alpine disturbances of the Beartooth Plateau in Montana were reported in the previous two workshops of this series (Brown et al. 1976; Brown and Johnston 1978). This paper will draw together the research progress to date and integrate it with basic principles of revegetation. Specifically, we will focus on revegetation techniques developed for alpine disturbances, assessing their affect on plant succession and long-term objectives. Finally, a proposal is made to redefine more natural criteria of alpine revegetation objectives based on these assessments.

ASSESSMENT OF REVEGETATION TECHNIQUES

Revegetation techniques include options ranging from no treatment to multiple-step methods of compound amendments. Generally, at least some level of treatment enhances success. Only rarely can drastic disturbances be revegetated within acceptable standards without some level of amelioration. Revegetation techniques are usually applied in an effort to accelerate the early stages of plant succession and to achieve advanced stages more quickly.

The most common long-range target of revegetation on alpine disturbances is the establishment of a plant cover similar to surrounding undisturbed plant communities. This probably is also true for disturbances in most other ecosystems of the mountain West unless viable alternatives can be economically justified. The implication is that the complexities of environmental limitations, the effects of cultural practices, and the physiological tolerance limits of plants can all be matched. Unfortunately, knowledge is frequently the most limiting factor, and scientists realize that native plant communities may never be duplicated identically because climate, soils, and other factors may now be different from that of the past (Ward 1974).

The level of technological sophistication in quantifying many of the physical and chemical factors of the environment has advanced significantly in the last decade. However, translating these measurements into meaningful terms of plant adaptability remains somewhat more elusive. Species adaptability itself remains a poorly defined quality. For example, the assertion that native species are better adapted to alpine disturbances than most commercially available introduced species (Brown and Johnston 1979) can be challenged. The alternative assertion can be made that climatically adapted species in a region may not be adapted to spoils on a disturbance. On the other hand, research shows that the characteristics of spoils can be altered with amendments, whereas climate generally cannot. Growth and survival data also tend to support the indication that native species are better adapted, but these are only indirect measures that must be reverified through field trials. Fortunately, rapid progress is being made in plant breeding (Dewey 1976) and plant physiology (Johnson 1978) and may soon provide more tangible means of assessing this variable.

The limiting factors to plant growth on alpine disturbances (such as short growing seasons, low summer temperatures, low fertility of disturbed soils, and so forth) have only been broadly defined (Brown et al. 1978, Johnston et al. 1975). In addition, some alpine plant species have shown promise for revegetation (Brown and Johnston 1978 and 1979, Brown et al. 1978), but their tolerance to specific environmental factors is still virtually unknown. A limited number of alpine species have been studied in detail (Billings 1974, Billings and Mooney 1968, Bonde 1968, Mitchell 1972 and 1978, Tranquillini 1964), but their revegetation potential is uncertain.

Although documented research of alpine revegetation is limited, a growing number of recent studies provide useful information (Bell and Bliss 1973, Belsky 1975, Brown and Johnston 1976, 1978 and 1979; Brown et al. 1976 and 1978; Gregg 1976; Johnston and Brown 1979; Johnston et al. 1975; Marr et al. 1974; Selner and King 1977; Willard and Marr 1970 and 1971). Unfortunately, little information is available that relates revegetation techniques with natural plant succession. Research on the Beartooth Plateau in Montana provides preliminary evidence that some revegetation techniques can be used to enhance succession (Brown and Johnston 1978, 1979). More recent analyses of these studies show that techniques are currently available that can advance plant succession sufficiently to meet both short-range and long-range revegetation goals. A brief summary of these studies and the techniques used in them is provided below.

Intensity of Revegetation Treatments

Plot Studies.

Field plot studies are frequently used to determine the minimum revegetation treatments required to achieve a protective plant cover. Alternative cultural practices, species mixtures, and other treatments are replicated in various designs to provide statistical verification of results. Brown and Johnston (1976) used this approach on the McLaren Mine in the Beartooth

Mountains. In autumn 1974, 72 plots were established on acid spoil material to test the effects of topsoil, spoil, fertilizer, and no fertilizer in all combinations on plant establishment and growth. Two different seed mixtures were also studied: a mixture of six native grasses and one sedge observed as active colonizers on the mine was seeded in half the plots; and a mixture of seven introduced species, commonly used for revegetation in other areas and commercially available, was seeded in the other half. Analyses of the spoil material showed low levels of fertility and poor physical and chemical characteristics for plant growth.

The plots were assessed each growing season for 5 consecutive years (1975 to 1979) for cover, plant production, density, and species composition and diversity. Each year the fertilized plots were retreated with a maintenance level granular fertilizer (16-40-5 NPK ratio) at the rate of 20 lbs. of N per acre (22.5 kg per ha). In retrospect, the results of these trials were predictable, providing quantitative measurements of the effects of these minimum treatments. The most favorable responses occurred on plots fertilized and seeded with the native species. However, these responses occurred much more slowly than expected. It was not until the third growing season (1977) after seeding that plant responses were strongly evident.

The unfertilized plots never produced a significant stand of vegetation on either the topsoil or spoil material after 5 years. The most favorable stands of vegetation were initially produced on the fertilized and topsoil plots, but by 1979 there was no significant difference between them and the fertilized spoil plots. Plant succession by invading colonizers was not significantly enhanced until 1978. During this period virutally all of the introduced species had died, and by 1978 these plots were supporting a stand of native colonizers. This study showed that fertilizer is an essential ingredient for the revegetation of this type of disturbance in the alpine zone, and that native colonizer species appear to be better adapted than most common introduced species. However, because of the acid nature of the spoil material, nutrient availability was severely limited.

Bioassay Studies.

A bioassay study of McLaren Mine spoil material was conducted under controlled greenhouse conditions to assess plant growth under various levels of intensive treatments (Brown and Johnston 1980). We studied amendments such as fertilizer, lime to raise pH, organic matter incorporated in the spoil to enhance water and nutrient holding capacities, and surface mulch to improve microclimatic conditions. These treatments, when compared with controls and the treatments used on the field plots, showed markedly enhanced rates of plant growth and development. Although this study was conducted under greenhouse conditions, it suggested that field applications may also enhance both plant development and succession more than the treatments used in the plot study. Also, this study showed that native alpine colonizers respond vigorously to cultural amendments in spoils.

Demonstration Area Studies.

The optimum treatments from both the bioassay and field plots studies were combined and applied to acid spoils on the McLaren Mine in 1976 (Brown and Johnston 1978). A 0.6 ha (1.5 ac) area was shaped, contoured, and then treated with optimum levels of fertilizer, lime, manure, native seed, and an organic surface mulch. The native species in the seed mixture were the same as those used on the plots in 1974. We wanted to determine if results from small field plots and greenhouse bioassay studies could be translated onto a large scale field application. Another objective was to test the hypothesis that increased levels of cultural treatments would enhance rates of plant development and succession.

The first-year results (1977) of this study were discussed during the third workshop of this series (Brown and Johnston 1978). Assessments of cover, plant production, plant density, species composition and diversity, and other characteristics have now been made for 3 consecutive years. The same maintenance level of refertilization has been applied each year as was used on the plots. The longer-term results of this intensive revegetation will be compared with recent results on the plot study, which represents less intense management. These results will also be compared with those of similar studies conducted on plant communities on-and-adjacent to the McLaren Mine.

Effect of Revegetation Treatments on Plant Responses

We assumed that the native, undisturbed plant communities adjacent to the McLaren Mine represent the highest level of plant development attainable under natural conditions in that area. As such, they provide an approximate target for the revegetation effort. Although more productive targets could undoubtedly be achieved through intensive post revegetation management, the objective here is to return the site to a self-sustaining system in harmony with natural successional forces as soon as possible.

On the other extreme, the natural successional communities of native colonizers on the mine represent the lowest acceptable level of plant development. The McLaren Mine was abandoned in 1952, and successional development has been progressing for nearly 30 years on these acid spoils. It is reasonable to assume, then, that various levels of revegetation treatments will result in plant communities whose characteristics are between these two extremes. Furthermore, those revegetation techniques that provide a vegetative cover most similar to the target in the least time would be judged most successful.

In order to quantify the relative position of the revegetation efforts with respect to the two target extremes, various vegetation characteristics were measured. We felt that many different characteristics should be analyzed to reduce the chances of bias that can result when only one or a few variables are considered. The characteristics measured were: plant cover; shoot biomass (g/m^2); root biomass ($g/m^2/10$ cm depth); plant density (number of individuals per unit area); and plant composition and species diversity (total number of species, and the number of species of forbs, grasses, and sedges). These analyses were made on five different kinds of plant communities in 1979: 1) native undisturbed communities adjacent to the McLaren Mine; 2) natural successional communities on the mine; 3) the demonstration area representing an intensive level of revegetation treatment; 4) the native species and fertilized plots treatment of the plot studies; and 5) the introduced species and fertilized plots of the plot studies. The plots in 4 and 5 represent a less intensive revegetation treatment. The results from the unfertilized plots are not included here because of the poor responses produced.

Plant Cover.

Plant cover percent is a frequently used index for soil surface protection and for watershed protection criteria (Packer 1951 and 1953, Meeuwig 1960). A comparison between the demonstration area and the two plot treatments of percent plant cover over time is presented in fig. 1. The first year after seeding, the demonstration area (McLaren Demo.) supported a plant cover more than 50 percent higher than either the native-fertilized (N-F) or the introduced-fertilized (I-F) plots had their first year. The two studies were started in different years, but the annual and growing season precipitation data were similar during their respective first-growing seasons. Also, the spoil material from the two sites had virtually identical characteristics. The data in fig. 1 show that the best plot treatment required about four years to develop a high level of plant cover. However, the demonstration area reached a higher level during the first year, and has maintained more than 50 percent plant cover since.

A comparison of plant cover on these two study sites with that on undisturbed and succession (McL dist.) plant communities in 1979 is shown in fig. 2. These data show that the demonstration area, after only 3 growing seasons, supports a higher plant cover than the undisturbed plant communities. However, the native-fertilized plots (McL 72 Nat) after 5 growing seasons have achieved only an intermediate cover between the undisturbed and successional communities. The introduced-fertilized plots (McL 72 Int) represent the invasion of native species after five years of succession, and not the growth of the originally seeded introduced species. Their relatively low cover is probably due to the short amount of time that succession has been progressing on them.

Shoot Biomass.

The production of plant biomass is a common unit for characterizing plant communities and is a useful index of site productivity. Shoot or above-ground production in alpine ecosystems is usually lower than most other terrestial ecosystems (Webber 1974) but can be a useful measure of grazing potential. A comparison of shoot production (g/m^2) among the five different plant communities is illustrated in fig. 3. Shoot production of the native-fertilized plots and of the demonstration area are both higher than either the undisturbed or the succession plant communities. This relationship is apparently due to the annual refertilization treatments on both revegetation sites. The introduced-fertilized plots are occupied by plants that are still too young and sparsely distributed to provide significant production. The demonstration area has maintained a shoot production level higher than the undisturbed communities for each of the 3 years since it was established, but the native-fertilized plots did not exceed that level until the fourth year.

Root Biomass.

Root biomass, another useful measure of site productivity, is frequently overlooked in revegetation assessments. Root biomass may be even more important than shoot production in assessments of revegetation because of its significance to plant survival, soil building, and site stability. The data in fig. 4 show that the demonstration area in only 3 years has attained a level of root biomass ($g/m^2/10$ cm depth) similar to that of native undisturbed communities. However, after 5 years, the best plot treatments still have lower root biomass than the natural successional communities on the mine. This is due to two primary influences: the spoil material is shallower, and the acid spoil on the plots was never limed--hence nutrients have not been as readily available in the early years after seeding when the plants were younger.

Plant Density.

Plant density is a useful characteristic of plant communities because it provides a relative measure of the spatial arrangement of plants and has significance to surface protection. The 1979 density data for the five plant communities are compared in fig. 5. Interestingly, the demonstration area has a lower total plant density than all of the other communities except the introduced-fertilized plots. But of greater significance is the relative density of seedlings to mature plants. Both the demonstration area and the native undisturbed communities have a relatively low proportion of seedlings, whereas the succession communities and the plots are composed primarily of seedlings. Thus, most of the plants on the demonstration area are large, each occupying a much greater area than the smaller plants of the other communities on the mine.

Generally, the plant communities on the mine are of a lower successional status than the native undisturbed communities adjacent to the mine. Plants on the mine are mostly bunch-grasses and sedges, whereas those in undisturbed communities are primarily forbs. An approximate successional sequence of development in the McLaren Mine area can be summarized as progression from low stages of succession primarily of grasses, to intermediate stages of grasses, sedges, and few forbs, to late stages of mostly forbs with few sedges and grasses. The data in fig. 5 illustrate a striking similarity between the demonstration area and the undisturbed communities.

Plant Composition and Species Diversity.

The composition and diversity of plants and species in a plant community offer a relative measure of floristic richness. This is particularly useful

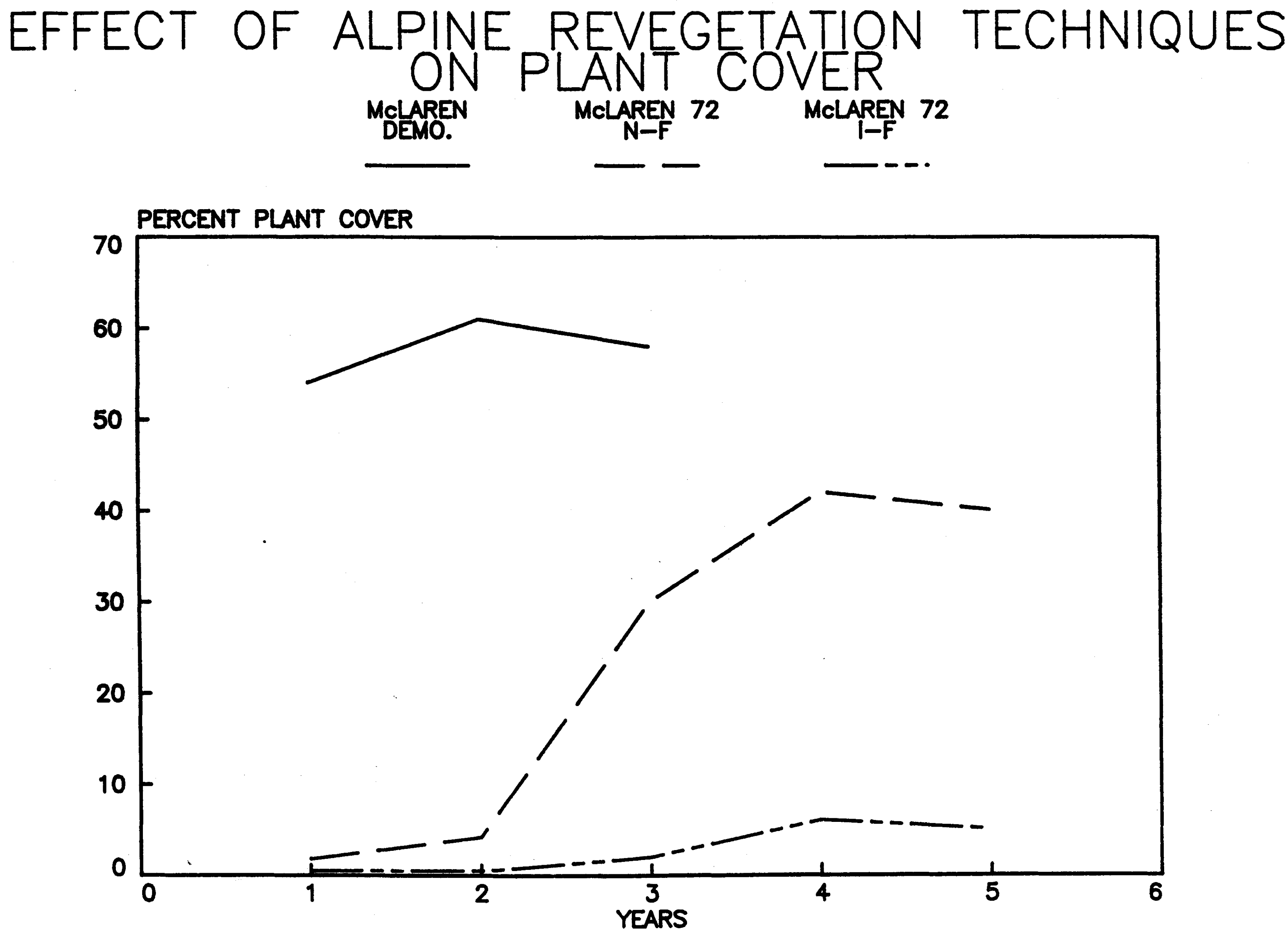

Figure 1. Percent plant cover as affected by time (years after seeding) for the McLaren Mine demonstration area (McLaren Demo.), the native-fertilized plots (McLaren 72 N-F), and the introduced-fertilized plots (McLaren 72 I-F).

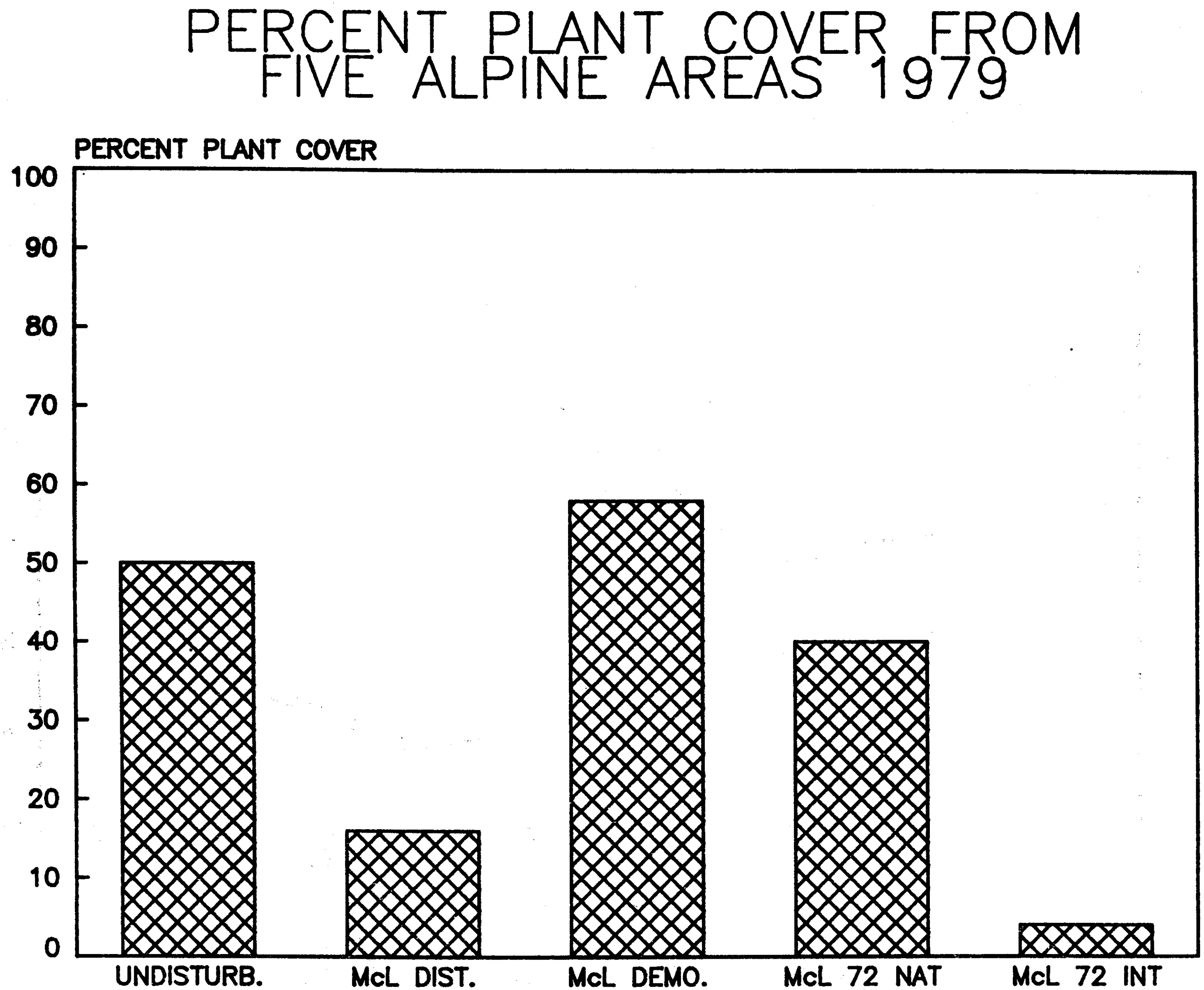

Figure 2. Comparison of percent plant cover among five plant communities in the McLaren Mine area. These include: native undisturbed plant communities (undisturb.); succession communities on the mine (McL. dist.); the demonstration area (McL. demo.); native-fertilized plots (McL. 72 nat.); and introduced-fertilized plots (McL. 72 int.).

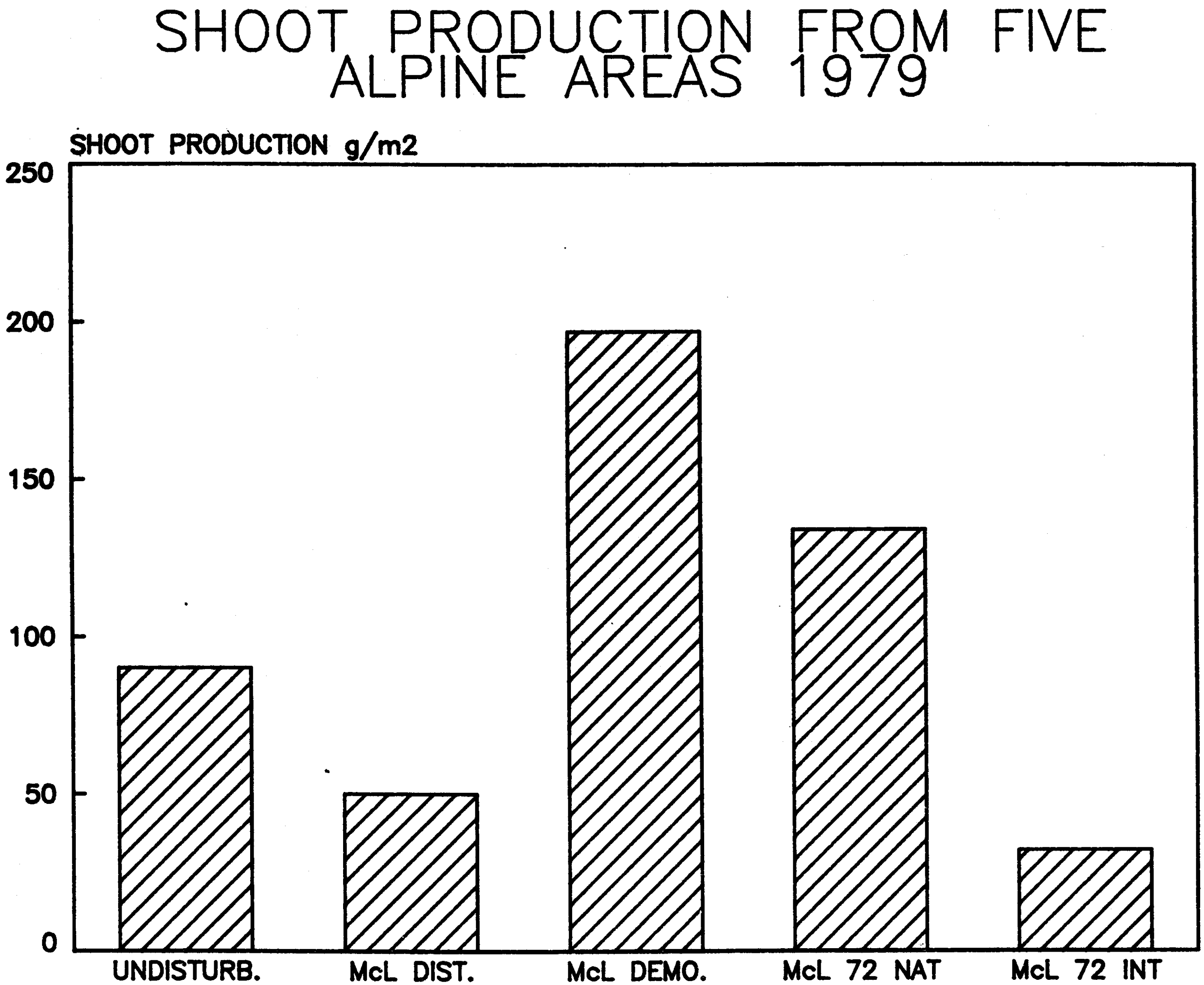

Figure 3. Comparison of shoot production (g/m^2) among five plant communities in the McLaren Mine area. These include: native undisturbed plant communities (undisturb.); succession communities on the mine (McL. dist.); the demonstration area (McL. demo.); native-fertilized plots (McL. 72 nat.); and introduced-fertilized plots (McL. 72 int.).

when comparing revegetation progress with target objectives, and is especially useful when analyzing plant density. The data in fig. 6 summarize the total species, forbs, and grasses, for each of the five communities. The number of sedge species is not included here but is represented by the difference between the total number of species and the sum of the number of forbs and grasses in fig. 6. The demonstration area has a similar number of species as the undisturbed communities, but with slightly fewer forbs and more grasses. The other plant communities on the mine are composed of fewer species, mostly of grasses with only a few forbs.

Although the undisturbed plant communities have a much higher plant density than the demonstration area (fig. 5), their flora is composed of smaller sized forbs with fewer grasses. These data, in addition to those in fig. 6, show that after only 3 years the demonstration area has attained a level of diversity more similar to that of the undisturbed communities than any of the other sites on the mine.

Assessment of Intensive Levels of Treatment

The remarkable rate of plant development on the McLaren Mine demonstration area is directly attributable to the intensive levels of site treatment provided during the last three years. Initially the acid spoils were treated with lime to raise the pH from about 3.6 to about 6.0. Recent spoil analyses verify that the pH has not declined appreciably. Also, the site has been fertilized each year in late July (the alpine spring) with a granular 16-40-5 fertilizer at a maintenance rate of 20 lbs. of N per acre (22.5 kg per ha). The three-year history of plant response on this site is summarized in fig. 7, which shows a gradual decrease in plant density, a steady increase in above-ground production, and a nearly uniform plant cover from year-to-year. These data help explain fig. 5 and 6: as the individual bunch-grass plants increase in size, competition results in a lower plant density. However, the larger mature plants are contributing to greater site productivity each year while maintaining a relatively high level of plant cover. Plant succession has also accelerated on the demonstration area as evidenced by the invasion of grasses and forbs not originally seeded there.

DISCUSSION AND CONCLUSIONS

Intensive levels of treatment appear to accelerate revegetated areas toward the target attributes of undisturbed plant communities. A number of ways exist to assess revegetation success, but focusing on the characteristics of adjacent native undisturbed communities has more considerable ecological merit. In such cases, the extremes of ecological succession are well defined. The disturbed condition represents the lower end of the successional scale, while the undisturbed plant communities represent the other extreme. The revegetated stand can then be evaluated over time as it progresses between these two extremes. This approach provides a quantitative means for

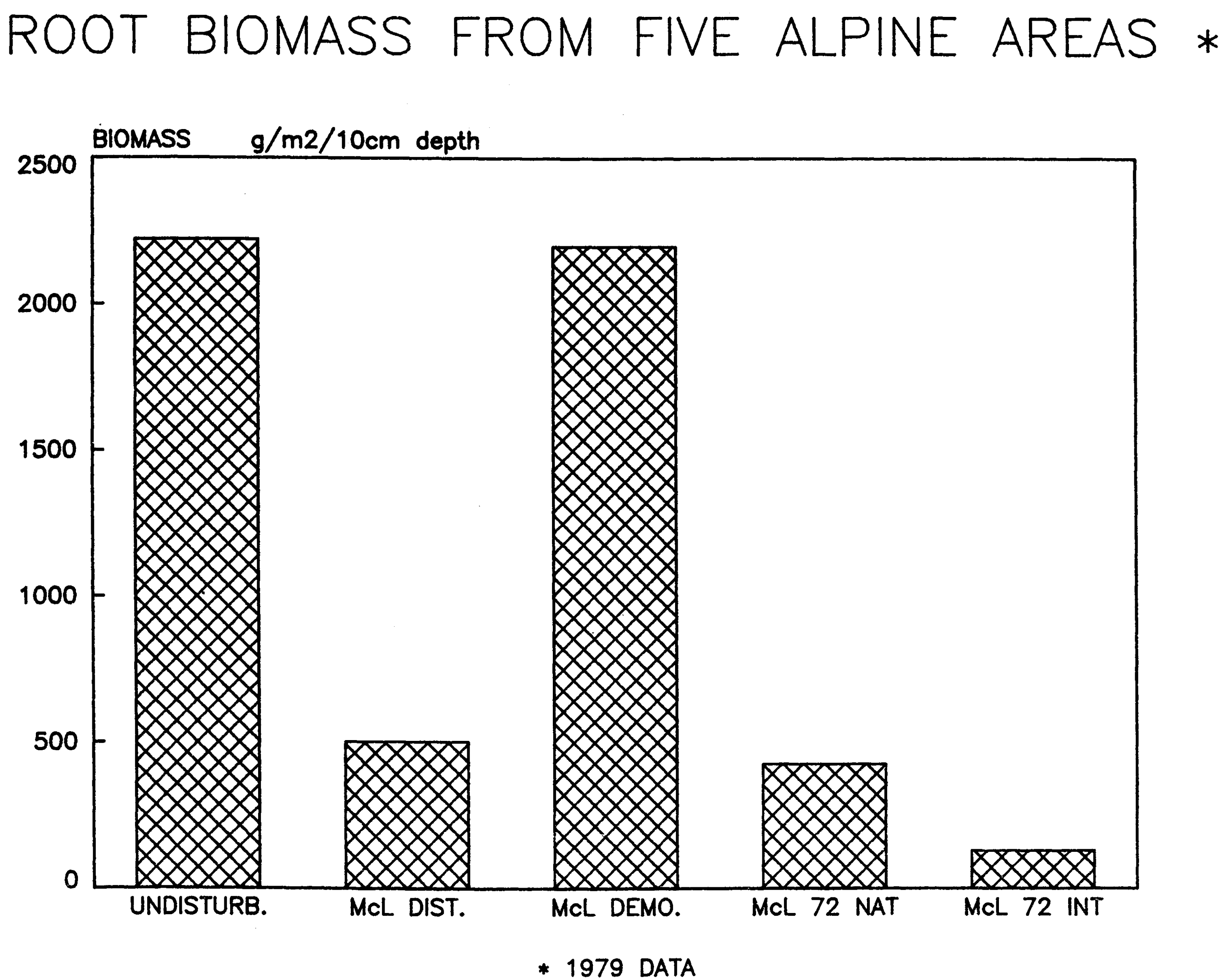

Figure 4. Comparison of root biomass (g/m^2/10 cm depth) among five plant communities in the McLaren Mine area. These include: native undisturbed plant communities (undisturb.); succession communities on the mine (McL. dist.); the demonstration area (McL. demo.); native-fertilized plots (McL. 72 nat.); and introduced-fertilized plots (McL. 72 int.).

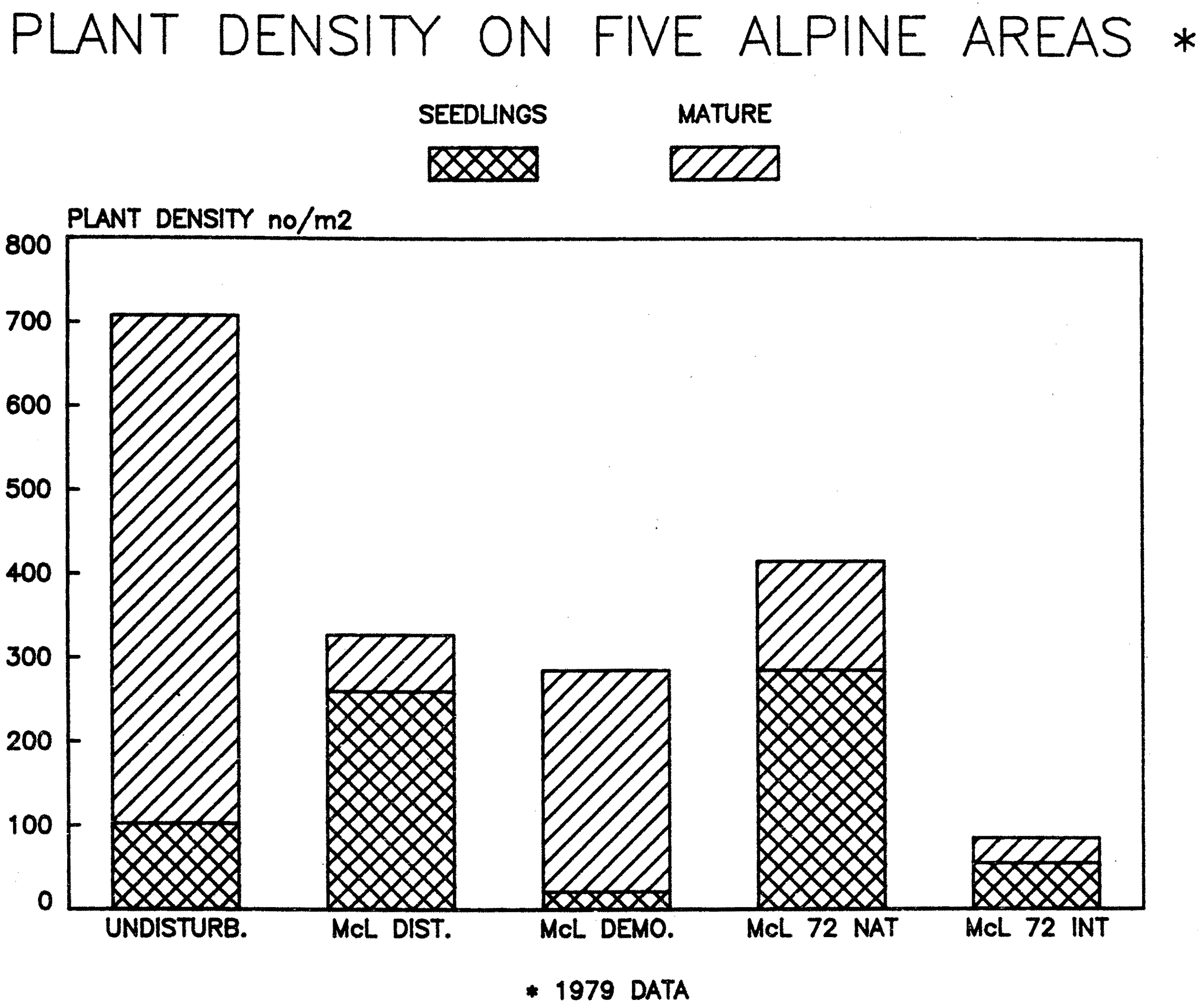

Figure 5. Comparison of plant density among five plant communities in the McLaren Mine area. These include: native undisturbed plant communities (undisturb.); succession communities on the mine (McL. dist.); the demonstration area (McL. demo.); native-fertilized plots (McL. 72 nat.); and introduced-fertilized plots (McL. 72 int.).

calculating and adjusting levels of subsequent cultural treatments needed to maintain the rate of desired stand development.

Measurement units selected for assessing revegetation success may vary depending upon targeted objectives. For example, the target may be a crop, a designed grazing allotment, a stand of uniform-aged trees, or a stand of vegetation similar to that of native plant communities. For mine-land disturbances at high elevations, the latter target is the most expedient. Even though revegetation and years of succession may not convert spoils into true, well-developed soil, a similar stand of vegetation to that of undisturbed communities appears to be possible. The time factor to reach a target cannot yet be defined but will vary with environmental limitations and the commitment of those responsible for the revegetation. It seems reasonable that a revegetated stand will resemble the posture of a native plant community when it becomes self-reproducing, stabilizes the soil on the site, and reaches a successional status involving native species of the area.

A proposed model for plant community development with time for various levels of revegetation treatment is presented in fig. 8. The scales shown are entirely arbitrary, and in fact, the time scale may be different for each condition illustrated. In cases where natural plant succession alone was allowed to progress unaltered, a considerable time factor may be involved to achieve target objectives. However, a low intensity level of treatment may enhance succession somewhat, perhaps more rapidly at first, but then may progress slowly after treatments are discontinued. Under intensive levels of site treatment on relatively good soil, it is possible to accelerate some aspects of plant development (such as shoot production) beyond the target levels in relatively short time (see fig. 2 and 3). However, after treatment is discontinued, these attributes likely will decline and may even fall below target levels for a time. Where spoil conditions are severely deficient and provide a poor medium for plant growth, intensive levels of treatment alone may not be sufficient to approach target objectives. The spoil medium may be capable of supporting only some lower level of stand development for considerable time until soil development processes alter it sufficiently to allow succession to progress further. We emphasize that the units of time involved may be measured in years, decades, or centuries for each instance.

Although economics may pose a constraint on the level of treatment in revegetation, other factors impinge on success or failure. For instance, there may be cases where it is more economical to commit more money in initial phases of revegetation, particularly if there is the possibility of having to repeat the entire procedure some years later when the stand fails. A little more monetary commitment may prove to be an inexpensive investment in terms of site stability.

At our present level of knowledge, particularly about revegetation of alpine disturbances, predicting target objectives in terms of time is not possible. We need more intensive research on the relationship between revegetation efforts and target objectives. Such factors as cover, production, and density are easily measured, yet we need to learn how these have

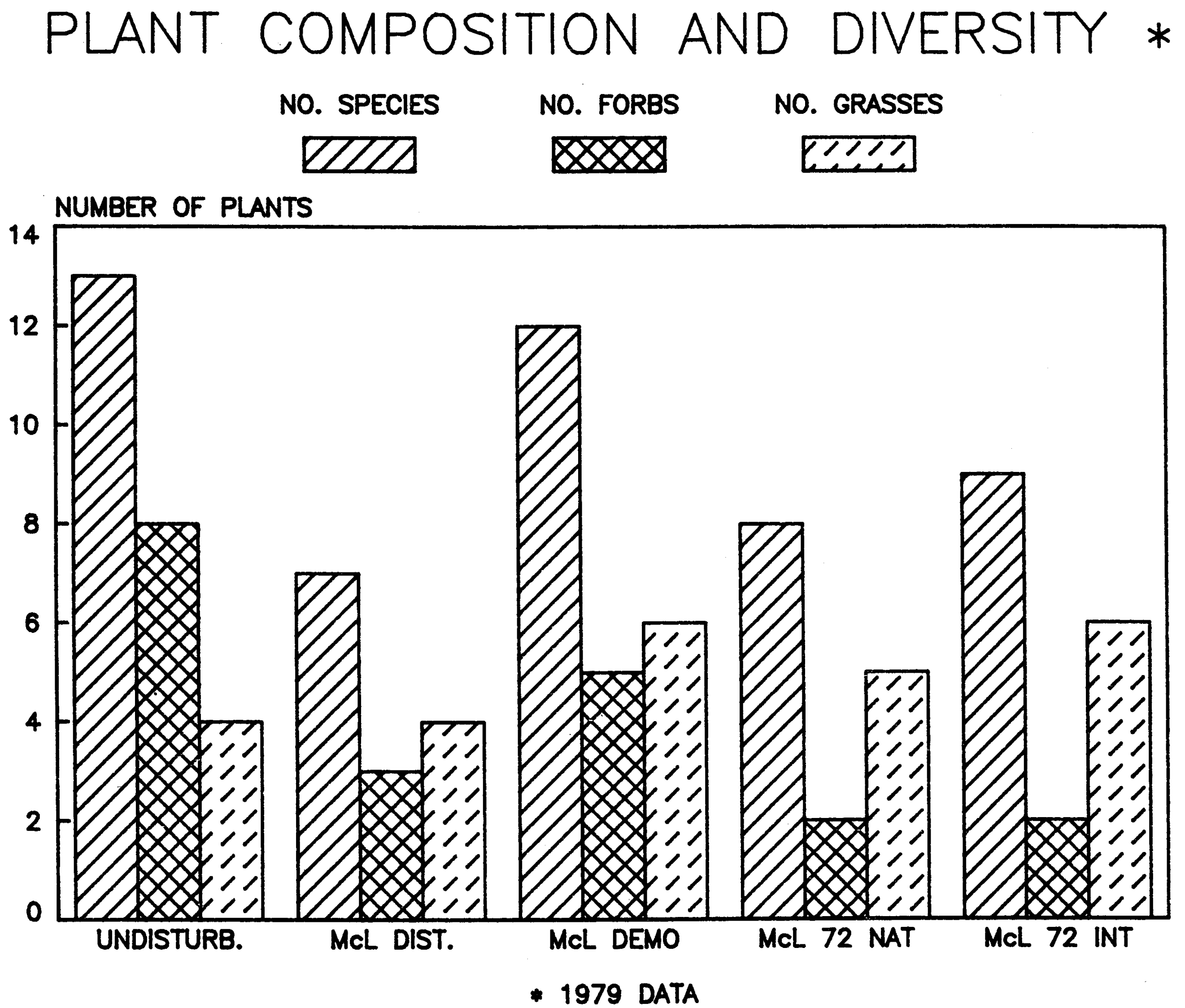

Figure 6. Comparison of the total number of species, number of forbs, and number of grasses (per m^2) among five plant communities in the McLaren Mine area. These include: native undisturbed plant communities (undisturb.); succession communities on the mine (McL. dist.); the demonstration area (McL. demo.); native-fertilized plots (McL. 72 nat.); and introduced-fertilized plots (McL. 72 int.).

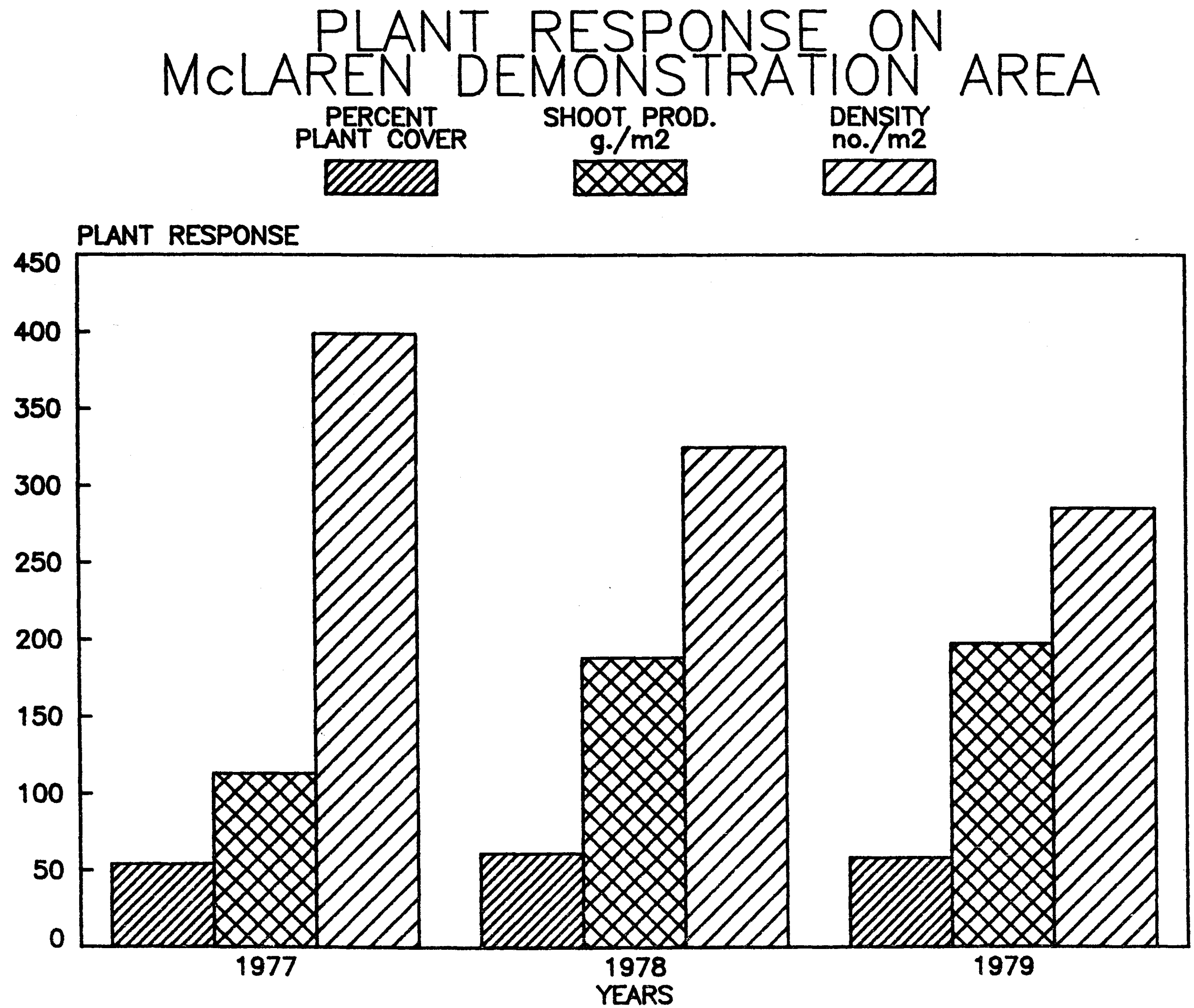

Figure 7. Comparison of percent plant cover, shoot production, and plant density on the McLaren Mine demonstration area for 1977, 1978, and 1979.

ecological significance and predictive value. In addition, we need to study plant species adaptability more intently so we can translate measurable environmental quantities into meaningful terms.

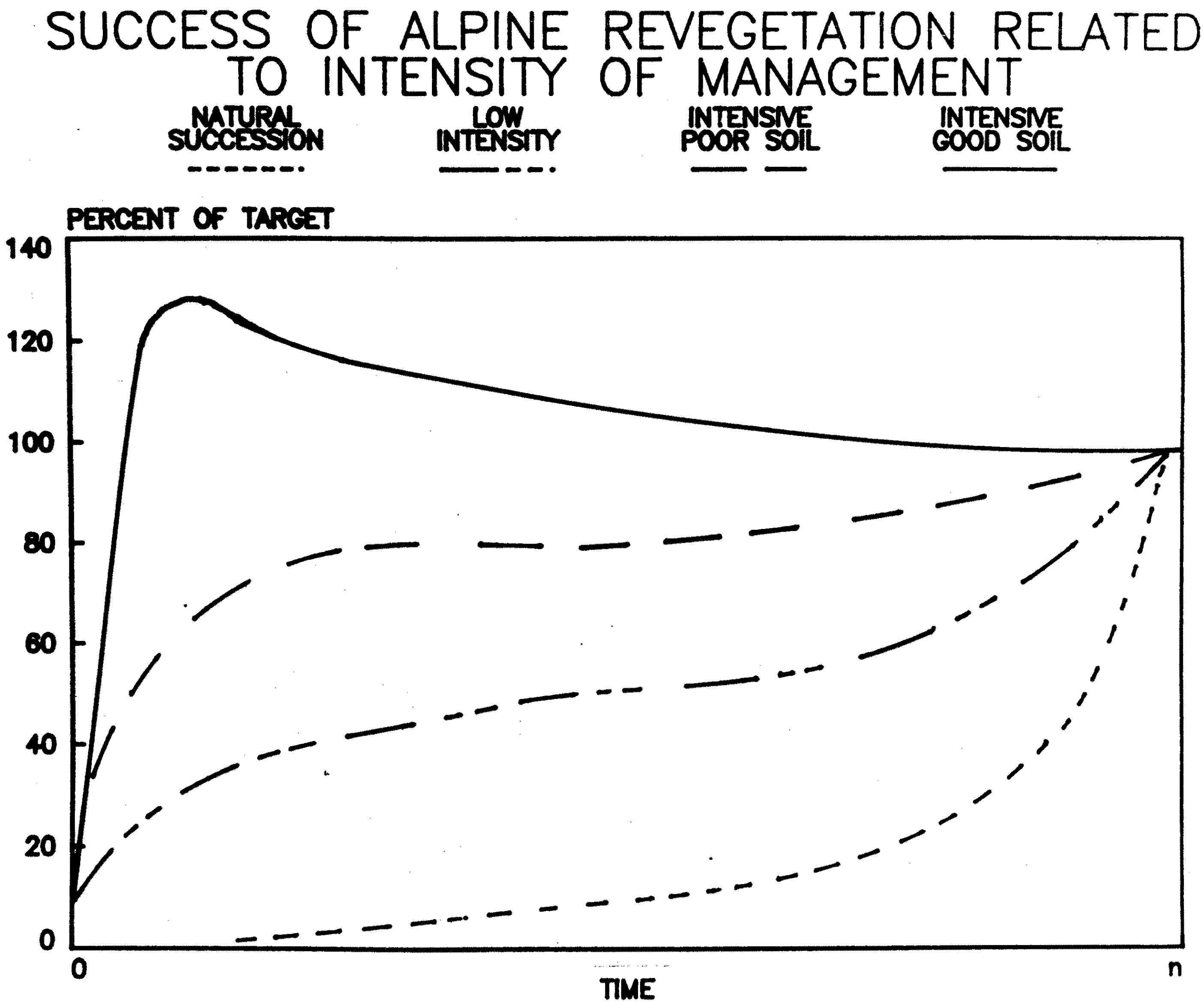

Figure 8. A proposed model of plant community development over time for various levels of revegetation treatment. Treatments considered include none (natural succession), low intensity, intensive on poor soils, and intensive on relatively good soils. The time scale may be different for each treatment illustrated.

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THE RECLAMATION PROCESS AS AFFECTED BY

THE SURFACE MINING REGULATIONS

By

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Director - Department of Environmental Control
The North American Coal Corporation
Western Division
Bismarck, North Dakota

Before the
High Altitude Revegetation Workshop
Colorado School of Mines
Golden, Colorado

February 26 and 27, 1980

Ladies and Gentlemen:

It is indeed gratifying to be asked to attend the meeting of the High Altitude Revegetation Workshop. There has been an impressive and productive record established by the committee and individual participants since inception of this group in the fall of 1973.

In many respects, high altitude revegetation begain in the early 1860's when settlers began to transplant trees and flowers around their cabins to keep the lady of the house happy, and to create some aesthetic relief in the early drab mining towns. These early plantings have been studied and reviewed by numerous individuals over the decades, in an effort to improve current revegetation practices, whether they were related to home sites, towns, transportation, water management, reforestation, or presently, to mining and other disturbances. Jim Feucht from the Colorado Extension Service has been active in the success of past plantings.

It became apparent in 1972 and 1973 that the need for more knowledge was imperative. Both the diversity of disturbed sites and types of disturbances requiring revegetation had far outstripped the rudimentary knowledge accumulated and practiced by what eventually proved to be a vast number of individuals. Each individual was locked away in his own mountain valley practicing his unique brand of mountain revegetation folk-art.

Dr. William Berg, Dr.Robin Cuany and myself encountered others in various states, industries, and government agencies who felt the need to exchange current information and form a cohesive unit to develop and distribute new technological and biological data to help solve the innumerable problems which influence the success or failure of high altitude revegetation.

The first attempt at a formal conference was January 31 and February 1, 1974. The workshop was held at Colorado State University with the three of us acting as co-chairmen. There were seven businesses and agencies which cooperated by sending speakers and sharing costs for the meeting and the proceedings. I think it is appropriate at this time to recognize an individual who contributed his personal and professional support and the contribution of his company. Without this assistance, this group would not have been initiated nor could the development and growth have been as viable. That person is Jim Ludwig, the senior Vice President of the Western Division of AMAX. The first field trip was held in the summer for on-site exposure. In 1975, a workshop was not held, but a work was published entitled Bibliography Pertinent to Disturbance and Rehabilitation of Alpine and Sub-Alpine Lands in the Southern Rocky Mountains. The bibliography was edited by Ordell Steen and Dr. William Berg.

Second and third workshops in 1976 and 1978 had sixteen businesses and agencies cooperating with approximately two hundred attendees from eleven states. Funds were developed at that time to finance a research position under Dr. Cuany's leadership,and the proceedings reflected a much more sophisticated and disciplined series of papers.

It is obvious that original philosophy to marry field requirements with specific research goals has not only been maintained, but has continued to produce new methodology and increased revegetation successes over the years.

I might add that it is imperative that the spirit of cooperation and the free exchange of problems, solutions, and techniques should continue to be the spirit of these workshops and field trips.

Certainly, there are no more units of the basic resources of land, air and water being created, and we are, therefore, charged with the imperative dictate that we utilize all of our resources under the most compatible managemental techniques to provide for the well-being of this nation and our descendants.

It has become apparent over the past ten years that the role of biologists and resource managers is becoming of primary importance to the compatible management and utilization of all resources. In effect, the role of environmental activities in the mining industry is to facilitate the exploration, development, and extraction of non-renewable resources by the manipulation, management, and conservation of renewable resources. This concept should be applied to other types of land disturbance, such as transportation, water management, urban areas, and agriculture.

The environmental movement of the 1960's focused the nation's attention upon the basic need to compare proposed impacts with the pre-existing conditions of the ecosystem. Primary considerations are to determine the extent of the proposed impacts, and to qualify which impacts are acceptable and which are not. Unfortunately, this basic, but important, procedure appears to have been lost by those who adhere to one environmental philosophy or another. Preservationists and exploitationists use impact analysis to prove their original point of view, and to hell with the needs of the resource or the environment. These two extreme camps spend most of their time, energies, and funds to impair, delay, and ultimately stop other persuasions in their endeavors. At the two extremes between total exploitation and total preservation, we find people who learn a few basic concepts and then fail to understand the interactions and complexities of the resources and ecosystems to be managed.

Basically, we are faced in this work with two undeniable facts:

1. We have an explosive human population, and

2. All resources, both renewable and non-renewable, are being depleted.

Certainly the answers to these two problems are not so simple as to create destruction of civilization through non-production of resources, nor should we use our resources with little thought as to management and continued productivity.

The future depends upon the abilities and success of the resource manager.

I do not pretend to be able to answer these basic problems at this time. I can only state that we must manipulate our resources wisely and create additional management techniques to provide a compatible interface between renewable and non-renewable resources and human requirements. This interface must be found between timber harvest and aesthetics, between mining and farming, and between human populations and air and water quality.

Over the past decade these basic conflicts have resulted in attempts by various agencies, research organizations, and special interest groups to develop legislative controls for preservation and/or utilization of resources. As often happens with the human being, we have a tendency toward overkill in our attempts to control our excesses. This tendency creates chaos and over-regulation, which has taken us from uncontrolled preservation. Affected is our standard of living, economic balance, and the availability of resources. It takes a long time to find the necessary middle road of resource management and conservation.

To illustrate this relationship, let us review the latest mining law. In August of 1977, Public Law 95-87, called the Surface Mining Control and Reclamation Act of 1977, was enacted by the U. S. Congress. The law was created at a time when state legislative controls on mining reclamation ranged from none at all to extremely complicative laws, such as those in North Dakota. PL 95-87 failed to recognize those State laws already in effect, but most importantly, Congress failed to fully realize regional physical differences within and between coal mining states. In an attempt to create some opportunity for states to help develop site-specific regulations, Congress created what was called an "open-door" attitude to encourage state participation. However, once the initial staff of OSM was in place, this fairly reasonable concept was reduced to a "state window," and after 18 months of activity by the federal government, the states are fighting to maintain a "crack" in the "window." This has added fuel to the fire of the "sagebrush rebellion."

An ambiguous law, coupled with stringent interpretation and resulting regulations, has provided for universal coal mining controls with little latitude for site-specific conditions.

I can give you some specific examples:

Water management on the prairies must be tailored to meet Kentucky mountain requirements; five years of compulsory management before bond release is required in geographical areas of over 26 inches of precipitation, and ten years of liability is required for areas under 26 inches of precipitation. There is no recognition for seasonable distribution, nor for the availability of moisture to vegetation.

East of the 100th meridian, so-called "alluvial valleys" are of no concern, but west of the 100th meridian these ambiguous geological formations are inviolate. Little thought was given as to whether the promulgated criteria for identification does, in fact, reveal an alluvial valley, nor is there room for determination of significance to the surrounding terrain.

Prime farmland was another area singled out by Congress for special treatment. The conferees of the House and Senate specifically discussed corn and soybean production as indicative of prime farm soils. This means maximum annual productivity. By the time federal agencies had created their definition, North Dakota inherited vast acreages of "prime farmlands" in the arid western half of the State, although one out of every two or three years summer fallow is the common farming practice. Excessive controls and increased costs are the result of regulations promulgated for so-called "prime farmlands." In the final analysis, if you can't reclaim the better soils, there is little hope for reclamation of soils with lesser inherent productivity. In North Dakota, there have been hundreds of acres of rangeland reclaimed and released from bonds, showing that soils less than "prime farmland" can indeed be successfully reclaimed.

Coal costs have risen sharply in the past eighteen months, and as a result, electricity has become a major consideration for families. Additional costs for manufacture of goods has added impetus to the inflationary spiral. At this time, we have no idea where the activities and the pressures of the government will lead the American public.

As I stated in the beginning, the institution of new laws will require a long time to find the middle road of resource management and conservation. The question at the present time is: How long does the country have before the excessive regulation, interpretation, and enforcement can no longer be supported by the economy or the need for continued technological development?

In conclusion, I have to say that Congress has created an ambiguous, poorly-written piece of legislation. The OSM, individual states, and industry must work together. We must find reasonable concepts so that resource management and conservation can proceed from a basis of the requirements of our environment, and not rely upon false relationships created by legislation.

Activities by legislative bodies have created the need for more data and technology to either improve reclamation efforts on disturbed lands, or to provide specific data which can be used to show which legislated controls are unworkable or need to be modified.

In this respect, organizations such as the High Altitude Revegetation Workshop can provide positive and knowledgeable assistance in attaining reasonable, professional, and prudent reclamation technology.

LATEST ADVANCES IN PLANT MATERIALS DEVELOPMENT AT THE MEEKER ENVIRONMENTAL PLANT CENTER

Wendell G. Hassell
Plant Materials Specialist
USDA Soil Conservation Service
Denver, Colorado

The Upper Colorado Environmental Plant Center is now in its fifth year of operation. It was established in 1975 by the White River and Douglas Creek Soil Conservation Districts, with funds from several cooperating state and federal agencies and private industry. The Center was established to collect, test and develop new plants for needs in the Upper Colorado River region.

To date, the Center is screening over 3,050 accessions or ecotypes of individual plant species in initial evaluation plots. They have assembled over 1,200 native plant seeds from this region. The Center has cooperatively established off-Center test plantings at: (1) Colony Oil Shale Development, Grand Valley; (2) Colowyo Coal Mine, Craig; (3) Energy Fuels Mine, Steamboat Springs; (4) Kerr Mine, Walden; (5) Tosco Oil Shale, Vernal; (6) Climax Molybdenum Mine, Leadville; and (7) Standard Metals Mine, Silverton. Approximately 300 different plants are being evaluated at these sites.

In addition to actual testing, the Center is developing techniques to induce seed germination and produce plants through the various stages of nursery and seed production operations.

Rather than generalize on the many aspects of the Center's testing, I would like to speak on some specific projects and species more directly related to high altitude revegetation.

Outstanding Species in Initial Evaluations

Agropyron subsecundum (Bearded wheatgrass)

Two accessions, PI-236691 and PI-236685, from Canada have shown outstanding characteristics. Compared to 24 ecotypes being evaluated, they are the most aggressive accessions. Also, PI-232151 from Montana has good stand, vigor and moderate forage yield. These accessions have been evaluated for four years.

Agropyron trachycaulum (Slender wheatgrass)

Evaluations have been recorded for four years on 84 ecotypes of slender wheatgrass. EPC-99 collected from the San Luis Valley area in Colorado rated good and was slightly above Primar slender wheatgrass in production. In 1978, forage yields of Primar were estimated at 5,020 lbs/acre (5,522 kg/ha), dry weight. Primar and EPC-99 have been the top accessions at Meeker.

However, at Climax, above 11,000 feet (3,300 m) elevation, EPC-99 has been longer lived than Primar. Stands of Primar declined the second and third years, but EPC-99 did not.

Bromus anomalus (Ncdding bromegrass)

Eight accessions are being compared. PI-232200 from Wyoming and PI-23675 from Canada were the only two accessions that produced good stands and have persisted in initial evaluations over three years.

Bromus inermis (Smooth brome)

PI-340070 from Turkey has good performance, rating as good or better than Manchar and Liso smooth brome. PI-340070 had an estimated yield of 7,665 lbs/acre (8,430 kg/ha) under dryland conditions in 1978. This accession is strongly rhizomatous and produced an abundance of seed. The checks, Manchar and Liso smooth brome, still performed better than most of the 37 accessions in evaluation.

Bromus marginatus (Mountain brome)

Of the 10 ecotypes evaluated, six performed better than the standard 'Bromar'. However, it should be noted Bromar's performance in other trials and field tests has been acceptable.

EPC-294 and EPC-106 established perfect stands and rated good vigor. EPC-294 originated from Gunnison, and EPC-106 east of Montrose, Colorado.

Some winter die-back has been noted in these plots at Meeker, possibly illustrating a characteristic of this species.

Danthonia (Oatgrass)

There were seven accessions assembled in this initial evaluation. PI-253189, D. provincialis from Yugoslavia, out-performed all other regionally collected D. parryi and D. califorica ecotypes.

Elymus glaucus (Blue wildrye)

Thirty-seven ecotypes were assembled from the region and plant induction stations. Generally, the regional-collected accessions were superior. EPC-322 from northwestern Colorado and EPC-167 from Steamboat Springs, Colorado established excellent stands and had good vigor. They have grown about 40 inches (100 cm) in height and show the best potential.

Elymus sibiricus (Siberian wildrye)

Two accessions, PI-314619 and PI-315427 from Dewey, Logan, Utah (USSR) and USSR, respectively, have produced good seed crops at Meeker. They mature extremely early and could have good potential for high altitude use. The seed is rather large and should contribute to better stand establishment. Seeding vigor was very good for the above two accessions at Meeker. Fourteen accessions are included in this evaluation.

Elymus triticoides (Bearded wildrye)

C-77 collected from near Leadville, Colorado has shown superior production to P-15594 at Meeker. Both demonstrated good stands and vigor. P-15594, *E. triticoides*, was collected near Riverton, Wyoming and has been tested for several years at the plant materials center in the Pacific northwest and Montana and Wyoming. The Soil Conservation Service in Montana and cooperating agencies are planning to propose P-15594 for release in 1980. Foundation seed will be available from the Bridger Plant Materials Center.

Festuca thurberi (Thurber fescue)

Six ecotypes have been evaluated for four seasons. EPC-357 from Los Alamos, New Mexico had the best initial stands and fair seedling vigor. In 1978, estimated production was 2,235 lbs/acre (2458.5 kg/ha), dry weight. EPC-309 originating 30 miles east of Meeker and EPC-587 from Mosca Pass, Colorado were also good performing accessions.

Attempts to increase seed of EPC-309 and EPC-357 in 1978 were unsuccessful. A small quantity (5-8 pounds) of EPC-587 seed was hand-collected and put into an increase planting in October 1979. Establishment of stands of Thurber fescue under irrigation on moderately salty soils at the Center has been difficult. Accumulation of salts near the center of the rows under irrigation may have a detrimental effect.

Some transplants of thurber fescue have been started at the Center for seed production.

Lupinus argenteus (silvery lupine)

EPC-117 *L. argenteus* was started in 1976 with 3 other ecotypes. Eight other accessions of Lupine are being evaluated at the Meeker EPC. EPC-117 has demonstrated a rhizomatous characteristic in about 1/2 of the individual plants. This accession was collected in Rio Blanco County, Colorado at about 7200 feet (2160 m).

Plants from the rhizomatous types are being selected for field testing and further evaluations.

Climax Field Evaluation Planting

The Climax plots are located at 11,200 feet (3,360 m) elevation on a disturbed site with topsoils rocky mixture 2 to 4 inches (5 to 10 cm) deep; below is a yellow clay subsoil.

Transplants were started in tubepak planters in February-March 1977 at the Environmental Plant Center greenhouse. The plants were hardened off at Meeker for three weeks before transplanting at Climax on July 14, 1977.

Ten plants of each accession were transplanted at 4-foot (1.2 m) spacing in each plot row. Tubepak plants were hand transplanted in 6- to 8-inch (15 to 20 cm) holes. The plants were watered in and watered once after transplanting. Plants have survived on natural precipitation after initial watering for establishment.

Some plants such as rabbitbrush accessions EPC-437 and 438 had very little root development due to the young age of plants. The tubepak root masses crumbled when transplanted. Evaluations on survival, vigor and height were made annually usually in July. Evaluations on transplanted plots are summarized in Table 1.

Summary of Outstanding Species

Chrysothamnus (Rabbitbrush)

Only one accession, EPC-811, C. parryi, has maintained good performance after three years. EPC-811 was collected at Buford, Colorado. All C. nauseosus (2 accessions) died out after the second winter. EPC-437, C. spp., collected on Monarch Pass, Colorado, has 50 percent plants remaining, but only rated fair for vigor in 1979.

Rabbitbrush seedlings were about 4 months old at time of transplanting.

The chrysothamnus seed was put directly into the germinator at the Center. EPC-811 seed had the highest germination, 87% in 30 days. The other ecotypes ranged from 76% to 49%.

Lonicera (Honeysuckle)

Two accessions of twinberry honeysuckle, EPC-675 and EPC-708, (L. involucrate) have performed excellently. They were collected from Rio Blanco County, northwest Colorado, and San Juan County, southwest Colorado, respectively. Four month seedlings were used in this project.

Table 1. 1977 Climax Field Evaluation Plantings - Woody Plants

Species	Accession No.	Origin	Initial (cm)	Height 1977 (cm)	Height 1978 (cm)	Height 1979 (cm)	% Live Plants 1979	Vigor 1/ 1979
Chrysothamnus spp. - rabbitbrush								
	EPC-437	Monarch Pass, CO	4	13	15	14	50	F
	EPC-438	Gunnison, CO	2	4	10	--	0	--
Chrysothamnus nauseosus - rubber rabbitbrush								
	EPC-506	---	10	25	20	--	0	--
Chrysothamnus parryi - Parry rabbitbrush								
	EPC-811	Buford, CO	11	27	20	28	100	G
Lonicera spp. - honeysuckle								
	EPC-634	Durango, CO	12	26	25	30	90	G
Lonicera involucrata - twinberry honeysuckle								
	EPC-675	Rio Blanco County, CO	10	17	30	38	100	E
	EPC-708	San Juan County, CO	10	18	30	35	100	E
	EPC-660	commercial	6	13	20	24	100	F
Physocarpus monogynus - mountain ninebark								
	EPC-376	Jemez Mountains, NM	8	15	18	8	60	P
Potentilla fruiticosa - shrubby cinquefoil								
	EPC-560	Lake George, CO	6	15	20	25	100	E
	EPC-287	Yellow Jacket, CO	5	9	14	18	100	G
	EPC-445	Fairplay, CO	5	11	16	20	100	G
Potentilla diversifolia - varileaf								
	EPC-156	Meeker, CO	3	8	14	18	100	E
Ribes spp. - currant								
	EPC-337	Meeker, CO	6	6	22	45	90	G
Ribes cereum - wax currant								
	EPC-529	Buena Vista, CO	10	25	26	29	90	G

1/ Legend: E = excellent; G = good; F = fair; P = poor; VP = very poor

EPC-708 had good leaf growth the first season after transplanting. EPC-708 and EPC-675 were in the early-bloom stage 7-21-78. No other honeysuckle or other genera had blossomed.

The honeysuckle species were stratified in cold moist sand for about 120 days; none germinated in stratification. EPC-708 and EPC-675 had 52% and 30% germination respectively in 30 days. These percentages are comparatively low: EPC-660 (78%) EPC-634 (85%). Accession EPC-708 germination was spread over a much longer period (60 days) then the others.

Physocarpus (Ninebark)

The one accession, *P. monogymus*, EPC-376, collected in north central New Mexico, performed poorly.

Ninebark EPC-376 was put in cold stratification for 120 days. 48% germinated in stratification and about 48% germinated in the germinator within 21 days.

Potentilla (Cinquefoil)

This plot contains three shrubby cinquefoil and one varileaf (herbaceous) cinquefoil. Transplants used in this trial were 3-4 months old. The cinquefoils as a group have shown the best performance overall. The three *P. fruiticosa* accessions (EPC-560, EPC-287 and EPC-445) have an average growth of 6-7 cm. per year. There has been 100 percent survival of all cinquefoils transplanted in 1977. The *P. diversifolia* has shown good vigor and persistence at this trial.

In germination studies at the Center, EPC-445 had 92% in 22 days without any seed treatment; or stratification. This compared to 76% for EPC-560, 72% for EPC-287 and 31% for EPC-156. The potentilla's were generally very easy to germinate. Germination started after 5 days in the germinator.

Ribes (Currant)

EPC-337, R. spp., from Meeker made 1.3 feet (32 cm.) growth in three years. This was the highest growth of any plant in the project. Both accessions of currant had good performance.

Both Ribes accessions were put into cold-sand stratification on October 22, 1976 and removed February 20, 1977. A minimal number germinated in stratification. 37% of EPC-529 germinated in 6 months. EPC-337 had 24% germination in one month.

The grass plots at Climax are on a disturbed site similar to the shrub plots, except there is less topsoil and the surface contains more rock.

Each accession of grass was seeded in rows 20 feet (6 m) long, rows were spaced at 24 inches (60 cm). The seed was drilled with a Planet Jr. hand-push seeder. The area was maintained under natural precipitation and climatic conditions.

Annual evaluations were made for percent stand, vigor, height and maturity. Table 2 is a summary of the performance ratings based predominantly on stands.

Alopecurus arundinacea (Creeping foxtail)

'Garrison' creeping foxtail was the only accession included, but its performance has declined from excellent to poor during 1977 to 1979.

Agropyron subsecundum (Bearded wheatgrass)

Accession EPC-810 from Jemez Mountain in New Mexico has been the only bearded wheatgrass that has maintained a stand during the first three years. Three other accessions of beardless have declined in stands at this site. EPC-810 had shown good vigor and growth. Heights measured in September 1978 were 21 inches (52.5 cm) and in August 1979, 15 inches (37.5 cm).

EPC-810 made seed in 1978. Although it was poor fill, it appeared better than the other beardless wheatgrasses. In early August 1979, all beardless wheatgrass accessions were in the early boot maturity stage.

Agropyron trachycaulum (Slender wheatgrass)

The overall performance of the slender wheatgrasses as a group was impressive in this project. Three of the five accessions have rated good to excellent during the 3-year period: EPC-99, EPC-119 and EPC-819. These three accessions rated similar in vigor and height. EPC-819 was slightly earlier maturing in 1978 than the other two.

Origin of these accessions are: EPC-99, San Luis Valley, Colorado; EPC-119, Buford, Colorado; and EPC-819, Clifflake, Rio Blanco County, Colorado.

Agropyron trichophorum (Pubescent wheatgrass) and

Agropyron intermedium (Intermediate wheatgrass)

All accessions of intermediate and pubescent wheatgrass have declined in performance during the 3-year period.

Table 2. 1977 Climax Field Evaluation Planting - Grasses

Species	Accession	Origin	Elev	Performance Rating 1977	1978	1979
			(feet)			
Alopecurus arundinacea - creeping foxtail						
	Garrison	North Dakota	--	E	G	P
Agropyron intermedium - intermediate wheatgrass						
	Greenar	USSR	--	E	VP	VP
Agropyron subsecundum - bearded wheatgrass						
	EPC-412	Colorado	--	E	G	F
	EPC-596	--	--	G	F	VP
	EPC-853	Colorado	--	G	VP	0
	EPC-810	New Mexico	--	G	G	G
Agropyron trachycaulum - slender wheatgrass						
	Primar	Montana	--	E	F	VP
	EPC-99	Colorado	8500	E	E	G
	EPC-119	Colorado	8000	G	E	E
	EPC-173	Colorado	6200	E	VP	0
	EPC-819	Colorado	9500	G	E	G
Agropyron trichophorum - pubescent wheatgrass						
	A-1776	USSR	--	VP	0	0
	Luna	USSR	--	E	F	F
Bromus anomalus - nodding brome						
	EPC-314	Colorado	10000	G	0	0
	EPC-295	Colorado	--	G	P	VP
	EPC-415	Colorado	--	F	0	0
	EPC-777	Colorado	--	G	VP	0
	EPC-868	Colorado	--	G	P	0
Bromus biebersteinii - meadow brome						
	Regar	Turkey	--	E	E	E
Bromus frondosus						
	EPC-823	Colorado	--	E	0	0
Bromus inermis - smooth brome						
	Manchar	China	--	E	E	E
Bromus marginatus - mountain brome						
	Bromar	Washington	--	E	VP	0
	EPC-821	Colorado	--	G	VP	VP
	EPC-294	Colorado	--	E	G	G
	EPC-406	Colorado	--	E	F	0
	EPC-602	--	--	E	VP	0
Bromus polyanthus						
	EPC-283	Colorado	7500	E	G	F

Table 2. (continued)

Species	Accession	Origin	Elev	Performance Rating 1977	1978	1979
			(feet)			
Carex spp. - sedge						
	EPC-284	Colorado	8700	0	0	VP
Deschampsia caespitosa - tufted hairgrass						
	EPC-678	Colorado	--	VP	0	0
	EPC-737	Colorado	--	VP	0	0
Elymus glaucus - blue wildrye						
	EPC-748	Colorado	9000	F	0	0
	EPC-273	Colorado	--	F	0	VP
Festuca arizonica - Arizona fescue						
	Redondo	New Mexico	--	E	G	G
	EPC-601	Colorado	9600	E	P	VP
	EPC-444	Colorado	10000	E	0	0
	EPC-374	New Mexico	8800	E	E	E
	EPC-389	Colorado	8700	E	0	0
Festuca arundinacea - tall fescue						
	P-14944	Nevada	--	F	VP	VP
Festuca idahoensis - Idaho fescue						
	EPC-315	Colorado	7500	0	0	0
	EPC-818	Colorado	--	VP	P	P
	P-6435	Washington	--	G	P	0
Festuca thurberi - Thurber fescue						
	EPC-815	Colorado	--	0	0	0
	EPC-127	Colorado	--	VP	VP	VP
	EPC-309	Colorado	9900	P	VP	0
	EPC-587	Colorado	9600	E	G	VP
	EPC-357	New Mexico	--	G	G	VP
Poa ampla - big bluegrass						
	Sherman	Oregon	--	VP	0	0
Poa spp. - blue grass						
	EPC-732	Colorado	--	G	G	E

Legend: E = excellent; G = good; F = fair; P = poor; VP = very poor;
0 = no plants

Bromus anomalus (Nodding brome)

None of the five accessions of nodding brome has maintained stands at this site. All accessions started out the first year with good stands, but they have deteriorated from very poor to nothing during the three years.

Bromus polyanthus and

Bromus frondosus

Neither of the above two accessions has demonstrated outstanding performance. EPC-823, B. frondosus, has died out completely. EPC-283 B. polyanthus has shown a steady decline in stands over the three years since 1977.

Bromus inermis (Smooth brome) and

Bromus biebersteinii (Meadow brome)

These two introduced varieties ('Manchar' smooth brome and 'Regar' meadow brome) have rated the highest for stand and vigor in this project. Both varieties have matured seed heads, but the fill has appeared poor. The performance of these two varieties is good.

Bromus marginatus (Mountain bromegrass)

'Bromar,' the only named variety in this group, started out well, but has declined to no stand in 1979.

EPC-294 from Gunnison, Colorado has maintained the best stands and made 31 to 28 inches (77.5 to 70 cm) of growth in 1978 and 1979, respectively. EPC-294 was about midway relative to seasonal maturity of the five accessions tested. EPC-294 was in the dough seed stage September 7, 1978, and in 1979 it was still vegetative on August 7. Vigor ratings for EPC-294 have been equal to or better than other mountain bromegrass in this trial.

Carex species (Sedge)

One accession, EPC-284, collected in Colorado, was seeded in this project. However, it wasn't until 1979, two years after seeding, that any plants started emerging. The stand is still relatively very poor.

Dischampsia caespitosa (Tufted hairgrass)

Two accessions were tested. Very poor stands emerged, but died out the second year.

Elymus glaucus (Blue wildrye)

Two accessions were included, but performance has been very poor.

Festuca arizonica (Arizona fescue)

Five accessions of Arizona fescue were tested; all initially had excellent stands. However, in 1979, only 'Redondo' and EPC-374 maintained a good stand. EPC-374 rated slightly above Redondo for vigor and stand in 1979. EPC-374 was 22 inches (55 cm) high, and 'Redondo' was 18 inches (45 cm) high on August 7, 1979. Both of these accessions originated from the Jemez Mountains in northern New Mexico.

Festuca arundinacea (Tall fescue)

Only one accession, P-14944, tall fescue, was in this trial. Performance started fair, but has declined to very poor.

Festuca idahoensis (Idaho fescue)

Three accessions were evaluated. However, performance has been poor.

Festuca thurberi (Thurber fescue)

Five accessions were initially seeded. Good stands were obtained from two accessions: EPC-587 and EPC-357. However, performance of these two grasses declined to very poor in 1979. EPC-357 was collected near Los Alamos, New Mexico, and EPC-587 originated from Mosca Pass in the San Luis Valley, Colorado.

EPC-127 from Gunnison, Colorado started out with a very poor stand, but the stand is still persisting and may show good persistence.

Poa ampla (Big bluegrass)

Initial stands of 'Sherman' big bluegrass were very poor, and all stands lost by the second year. 'Sherman' was the only variety of big bluegrass included.

Poa spp. (Bluegrass species)

EPC-732 bluegrass was an extremely impressive accession. Height, stand and vigor have improved during the test period. This accession was originally collected near Meadow Lake, Rio Blanco County, Colorado. This accession seems to mature relatively early and should produce seed at this location.

Silverton Standard Metals Field Evaluation Planting

The Silverton, Colorado Cooperative Standard Metals plots were started in 1978. Additional plots were added in 1979. The site is located one mile east of Silverton on tailings pond number 2 at 9,700 feet (2910 m) elevation. The average daily high temperature for June, July and August is 70° and the average daily low for the same period is 32° F. The recorded average frost-free period is 24 days. The average annual precipitation is 24 inches (60 cm). However, evapotranspiration during May, June, July and August is greater than the precipitation. Precipitation during the same months are 1.4, 1.6, 2.8 and 3.2 inches (3.5 cm, 1.6 cm, 2.8 cm and 3.2 cm), respectively.

Evaporation rates on the site differ at the top of the tailings pond and on the slopes, as reported by Standard Metals measurements. The maximum measured on top was 0.54 inches (1.35 cm) in one day, compared to 0.25 inches (0.625 cm) on the tailing slope.

Standard Metals Tailings Material

Listed below are soil texture, pH and conductivity for samples taken from various locations on the tailing pile and peat soil. Texture is quite variable and is typically stratified. Conductivity and pH of tailings indicate no adverse effect to plants that would naturally grow in this climatic setting. However, natural fertility is very low. Side slopes soils have very low water-holding capacity, which is a limiting factor in establishing and maintaining plants.

A Soils Analysis of Pond #2 and Peat Soil

	Site Location		
Test	Top-Center 8-10 Inches	South Slope 6-8 Inches	Peat Soil
pH	7.4	7.2	6.6 to 1.2
Nitrate Nitrogen	20 ppm	Neg	3100 ppm
Phosphorus (P_2O_5)	Neg	17 ppm	600 ppm
Potassium	150 ppm	75 ppm	400 ppm
Calcium	2800 ppm	--	--
Magnesium	trace	4 ppm	--
Manganese	25 ppm	5 ppm	--
Aluminum	Neg	Neg	--
Ferric Iron	50 ppm	8 ppm	--
Sulfate	25 ppm	2000 ppm	--
Chloride	15 ppm	--	--
Ash	--	--	14

The acid peat-soils are probably tied with pyrite oxidation and/or mill tailings water.

On June 21, 1978, three replications of 60 accessions, mostly shrubs, were transplanted from tubepaks and potted plants. Species included in this project were: mountain mahogany, serviceberry, chokecherry, redosier dogwood, honeysuckle, silver buffaloberry, rabbitbrush, virginia creeper, squaw-apple, shrubby cinquefoil, twinberry, scarlet elder, aster, littleleaf mockorange, Oregon grape, caragana, golden pea, mulesear wyethia, ninebark fireweed and penstemon.

Holes were dug approximately 12 inches (30 cm) deep. One-half gallon peat-fertilizer mix was put in the bottom of each hole. Water was applied before, to wet the soil, and after transplanting.

The peat-soil was obtained from a local natural-occurring source. 34-20-9 fertilizer was used for fertilizer. One-half gallon of this mix provided each plant approximately 0.014 pounds (0.035 cm)N., 0.008 pounds (0.02 cm) P_2O_5 and 0.004 pounds (0.01 cm) K.

Top of Tailings

The on-site peat material used in transplanting combined with tight soil conditions on the tailing top apparently was toxic, and most plants died the first season. Twenty-six species of grasses and legumes were also direct-seeded on the top site. The planting was made June 22, 1978. The seed was hand-planted in furrows which had been treated with the above peat material. A small 3-inch (7.5 cm) furrow was dug and filled half way with peat. One-half inch (1.25 cm) of sandy tailing material was placed over it and seed drilled into the sand about one-half inch (1.25 cm) deep.

The mountain bromegrass was the only species showing germination the first season. However, seedlings died at about 1/2-inch (1.25 cm) height. The second spring (1979) several grasses showed some germination (10-50%): 'Arriba' and 'Rosana' western wheatgrass, 'Sodar' streambank wheatgrass, basin wildrye, slender wheatgrass and beardless wildrye. However, by the end of summer, all plants had died.

Tailing Slope Plots

The above shrubs were also planted on the slope, but only four plants per plot with no replications. Similar transplanting procedures were used. However, the soils are sandy, and plant success was much better. About one-third of the plants showed some success the second season.

Several types of containers and ages of plants were used in the project. With the exception of one accession of Rocky Mountain penstemon and one gilia, none of the bareroot transplanted material survived the first season. There were a total of eleven accessions planted bareroot. The bareroot material was dug from a local source near the Meeker EPC and transplanted to the Silverton site.

Seven of the eight accessions (87%) transplanted in tarpaper pots showed survival the first season.

There was no obvious difference between the 1977 (T 77) and 1978 (T 78) tubepak material in the two species, mountain mahogany and rabbitbrush, where they could be compared. However, 15 accessions or plots of 1977 tubepaks showed some surviving plants in 100 percent of the plots. The corresponding survival of 1978 tubepaks was 41 percent in 17 plots.

Accessions that have shown potential at this site based on two years' evaluations are listed below and shown in Table 3.

Artemisia ludoviciana (herbaceous sage)

Two ecotypes, EPC-328 and EPC-451 from Georgetown, Idaho and Franktown, Colorado, respectively, have been evaluated at Meeker and Steamboat Springs, Colorado. Performance of EPC-328 has rated slightly above EPC-451 at these locations. EPC-328, *Artemisia ludoviciana*, collected near Georgetown, Idaho, has done extremely well on-site and is spreading by rhizomes. This plant made seed and rhizomes the first season, spreading about 10 inches (25 cm). It measured 18 inches (42 cm) in height August 1979. EPC-328 on tailings at Silverton to date looks very promising.

At Meeker, deer utilized about 40% of the seasons growth of EPC-328 compared to about 30% for EPC-451. The Provo shrub laboratory is presently analyzing EPC-328 foilage in relation to desirability for game use.

Cercocarpus montanus (mountain mahogany)

Accession No. EPC-561 had the best performance. It was collected near Lake George, Teller County, Colorado 8200 feet (2460 m) elevation. Five ecotypes of mountain mahogany are being evaluated at Silverton.

Chrysothamnus spp. (rabbitbrush)

Ecotype EPC-304 has shown the best performance of the three accessions being evaluated. EPC-304 was collected in Gunnison County, Colorado in 1975 at 8000 feet (2400 m) elevation.

At Meeker in an evaluation orchard EPC-304 has 100% survival in a 1977 planting and has good performance compared to 16 accessions being evaluated. EPC-304 measured 18 inches (40 cm) height and 25 inches (62 cm) cm) spread after two years at Meeker. However, plants did not survive at the Tosco site southwest of Vernal, Utah.

Table 3. Transplanted Species at Standard Metals - Silverton

Species	Variety or Accession	Type Transplant	Performance 1978	Performance 1979
Allium spp. - wild onion				
	EPC-386	T 78	--	--
Aster - aster				
	EPC-946	T 78	--	--
Amelanchier alnifolia - sackatoon serviceberry				
	EPC-470	T 78	?	F
	EPC-154	BR	--	--
Artemisia ludoviciana - herbaceous sage				
	EPC-328	T 78	E	E
Artemisia tridentata - big sage				
	EPC-439	T 77	G	F
	EPC-439	T 77	G	P
Artemisia spp. - sagebrush				
	EPC-896	T 77	P	--
Achillea millefolium tanulosa - western yarrow				
	EPC-157	T 78	--	--
Cercocarpus montanus - mountain mahogany				
	Montane	TP	P	--
	EPC-561	T 78	P	G
	EPC-435	T 78	P	--
	EPC-120	T 78	G	F
	EPC-149	T 77	P	P
Castilleja spp. - paintbrush				
	EPC-464	BR	--	--
Chrysothamnus spp. - rabbitbrush				
	EPC-304	T 78	G	G
	EPC-506	T 77	P	P
	EPC-503	T 77	P	F
Cornus stolonifera - redosier dogwood				
	NM-1121	TP	P	--
Dianthus deltoides - maiden pink				
	BN-10-880-63	T 78	--	--
Epilobium angustifolium - fireweed				
	EPC-927	T 78	--	--
Forestiera neomexicana - New Mexico forestiera				
	Jemez	TP	P	F
Gilia spp. - gilia				
	EPC-738	BR	?	G

Table 3. (continued)

Species	Variety or Accession	Type Transplant	Performance 1978	1979
Lonicera alba - honeysuckle				
	NM-1181	TP	G	--
Linium lewisi - Lewis flax				
	EPC-673	T 78	--	--
Oenothera hookeri - hooker evening primrose				
	EPC-477	T 78	--	--
Parthenocissus spp. - Virginia creeper				
	EPC-845	T 77	VP	P
Peraphyllum ramosissimum - squaw-apple				
	EPC-651	BR	--	--
	EPC-631	T 77	G	F
Penstemon barbatus - beardlip penstemon				
	EPC-368	T 78	--	--
Penstemon spp. - penstemon				
	EPC-270	BR	F	F
Philadelphus microphyllus - littleaf mockorange				
	EPC-353	T 78	P	--
Potentilla fruiticosa - shrubby cinquefoil				
	EPC-445	T 77	G	E
	EPC-445	T 77	G	G
	EPC-351	T 77	P	F
Potentilla diversifolia - varileaf cinquefoil				
	EPC-156	T 77	G	G
Prunus virginiana - common chokecherry				
	EPC-174	T 77	P	--
	NM-716	TP	F	--
	EPC-565	BR	--	--
	EPC-174	T 77	VP	--
	EPC-229	T 78	--	--
Rosa spp. - rose				
	NM-1070	TP	P	--
	EPC-405	T 78	F	G
Rhus trilobata - skunkbush sumac				
	Bighorn	TP	--	--
Ribes spp. - gooseberry				
	EPC-228	BR	--	--
Rhamnus smithii - Smith buckthorn				
	EPC-469	BR	--	--

Table 3. (continued)

Species	Variety or Accession	Type Transplant	Performance 1978	Performance 1979
Salix spp. - willow				
	EPC-986	T 77	G	E
Shepherdia argentea - silver buffaloberry				
	NM-1163	TP	P	--
Thermopsis spp. - golden pea				
	EPC-583	BR	--	--
Wyethia amplexicaulis - muleears wyethia				
	EPC-292	BR	--	--

Legend

Type Transplants:
- T 77 = 1977 Tubepaks from Meeker EPC
- T 78 = 1978 Tubepaks from Meeker EPC
- TP = tarpaper pots from Los Lunas PMC
- BR = bareroot plants from Meeker EPC

Performance:
- E = excellent
- G = good
- F = fair
- P = poor
- VP = very poor
- dash (--) = no plants

Potentilla fruiticosa (shrubby cinquefoil) and

Potentilla diversifolia (varileaf cinquefoil)

Accession EPC-445 and EPC-156 of the above two potentilla species respectively had good performances at Silverton the two seasons evaluated. These two also performed well at Climax and a discriptive write-up was given previously with the Climax evaluations.

Rosa spp. (wildrose)

EPC-405 R. woodsii was one of two accessions in evaluation. It originated from Summit County, Colorado at 8300 feet (2490 m) elevation. Performance rating for EPC-405 has shown improvement in the two years at Silverton.

Salix spp. (willow)

EPC-986 was collected at the Silverton site and rooted in tubepak planters in 1977. This accession has performed well on the tailing slope. It is also invading naturally on the lower area as moisture is applied on the tailings slope.

Thirteen grasses and three forbs were seeded similarly to the above on the sandy slopes. By August 28th of the first season, 15 of the 16 species had some germination. Outstanding species to date are: 'Largo' and 'Jose' tall wheatgrass and 'Arriba' western wheatgrass. Evaluations have been summarized for 1978 and 1979 in Table 4. All plots were irrigated in 1978 and 1979.

Table 4. Summary of Performance of Seeded Species - Standard Metals - Silverton

Species	Variety or Accession	Performance 1978	1979
Alopecurus arundinacea - creeping foxtail	Garrison	VP	?
Agropyron desertorum - desert wheatgrass	Standard	P	F
Agropyron elongatum - tall wheatgrass	Jose	G	E
	Largo	G	G
Agropyron intermedium - intermediate wheatgrass	Tegmar	G	P
Agropyron riparium - streambank wheatgrass	Sodar	F	P
Agropyron smithii - western wheatgrass	Arriba	F	G
	Rosana	P	VP
Astragalus cicer - cicer milkvetch	Lutana	P	VP
Coronellia varia - crownvetch	Chemung	F	0
Elymus cinereus - basin wildrye	Magnar	F	F
Elymus triticoides - beardless wildrye	P-15594	0	0
Festuca ovina duriuscula - hard fescue	Durar	P	0
Penstemon strictus - Rocky Mountain penstemon	Bandera	P	VP
Pleum pratense - timothy	Climax	P	P

Legend Performance: E = excellent; G = good; F = fair; P = poor; VP = very poor; 0 = no plants

Highlight of Other Activities at the Center

Seed Increases

'Bromar' mountain brome has been successfully treated for head smut at Meeker. In 1979 a four acre field produced about 500 lbs per acre (550 kg/ha) registered class seed. This will greatly contribute to getting mountain brome grass into seed production and available on the commercial market.

Endangered Plant Species

In cooperation with the U.S. Fish and Wildlife Service, the Environmental Plant Center is establishing a nursery of endangered plant species. Seed has been collected and plants of the following species are growing at the Center:

Aquilegia barnabyi (yellow oil shale Columbine)
Cryptantha stricta (upright cryptantha)
Astragalus lutosus (Dragon milkvetch)
Festuca dasyclada (Utah fescue)

The cooperative effort by government and state agencies and private industry has contributed to the progress and continued success at the Upper Colorado Environmental Plant Center.

IMPROVED PLANT TRAITS FOR HIGH ALTITUDE DISTURBANCES

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INTRODUCTION

The lack of commercially available adapted plant material is one of the major problems associated with rehabilitating high altitude disturbances (Berg, 1974; Brown et al., 1978). Because of the costs associated with the revegetation of these disturbances and the potential for erosion on these sites, only the best available plant materials should be used. Unless plant cultivars are developed specifically for high altitude use, optimum long-term returns from revegetation projects in these areas cannot be assured (Cuany, 1974).

Native species represent a logical starting place for the examination of adapted plant materials. Natural selection isolates plants that can successfully compete for limiting environmental factors in high altitude areas. Plant survival in these habitats is linked critically to the physiological mechanisms similar to those that have evolved in native species. However, not all native species may be the best suited for revegetation. On many sites environmental conditions may have been altered such that species other than natives might be better adapted for revegetation. Therefore, plant materials from other similar climates should be examined in any program for evaluating promising plants for high altitude revegetation. The key consideration should not be area of origin, but rather suitability of the plants to the present altered environment and the projected use of the revegetated site.

A number of features that adapted plant materials for high altitude disturbances should possess have been identified (Billings, 1974; Brown et al., 1978). Two of these that deserve special attention are drought resistance and nitrogen fixation.

DROUGHT RESISTANCE

Although drought is an important selective force in many ecosystems, it is not commonly considered to be of particular importance in high altitude environments. Although large portions of these areas have an abundance of water, many high altitude sites can develop moderate to relatively severe atmospheric and soil moisture stress levels during the growing season. For example, Bliss (1956) noted microsite soil moisture variability in the Medicine Bow Mountains in Wyoming. He found alpine meadows that were constantly saturated and fellfield sites where soil water potentials were often below -15 bars. Similarly low soil water potentials have been found in disturbed areas in the Beartooth Mountains in Montana by Brown et al. (1976) where water potentials in the top 15 cm soil layer often were lower than -20 bars.

In addition to soil water stress, atmospheric water stress can also be severe in high altitude habitats. Salisbury and Spomer (1964) measured leaf-to-air temperature gradients of more than 20°C in alpine areas of Colorado. With these large leaf-to-air temperature gradients, the water vapor difference (WVD) between saturated leaf vapor pressure and ambient vapor pressure (i.e., the driving force for transpirational water loss) can exceed 20 millibars in some instances. In contrast, when relative humidity is high and leaf temperature is close to air temperature, WVD may be less than 1 millibar. The most severe water stress in high altitude environments likely occurs on windy, exposed ridges, and snow-free areas. Thus, high altitude areas exhibit considerable microsite variability with respect to soil and atmospheric water stress. As a result, plant water stress may develop in many years in the more exposed sites and in very dry years may even occur in the more mesic microsites.

Drought stress probably has its greatest impact on emerging seedlings on disturbed high altitude areas. Because of high radiation loads, strong winds, and rocky soils with low water-holding capacities, successful plant establishment on these disturbances likely hinges on the seedling's ability to withstand drought stress. Consequently, the success of high altitude revegetation efforts could be improved by developing plant cultivars that exhibit superior establishment under drought stress.

Johnson (1980) identified the following major steps necessary in selection for drought resistance: 1) drought characterization, 2) definition of selection criteria, 3) assemblage of a broad genetic base, 4) development of screening techniques, and 5) application of the screening procedures. Each of these steps will be examined with particular reference to high altitude plant species.

Drought Characterization

Not only is the total amount of precipitation important in characterizing the drought in an ecosystem, but also its distribution. This is particularly applicable in high altitude areas where it makes a great deal of difference as to whether the precipitation is in the form of rain or snow. Although fairly large amounts of snow may fall on many high altitude areas, strong winds and terrain characteristics dictate where snow accumulates. Meltwater runoff from snowbanks can in turn influence adjacent sites by providing near-optimum amounts of water for plant growth during the entire growing season. Contrastingly, areas such as wind-swept, exposed ridges may experience very small accumulations of snow and consequently plants growing on these sites may exhibit severe water stress relatively early in the growing season. Because microsite variability plays such an important role in determining whether plants will exhibit drought stress, the particular area of concern has to be carefully defined. Both intensity and duration of the water deficit are important in determining the particular drought adaptations that are key factors associated with plant responses to drought.

Defining The Selection Criteria

Plants that are able to grow and survive in areas subjected to periodic water deficits are generally termed drought resistant. Drought resistance adaptations are classically categorized into avoidance and tolerance mechanisms (Levitt, 1972). Avoidance mechanisms allow the plant to escape drought stress, and tolerance mechanisms enable the plant to either postpone or withstand dehydration. Adaptations to drought stress include a wide variety of both morphological and physiological mechanisms.

Many possibilities exist for screening breeding populations for anatomical or morphological characteristics related to drought resistance. However, many interactions are present between morphological characteristics and the environment. Because of these interactions, essentially no morphological or anatomical characteristic has proven useful as a reliable guide for indicating drought resistance. Additionally, breeding lines that do well under drought conditions, may not do as well as other lines under more favorable conditions. As a result, selection for drought resistance should probably be based on plant response to drought stress rather than on specific morphological plant characteristics and should be done under closely simulated field conditions.

Inasmuch as accumulated snow and subsequent meltwater runoff are important in determining the productivity of many high altitude areas, rapid growth during periods when moisture is available is an essential plant characteristic. This adaptation, drought avoidance, allows the plant to grow and mature during periods when moisture is most favorable for growth. As a result, in seeded high elevation disturbances successful seedling establishment likely hinges on the ability of the seed to germinate and emerge rapidly under low temperatures. This ability coupled with early root initiation and rapid root extension allows the seedling to grow during the early portion of the growing season, a time period when moisture is most favorable for plant growth. It also allows the seedling to successfully compete with evaporative drying for the rapidly diminishing water near the soil surface. Since seedlings may not receive additional precipitation for 10 to 20 days after emergence, the ability to survive desiccating conditions and resume growth after drought is another important attribute.

Assembling a Broad Genetic Base

Genetic advance in a plant improvement program critically hinges on assembling a broad collection of differentiated germplasm. This diverse germplasm serves as a breeding pool for obtaining variation for particular characteristics. Genetic variation is fundamental to any plant improvement program and dictates potential progress. Because selection for drought resistance probably involves many different genes, each having a small effect, genetic variation is even more critical when selecting for drought resistance.

Although low mean summer temperatures and an abbreviated growing season are overriding features of alpine environments, high altitude habitats contain many diverse microenvironments. These habitats range from rocky, windswept ridges to protected leeward slopes often only a few meters apart. Fortunately, natural selection operating in these diverse habitats apparently has provided a highly variable pool of plant germplasm. Interactions of local plant populations with their environments seem to have resulted in significant genetic differentiation within high altitude plant species.

Development of Screening Techniques

After assembling a diverse germplasm pool, plant improvement generally involves screening this source population to isolate plants that have desired performance. As a result, reliable screening techniques form an integral component of a plant improvement program. These screening techniques should: 1) assess plant performance at the critical developmental stage, 2) be completed in a relatively short time, 3) use relatively small quantities of plant materials, and 4) be capable of screening large populations. Because of the necessity to fulfill all of these requirements, selection criteria for improving plant performance under drought stress may require a compromise between impossibly complex measurements and convenient, rapid screening techniques.

Application of Screening Procedures

Final evaluation of plant materials from a plant selection program should be based on field performance. However, laboratory selection techniques are important tools because the climatic variability under field conditions can rarely be duplicated from one year to the next.

Consequently, it becomes important to provide a more controlled environment where selection conditions can be duplicated in successive selection cycles. Because high altitude environments provide strong selective pressures and because widespread genetic variability is apparently present within many high altitude plant species, selection and breeding of high altitude species would likely yield valuable plant materials in a relatively short time.

Both field and laboratory screening procedures can be effectively used during several phases of a plant improvement program. Ideally the earlier the techniques can be incorporated into the plant improvement program, the greater the likelihood that the desired characteristics will still be within the breeding pool. Screening techniques that may have particular applicability within the context of plant improvement programs for high altitude disturbances include:

1) *Germination Under Low Temperatures.* It is important that seedlings germinate, emerge, and initiate growth immediately at the onset of the short high altitude growing season. Environmental conditions particularly on more exposed sites may result in a relatively short time period early in the growing season when moisture is adequate for plant growth. Because low temperatures are especially prevalent during the early portion of the typically cool, high altitude growing season, plant ecotypes that are able to germinate and develop at low temperatures will have a better opportunity of successful establishment before water becomes limiting. This drought avoidance adaptation allows the seedling to avoid or escape drought. A thermo-gradient bar technique provides the capability for examining seed germination under a range of constant temperatures (Halldall and French, 1958) or fluctuating temperatures (Grime and Thompson, 1976). This technique can be used to determine the precise germination response to temperature and examine ecotypic variation within a species.

2) *Rapid Root Elongation.* After the seed has germinated, it is important for the seedling to have a rapid rate of root elongation. This is particularly applicable in high altitude areas where high radiation loads and strong winds result in rapid drying of the surface soils. In this case the more rapidly the roots can penetrate into the underlying moist soil layers, the greater liklelihood the seedling will be better able to withstand the rapid drying of the surface soils. Rapid screening of many potential breeding lines could likely be accomplished with little difficulty, because many different ecotypes can be examined at the seedling stage and because rapid root elongation should necessarily be examined two or three weeks after germination.

3) *Ability to Recover After Drought.* Controlled environment chambers have proven particularly successful in the identification of drought resistant seedlings. In this procedure seedlings are exposed in an environmental chamber programmed to represent field conditions prevalent during establishment. After an acclimation period in the chamber, water is withheld for a time period that represents a realistic rate of stress development. The seedlings are rewatered after this drought exposure period, given a few weeks for recovery, and their recovery ability is rated. This technique of withholding water and observing subsequent seedling recovery is appealing because of its simplicity and capacity to evaluate large populations.

BIOLOGICAL NITROGEN FIXATION

Fertilizer application is essential for successful plant establishment on high altitude disturbances (Brown, 1974; Brown et al., 1976; Berg and Barrau, 1978). Because of the increasing cost of nitrogen fertilizer and its application and the desire to restore disturbed areas to a self-sustaining state as rapidly as possible, providing nitrogen inputs through biological nitrogen fixation by legume-*Rhizobium* associations deserves research emphasis. Considerable information exists concerning the value of legume-*Rhizobium* associations in field-crop situations and in commercial tree nurseries, but little documentation exists regarding the potential role that legume-*Rhizobium* associations could play in increasing the nitrogen levels of high altitude disturbances.

Probably some of this lack of data for legume-*Rhizobium* associations in high altitude areas may be attributable to their relatively rigorous environment. For most temperate legumes nitrogen fixation is maximum between 20 and 30°C. These are much higher than the low mean growing season temperatures experienced in high altitude areas. However, the response of nitrogen fixation to temperature can be markedly affected by the legume's area of origin (EK-Jander and Fahraeus, 1971). Consequently, legume-*Rhizobium* associations that evolved in high altitude environments may have unique adaptations that enable them to have lower temperature optima than associations from more temperate ecosystems. Legume-*Rhizobium* associations with the ability to remain viable over winter as found by Pate (1958) may be particularly applicable in high altitude environments. As a result, extrapolation of nitrogen fixation results from legume-*Rhizobium* associations that evolved in low elevation environments may not accurately reflect the capabilities of associations evolved in high altitude environments.

During the 1979 growing season, acetylene reduction rates of excised root segments with attached nodules were determined in the field to estimate nitrogen fixation activity in two native legume species growing at 3,207 m elevation in the Beartooth Mountains in Montana. Legume root systems were excavated and root segments with attached nodules were immediately excised and placed in 20cc plastic syringes for exposure in a 10% acetylene atmosphere. After a one-hour exposure period, gas samples were withdrawn and placed in 10 ml Vacutainer[2/] blood collection vials. The vials were then taken to the laboratory for subsequent ethylene analysis by gas chromatography (Johnson and Rumbaugh, 1980). Soil cores were also examined for their acetylene reduction activity. In this procedure two 19.8 cm long and 7.6 cm diameter soil cores were taken over the center of the main stem, placed in cloth bags, and exposed to a 10% acetylene atmosphere for one hour in polyvinyl chloride chambers equipped with fans for air circulation. Using the same sample collection procedure described above, gas samples were withdrawn and transported to the laboratory for subsequent ethylene analysis.

Trifolium parryi nodules were typically less than 2mm in diameter as compared with the larger *Lupinus argenteus* nodules, which sometimes were larger than 1 cm in diameter. However, *Trifolium parryi* nodules exhibited a higher rate of acetylene reduction activity than *Lupinus argenteus* both on a per g nodule fresh weight and dry weight basis (Table 1). These differences in relation to nodule size and nodule number were apparently compensatory as evidenced by the lack of statistically significant differences when soil cores were compared on a soil volume basis (Table 2).

Acetylene reduction activities were also determined for *Lupinus argenteus* on adjacent disturbed and undisturbed sites at Lulu Pass near Cooke City, Montana. Lulu Pass is located at 2,975 m elevation and is between the Glengary and McLaren Mines, which were abandoned in the early 1950's. The vegetation and underlying organic layers at the disturbed site were apparently removed by a bulldozer for road construction. The disturbed site is characterized by sparse, isolated plants of *Lupinus argenteus* and *Deschampsia caespitosa* growing on a coarse-textured gravel "soil." An adjacent, undisturbed site approximately 5 meters away is characterized by a dense vegetational cover typical of a well-established, forb-dominated community. *Lupinus argenteus* was found abundantly on this site.

Acetylene reduction activities obtained on excised root segments of *Lupinus argenteus* using the syringe technique were significantly higher on the disturbed site than the undisturbed site (Table 3). Because nitrogen content was probably greater on the disturbed site and because favorable soil nitrogen contents are known to reduce nitrogen fixation, these results were not unexpected.

[2/] Mention of a trademark name or proprietary product does not constitute endorsement by the USDA and does not imply its approval to the exclusion of other products that may also be suitable.

Table 1. Acetylene reduction activities of *Trifolium parryi* and *Lupinus argenteus* obtained using excised root segments with attached nodules on August 15, 1979, at Gardner Lake in the Beartooth Mountains in Montana at an elevation of 3,207 m.

		Acetylene reduction (μ moles ethylene per hour)	
Species	N	per g nodule fresh weight	per g nodule dry weight
Trifolium parryi	11	38.2	71.0
Lupinus argenteus	12	16.6	31.0
Standard Deviation		3.6	6.9
Significance		***	***

***Significant at 0.01 level of probability.

Table 2. Acetylene reduction activities of *Trifolium parryi* and *Lupinus argenteus* obtained using soil cores at Gardner Lake in the Beartooth Mountains in Montana at an elevation of 3,207 m on August 15, 1979.

		Acetylene Reduction (μ moles ethylene per hour)		
Species	N	per g nodule fresh weight	per g nodule dry weight	per cc soil
Trifolium parryi	6	57.6	109.7	0.0051
Lupinus argenteus	6	21.3	57.3	0.0071
Standard Deviation		12.5	22.4	0.0008
Significance		*	NS	NS

*Significant at 0.10 level of probability

Table 3. Acetylene reduction activities of *Lupinus argenteus* obtained using excised root segments with attached nodules at Lulu Pass in the Beartooth Mountains in Montana at an elevation of 2,975 m on August 16, 1979.

		Acetylene reduction (μ moles ethylene per hour)	
Site	N	per g nodule fresh weight	per g nodule dry weight
Disturbed	12	9.1	26.1
Undisturbed	11	4.7	12.6
Standard Deviation		2.1	5.5
Significance		*	***

*Significant at 0.10 level of probability.

***Significant at 0.01 level of probability.

Although the acetylene reduction results are from only two legume species and from only a limited number of sites, these data do provide quantitative evidence that native legume species are indeed capable of fixing significant amounts of nitrogen, even under the rigorous environmental constraints imposed by high altitude environments. These data also substantiate that at least for *Lupinus argenteus* potential exists for providing biologically fixed nitrogen on harsh, infertile alpine disturbances.

From this brief survey it is apparent that further documentation is necessary concerning the magnitudes of nitrogen fixation for other legume species growing in high altitude areas, the profile of nitrogen activity for promising legume species during the abbreviated high altitude growing season, the ability of different legumes to provide nitrogen to associated species on high altitude disturbances, and the ecotypic variation that may be present in promising high altitude legumes. This work should be initiated immediately so that high nitrogen fixing species and ecotypes of high altitude legumes can be identified and eventually made commercially available. Legume selection could then be based both on agronomic performance (Townsend, 1974) and capability of providing biologically fixed nitrogen.

SUMMARY

Because of intensifying pressures that alpine areas are receiving from activities such as recreation, mineral exploration, water harvesting, and mining, revegetation of high altitude lands will likely become increasingly important in the future. Inasmuch as natural rehabilitation in high altitude ecosystems is measured in terms of centuries and because these areas are particularly susceptible to erosion, revegetation success can be facilitated by providing the very best adapted plant materials. Drought resistance and nitrogen fixation are two characteristics that should be carefully considered regarding plant selection for high altitude revegetation. Plant selection for drought resistance should include: 1) characterization of the drought, 2) defining the selection criteria, 3) assembling a broad genetic base, 4) development of screening techniques, and 5) application of the screening procedures. Additionally, because nitrogen is frequently a limiting nutrient in disturbed high altitude areas, the potential of legumes for providing biological nitrogen fixation should be examined. Data presented in this paper documents that native legume species from high altitude areas are capable of fixing significant amounts of nitrogen and quantifies fixation rates found on disturbed and undisturbed sites in the Beartooth Mountains in Montana. Intensive surveys should be initiated immediately to document the potential of different species and ecotypes in providing biologically fixed nitrogen on high altitude disturbances.

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ALPINE REVEGETATION RESEARCH AT THE CLIMAX MOLYBDENUM MINE

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INTRODUCTION

Disturbances of the alpine at the Climax Molybdenum Mine have increased at a steady rate since the initiation of an open-pit operation in 1973. This disruption of the alpine will require intensive revegetation techniques to rehabilitate the watershed, wildlife habitat, and aesthetics of this alpine tundra.

The Climax Mine straddles the Continental Divide at Fremont Pass, Colorado. In this unique position runoff from the mine area travels into 3 drainages; Ten-mile Creek which drains into Dillon Reservoir, a major water supply of Denver; the Arkansas River, a major supplier of municipal and agricultural water to southeastern Colorado; and the Eagle drainage which is a tributary of the Colorado River. The importance of this watershed requires that proper reclamation procedures be developed to reclaim this alpine environment.

Alpine areas are characterized by their short, cool growing seasons, miniature vegetative life forms (Billings, 1979) high ultraviolet radiation (Caldwell, 1971), rocky shallow soils (Retzer, 1962) and a high evaporation rate (Johnston et al., 1975). Revegetation requires a relatively long period of time due to these harsh growing conditions. Recovery of alpine disturbances by natural successional process alone would require centuries (Griggs, 1956, Willard and Marr, 1971). Our present information is limited (Brown et al., 1979), concerning the reconstruction of alpine ecosystems. The present research at the Climax mine will hopefully add to the information that is needed to provide optimum conditions for vegetation reestablishment.

Within the Climax mine area the plant growth environment is highly variable. Billings refers to these changes as mesotopographic and microgradients (Billings, 1973). These gradients increase the revegetation problems due to the changes in moisture, soils, wind and length of growing season. Revegetation problems are further compounded by the production of waste rock from the mining operation. In recognizing these differences two sites were selected with widely differing plant growth environments. These two sites will be referred to as the Cirque and Alpine Meadow research sites.

The Cirque research site is located at 12,600 feet on a wide bench formed by the deposition of mine waste rock. This waste rock is produced by the open-pit mining operation as the ore body is uncovered, and forms the growth medium for the Cirque site. It is a very coarse textured unprocessed material that is removed from the open-pit and deposited in unmined areas as waste material. Most of this rock is of igneous origin but varies depending upon where in the mine it is produced. Waste rock will cover a large part of the area to be revegetated at the Climax mine. Major problems with this material as a plant growth medium are its lack of fine soil particles and lack of plant-available nitrogen and phosphorus. A major treatment on this site utilizes woodchips and sewage sludge to add and hold nutrients and organic materials necessary to initiate soil development. Woodchips have a high carbon to nitrogen ratio, about 90 to 1. Available nitrogen in the sludge is considerably greater than current plant requirements. The addition of woodchips in conjunction with large amounts of nitrogen from the sludge allows for the fixation of this nitrogen in organic complexes, thus reducing nitrogen loss through leaching. The organic matter increases the water and nutrient holding capacity of the rock waste and eventually should supply a slow release source of plant-available nitrogen to the system. Brown (1976) found through research at the Urad Mine, that the most economical and beneficial soil amendment for rock waste was an initial application of 20 tons/acre of both sewage sludge and wood chips, followed by an additional 10 tons/acre sewage, 2 to three years later.

The Alpine Meadow research site is located northeast of Fremont Pass at the upper edge of McNulty drainage basin. At present the basin is undisturbed, but future plans call for a waste rock dump to cover much of the McNulty basin area. This site was developed to answer questions posed by the future disturbance of the natural soils, related to the construction of the waste rock dump. The research site is located on a west-facing slope of 3 degrees at 11,900 feet. The soil is relatively deep, having developed from a red micaceous sandstone that forms the surface of the north and west-facing slopes of the basin. Winter snow accumulation provides moisture for this thickly vegetated meadow on which *Deschampsia caespitosa* is a dominant species.

The objectives of the research being carried out at the Cirque and Alpine Meadow research sites include the following:

-- determine which of 5 mulches will produce best results for revegetation.

-- compare effects of adding inorganic nitrogen and phosphorus fertilizer and organic fertilizer (sewage sludge).

-- compare effects of adding inorganic nitrogen fertilizer for only one year as compared to adding this fertilizer for several years.

-- determine optimum wood chip and sewage sludge rates for plant growth on waste rock.

-- compare growth and development of introduced plant species and native plant species.

-- determine which native plant species are best suited to alpine revegetation at Climax.

SEED SOURCE

One of the main goals of the present alpine research at Climax is to evaluate the growth and persistence of native species established from seed. Native, or indigenous alpine plant species as well as introduced seed presently being used on subalpine disturbances at Climax are being investigated at both alpine research sites.

Brown et al. (1976) reported that stands of commercially-available introduced grasses began to deteriorate after three growing seasons on an alpine mine site, while the native species showed increased vigor and rates of spread. Brown and Johnston (1979) later reported the successful use of introduced species *Alopecurus pratensis*, meadow foxtail, for alpine use. Alpine plant species have adapted their growth form, metabolic and reproductive attributes to the alpine environment (Billings and Mooney, 1968). Natural selection has encouraged those plant species best adapted to alpine growing conditions while discouraging less successful species. Plant selection for revegetation should consider these natural processes.

Dependable commercial alpine seed sources do not yet exist. Thus, to obtain native seed for our research needs, seed collection was necessary. A species list of prominent and pioneer plants was developed by Dr. Beatrice Willard, Dr. Robin Cuany, Dr. William Berg, and Ron Zuck, and was used as the basis for collection. Seed was collected during late August and September of 1978 from areas around the Climax mine and from Rocky Mountain National Park. Seed was collected and cleaned by hand. This process is expensive and time-consuming.

The seeding rates were determined by the amount of seed collected rather than any preconceived plan. Individual species plots were seeded containing each species collected. Also an alpine seed mixture was made up from 17 grasses, sedges and forbs that was used to seed the fertility and mulch, native seed study, and seed source and fertility treatment plots (Table 1). This mixture was well stirred and divided into aliquot portions for the individual treatment plots.

Table 1. Percent composition by pure live seeds of native seed mix.

Species	% Mixture by no. of Pure Live Seed	Pure Live Seed per m^2
GRASSES		
Agropyron latiglume	0.7	9.7
Agropyron scribneri	0.1	1.8
Carex atrata var. *chalciolepis*	1.0	13.1
Carex ebenea	6.6	88.3
Deschampsia caespitosa	20.8	279.8
Festuca thurberi	4.4	59.6
Phleum alpinum	13.4	180.0
Poa alpina	17.7	238.1
Trisetum spicatum	8.8	118.8
FORBS		
Androsace septentrionalis	0.6	7.8
Artemisia arctica	2.0	27.6
Castilleja spp.	8.4	113.2
Geum rossii	0.9	12.4
Hymenoxys grandiflora	0.4	5.6
Polemonium viscosum	2.3	31.4
Potentilla diversifolia	8.1	108.4
Rumex sp.	3.7	49.4
		1345

The Climax seed mix made up largely of introduced species adapted to the subalpine is also being investigated for its revegetation potential on alpine disturbances (Table 2).

The native seed mix was seeded at the rate of 8 lbs/acre. This rate sounds extremely low but it calculates out to 125 pure live seeds per square foot. The Climax mixture was seeded at the rate of 40 lbs/acre, this turns out to be about 470 pls/ft^2. This difference in seeding rate between the two seed mixtures shows up clearly in the first year results. An alphabetical list of all plant species used in this research follows this paper (Table 7).

METHODS AND MATERIALS

CIRQUE RESEARCH SITE

Four studies are currently being conducted at the Cirque research site.

1. Fertility and mulch study
2. Topsoil study
3. Climax seed mix study
4. Native seed mix study

One replication of thirty-five plant species in individual species plots is also included.

To begin construction of the research site, the rock waste surface was ripped with a grader in two directions, perpendicular to one another, to a depth of 1-2 feet. The ripping depth was variable due to the presence of large boulders embedded in the surface.

After ripping the plots were laid out utilizing ten treatment plots replicated 3 times for a total of 30 plots. The treatment plots are 30 x 30 feet square and each plot is divided into 3 equal 10 x 30 feet sections. The four studies are divided among the ten treatment plots.

Inorganic fertilizer applications were raked into the rock waste surface while sewage sludge - woodchip applications were worked into the rock waste using hand picks. Seed rates for the site included Climax seed mixture at 40 lbs/acre and native seed mixture at 8 lbs/acre.

The appropriate seed mixture was hand broadcast over the treatment plot and raked to cover the seed. The appropriate mulch material was then applied to the treatment plot.

Table 2. Percent in mixture by number of pure live seed of Climax seeding mixture.

Scientific Name	Variety	Common Name	% in Mixture by no. of pls
Agrostis alba		Red top	31.1
Alopecurus arundinaceus	Garrison	Creeping foxtail	8.4
Astragalus cicer		Milkvetch	1.8
Bromus inermis	Manchar	Smooth brome	3.7
Dactylis glomerata	Potomac	Orchardgrass	4.7
Festuca ovina	Durar	Hard fescue	7.0
Festuca rubra	Pennlawn	Red fescue	6.7
Phleum pratense	Climax	Timothy	10.8
Poa pratense	Newport	Kentucky bluegrass	10.1
Secale cereale	Balbo	Rye	0.7
Trifolium repens		White Dutch clover	15.0

1. Fertility and Mulch Study

Three fertility programs and five mulch treatments are investigated in this study. The three fertility programs are:

1. 300 lbs/acre diammonium phosphate (18-46-0) applied first year only.

2. 20 tons/acre woodchips and 30 tons/acre sewage sludge.

3. 300 lbs/acre of diammonium phosphate (18-46-0) applied first year with subsequent maintenance nitrogen applications.

Each treatment plot was seeded with the native seed mixture (Table 1). One of five mulch treatments was then applied to each of the treatment plots. The mulch treatments are:

1. Straw at 2 tons/acre with plastic netting
2. Jute netting
3. Excelsior mat
4. Woodchips at 20 tons/acre
5. Control (no mulch)

2. Topsoil Study

Soil was applied to a depth of four inches over the rock waste. Diammonium phosphate was added and the plot was seeded with the native seed mix. A straw mulch at 2 tons/acre held in place with plastic netting was laid down to complete the treatment.

3. Climax Seed Mix Study

Three sewage sludge rates are combined with three rates of woodchips in all combinations. The sewage sludge rates are 10, 20, and 30 tons/acre. The woodchip rates are also 10, 20, and 30 tons/acre. The treatment plots were then seeded with the Climax seed mixture and covered with a straw mulch (2 tons/acre) and held in place with plastic netting.

4. Native Seed Study

A single treatment plot was covered uniformly with 20 tons/acre woodchips and divided into 3 sections to receive 3 rates of sewage sludge 10, 20, and 30 tons per acre. The plot was seeded with the native seed mixture. A straw mulch (2 tons/acre) with plastic netting was applied to the entire plot to complete the treatment.

Individual Species Plots

One replication of thirty-seven plant species each seeded in three rows on six-inch centers, twenty feet long is also included in the research site (Table 3). The plot area was split in half; one half receiving diammonium phosphate (300 lbs/acre) and the other half received woodchips (20 tons/acre) and sewage sludge (30 tons/acre) Each species was then broadcast seeded and raked to cover the seed. A straw mulch (2 tons/acre) was applied and covered with plastic netting.

ALPINE MEADOW RESEARCH SITE

Four studies are being conducted at the Alpine Meadow research site:

1. Fertility and mulch study
2. Climax seed mix study
3. Seed source and fertility study
4. Individual species seedings

Site construction was begun by removing the sod layer from the entire site area. Topsoil was removed to expose subsoil material for the treatment plots. This topsoil was placed in two long benches for the individual species seedings.

The plot design was similar to that used at the Cirque site. Ten 30 x 30 ft treatment plots, each replicated three times were laid out at the site area. Each treatment plot was further divided into three equal 10 x 30 ft sections.

The treatment plot areas were chiseled to a depth of 3 inches in preparation for each treatment. All fertilizer applications were worked into the top three inches by hand raking. Sewage sludge rates are on a dry weight basis. The seed mixtures were hand broadcast over the plot area and raked to cover the seed. After seeding the appropriate mulch was applied to the treatment plot.

1. Fertility and Mulch Study

This study includes three fertility programs and five mulch materials as variables in the study. Each section received one of three possible fertility programs.

Table 3. Plant species seeded in individual species plots at the Cirque research site, 1978.

GRASSES, SEDGES

Agropyron latiglume
Agropyron scribneri
*Agrostis alba**
*Alopecurus pratensis**
*Bromus inermis**
Carex atrata var. *chalciolepis*
Carex ebenea
*Dactylis glomerata**
Deschampsia caespitosa
*Festuca ovina**
*Festuca rubra**
Festuca thurberi
Phleum alpinum
*Phleum pratense**
Poa alpina
Poa glauca
*Poa pratensis**
*Secale cereale**
Trisetum spicatum

FORBS

Androsace septentrionalis
Antennaria rosea
Artemisia arctica
*Astragalus cicer**
Castilleja spp.
Cirsium sp.
Geum rossii
Hymenoxys grandiflora
Mertensia viridis
Oxygria digyna
Paronychia sessiliflora
Phlox condensata
Polemonium viscosum
Potentilla diversifolia
Rumex sp.
Trifolium dasyphyllum
Trifolium parryi
*Trifolium repens**

* Introduced species.

1. 300 lbs/acre diammonium phosphate (18-46-0) applied first year only.

2. 10 tons/acre sewage sludge

3. 300 lbs/acre diammonium phosphate (18-46-0) applied first year with subsequent maintenance nitrogen applications.

After the fertilizer applications the five treatment plots were seeded with the native seed mixture and each received one of the following mulches:

1. Straw at 2 tons/acre with plastic netting
2. Jute netting
3. Excelsior mat
4. Woodchips at 20 tons/acre
5. Straw at 2 tons/acre tackified the first year with plastic netting which was removed after the first winter.

2. Climax Seed Mix Study

Several variables are investigated in this study including the three fertility programs mentioned above in the fertility and mulch study and two mulches:

1. Straw at 2 tons/acre held with plastic netting
2. Straw at 2 tons/acre crimped into the subsoil

3. Seed Source and Fertility Study

Two treatments were used, both with three rates of sewage sludge at 5, 20, and 40 tons/acre. After mixing in the sewage sludge, one treatment was seeded with the native seed mix, while the other received the Climax seed mixture. Both treatments were then mulched with straw (2 tons/acre) held in place with plastic netting.

4. Individual Species Seeding

Fifty-three plant species, including native and introduced, are included in the individual species plots seeded in the fall of 1978. Thirty-five species were seeded in three replications each of three row plots, six inches apart and twenty feet long (Table 4). Eighteen other species, some duplicates of the previous 35, were collected in smaller amounts and seeded in only one replication (Table 5). Several

Table 4. Plant species seeded in three replications in individual species plots at the Alpine Meadow research site, 1978.

GRASSES, SEDGES

Agropyron latiglume
Agropyron scribneri
*Agrostis alba**
*Alopecurus pratensis**
*Bromus inermis**
Carex atrata var. *chalciolepis*
Carex ebenea
*Dactylis glomerata**
Deschampsia caespitosa
*Festuca ovina**
*Festuca rubra**
Festuca thurberi
Phleum alpinum
*Phleum pratense**
Poa alpina
Poa glauca
*Poa pratensis**
*Secale cereale**
Trisetum spicatum

FORBS

Androsace septentrionalis
Antennaria rosea
Artemisia arctica
*Astragalus cicer**
Castilleja
Geum rossii
Hymenoxys grandiflora
Mertensia viridis
Oxyria digyna
Polemonium viscosum
Polygonum bistortoides
Potentilla diversifolia
Rumex sp.
Trifolium dasyphyllum
Trifolium parryi
*Trifolium repens**

* Introduced species.

Table 5. Plant species seeded in one replication in individual species plots at the Alpine Meadow research site, 1978, area collected is also given if other than Climax.

GRASSES

Carex sp. (Chicago Ridge)

Deschampsia caespitosa (Disturbed site)

Poa fendleriana (Iceberg pass)

FORBS

Anemone sp.

Angelica grayii

Arenaria fendleri

Arenaria obtusiloba

Arenaria sp. (Old Fall River Road)

Caltha leptosepala

Cruciferea sp.

Geum rossii (Old Fall River Road)

Polygonum bistortoides (Old Fall River Road)

Senecio (Chicago Ridge)

Sibbaldia procumbens

Sibbaldia procumbens (Old Fall River Road)

Trifolium dasyphyllum (Niwot Ridge)

Trifolium nanum

Trifolium nanum (Old Fall River Road)

of these 18 species were collected in areas other than Climax, such as Niwot Ridge and the Old Fall River Road in Rocky Mountain National Park. Seed from *Deschampsia caespitosa* found growing on a nearby disturbed site is also included. These species are seeded on raised benches of topsoil which were fertilized with diammonium phosphate and mulched with straw (2 tons/acre) and covered with plastic netting.

In the summer of 1979, nine plant species were collected from the Climax area and seeded in individual species plots on topsoil. These plant species included six species also seeded in 1978 and three species not previously seeded (Table 6).

RESULTS

Only one summers growing data have been obtained from the alpine research plots seeded in 1978. The following results indicate seedling emergence only and cannot be projected to future growth and persistence of plant species. Differences in measured plant density between the Cirque and Alpine Meadow sites are quite large. The Alpine Meadow site had an overall plant density three times greater than the Cirque site. This is to be expected when differences in the growth medium are considered.

SPECIES SELECTION

The following species show greatest promise for alpine revegetation at Climax:

<u>GRASSES</u>

Agropyron latiglume
Agropyron scribneri
Deschampsia caespitosa
Festuca thurberi
Phleum alpinum
Poa alpina
Trisetum spicatum

<u>FORBS</u>

Androsace septentrionalis
Geum rossii
Hymenoxys grandiflora
Mertensia viridis
Oxyria digyna

Table 6. Plant species seeded in individual species plots in 1979.

GRASSES
Agropyron latiglume
Deschampsia caespitosa
Phleum alpinum
Poa alpina
Poa rupicola†
Stipa lettermani†
Trisetum spicatum
FORBS
Achillea lanulosa†
Potentilla diversifolia

† Species first seeded in 1979.

Several of these species have proven successful for revegetation on the Beartooth Plateau (Brown and Johnston, 1979).

The introduced species of the Climax seed mixture produced greater densities of seedlings than the native seed mix under comparable treatments, even when differences in the seeding rate are considered. This is not unexpected for the first growing season.

FERTILIZER AND OTHER SOIL TREATMENTS

Measurements from the fertility studies showed little differences between those treatments receiving inorganic fertilizer and treatments receiving sludge or sludge and woodchips. Only slight differences were found between various rates of sewage sludge and woodchips combinations.

MULCHES

Wide variations in seedling density were measured between the mulches tested. The excelsior mulch proved to be best in promoting germination and seedling emergence at both research sites. At the Cirque site, on rock waste, the woodchip mulch was second while jute and straw were not much better than no mulch in promoting germination. On the subsoils at the Alpine Meadow site, straw was more effective than jute or woodchips. At the Alpine Meadow research site, it was observed that the soil surface was still moist in late summer under the excelsior mulch; this was not true of any other mulch or similar area outside of the research site.

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Table 7. Plant species used at the Climax alpine research site and germination information if available.

Species	% Germination		% Dormant		Tetrazolium Test	
	1978	1979	1978	1979	1978	1979
Achillea lanulosa	-	59	-	6	-	78
Agropyron latigulme	28	57	2	20	60	83
Agropyron scribneri	46	-	-	-	44	-
*Agrostis alba**	88	-	-	-	-	-
*Alopecurus pratensis**	70	-	-	-	--	-
Androsace septentrionalis	93	-	-	-	90	-
Anemone sp.	-	-	-	-	-	-
Angelica grayii	-	-	-	-	-	-
Antennaria rosea	12	-	35	-	80	-
Arenaria fendleri	-	-	-	-	-	-
Arenaria obtusiloba	-	-	-	-	-	-
Arenaria sp. (Old Fall River)	-	-	-	-	-	-
Artemisia arctica	83	-	-	-	76	-
Artemisia scopulorum	-	-	-	-	-	-
*Astragalus cicer**	92	-	-	-	-	-
*Bromus inermis**	90	-	-	-	-	-
Caltha leptosepala	-	-	-	-	-	-
Carex atrata var. *chalciolepis*	25	62	10	13	38	78
Carex ebenea	37	54	45	-	60	54
Carex sp. (Chicago ridge)	-	-	-	-	-	-
Castilleja spp.	-	-	47	-	54	-
Cirsium sp.	-	-	-	-	-	-
Cruciferea sp.	-	-	-	-	-	-
*Dactylis glomerata**	90	-	-	-	-	-

Table 7. Continued.

Species	% Germination		% Dormant		Tetrazolium Test	
	1978	1979	1978	1979	1978	1979
Deschampsia caespitosa	25	38	23	-	72	43
Deschampsia caespitosa (Disturbed site)	-	-	-	-	-	-
Dryas octopetala	-	-	-	-	-	-
*Festuca ovina**	80	-	-	-	-	-
*Festuca rubra**	90	-	-	-	-	-
Geum rossii	42	-	-	-	42	-
Geum rossii (Old Fall River)	-	-	-	-	-	-
Hymenoxys grandiflora	60	-	-	-	62	-
Mertensia viridis	13	8	--	7	10	24
Oxyria digyna	30	-	37	-	64	-
Paronychia sessiliflora	-	-	-	-	-	-
Phleum alpinum	47	63	-	-	48	65
*Phleum pratense**	85	-	-	-	-	-
Phlox condensata	-	-	-	-	-	-
Poa alpina	89	88	-	-	94	77
Poa fendleriana (Iceberg pass)	63	-	-	-	64	-
Poa glauca	22	-	-	-	21	-
*Poa pratensis**	80	-	-	-	-	-
Poa rupicola	-	52	-	-	-	52
Polemonium viscosum	7	6	40	64	24	80
Polygonum bistortoides	-	-	-	-	-	-
Potentilla diversifolia	39	14	27	11	68	63
Rumex sp.	29	-	35	-	52	-
Salix glauca	-	-	-	-	-	-

Table 7. Continued.

Species	% Germination		% Dormant		Tetrazolium Test	
	1978	1979	1978	1979	1978	1979
*Secale cereale**	91	-	-	-	-	-
Sibbaldia procumbens (Old Fall River)	-	-	-	-	-	-
Sibbaldia procumbens	-	-	-	-	-	-
Stipa lettermani	-	15	-	66	-	87
Trifolium dasyphyllum	13	18	-	47	85	65
Trifolium dasyphyllum (Niwot)	-	-	-	-	-	-
Trifolium nanum	-	-	-	-	-	-
Trifolium nanum (Old Fall River)	-	-	-	-	-	-
Trifolium parryi	-	-	-	-	-	-
*Trifolium repens**	96	-	-	-	-	-
Trisetum spicatum	90	73	-	-	94	70

* Introduced species

( ) Indicates area of collection if other than Climax

PROBLEMS IN TESTING SEEDS OF REVEGETATION SPECIES

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Most of the seeds received for testing at an official or commercial seed laboratory are those associated with species of agricultural crops, flowers, vegetables or common trees. For these seeds the testing procedures have been worked out in detail and standardized. However, in the past few years seeds of strange species which were seldom seen by seed analysts began arriving at seed laboratories such as: Indian paintbrush, Alpine timothy, Arizona fescue, Sagebrush, Serviceberry, Shadscale, Winterfat, etc. Obviously there were no standardized procedures for testing them. In response to the need for uniform procedures for analyzing these species, The Association of Official Seed Analysts established a large committee to develop testing procedures for them. The committee's work will not be finished for some time, so in the meantime we continue to struggle. However, we have established some generalizations and guidelines that have been helpful to us.

<u>General Condition of Seed Samples</u> - There is a tendency for these samples to be low in quality. Just as seed analysts do not know how to test these species, neither do harvesters nor processers know exactly how to do their job. Most species that have not been subjected to domestication have highly developed dispersal mechanisms that release the seeds from the parent plant when they reach maturity. If the harvester is not doing his job before the seeds are released he will lose much of his crop to the ground. On the other hand, if he becomes over-anxious and harvests much too early, the seed will be immature and often devoid of viable embryos. The harvester also has a problem of getting a pure product. It is difficult to gather seeds from woody stems without incorporating large amounts of leaf and stem material or to gather seeds from widely dispersed plants without inadvertantly gathering seeds from other species. Such mixed materials are then often subjected to rigorous cleaning procedures to upgrade the general purity of the seed mass. Often times this cleaning improves the general purity but damages the quality of the individual seeds. Remember that each seed is at its highest quality when it is matured and attached to the stem. From then on it is all down-hill and any manipulation of the seed thereafter can only hasten the down-hill quality movement. Seed quality over subsequent

seasons is expected to improve if harvesters and processors acquire more understanding of the species' seed production modes and how to minimize the degrading effects of harvesting and processing.

Sampling - Seed lots that are overly chaffy or contain excessive contamination are difficult to sample and samples are often unrepresentative. Simply stated: a poor sample produces a poor seed test - there is no reason to expect anything else. Improper lot sampling is by far the greatest problem in seed testing. A good sample contains 2500 units for purity analysis and ten times that amount for a noxious weed exam. For frequently tested crop kinds, the amount of material needed to produce a sample size of 25000 units has been established. Naturally this work has not been done for many of the species that are new to seed analysts. The common-sense practice of taking subsamples from as many locations in the seed lot as can be reached should be followed for all species. These subsamples can be blended thoroughly and a portion of this blend which will approximately yield 25000 units can be submitted to the seed laboratory with reasonable assurance that a repeatable analysis can be made from it.

Purity Analysis - A purity analysis of a seed sample involves separating the 2500 units into four fractions: pure seed, weed seed, other crop seed and inert material. Again our lack of familiarity with seeds of several revegetation species causes seed analysts to sometimes wonder what the seed unit really is: For example: is the huge awn attached to needle-and-thread removed or left attached; do we leave the fuzz attached to the seed of winterfat or do we remove the seed from the fruit coat altogether; and do we break away the hard fruit coat of the saltbushes to see if a seed is inside or just assume that a seed is inside and call all fruits a "seed unit"? Whatever we finally decide to do, it is most important that we all test a particular species exactly the same way. The standardization of testing procedures for each species insures that if a seed lot is tested repeatedly, you can expect each test result to be the same (or within reasonable limits) when compared with other tests of the same seed lot.

Chaffiness of seed is always a problem in purity analysis because most of the seed testing equipment is designed for free flowing seeds. We are in the process of redesigning seed testing equipment to accommodate chaffiness.

Viability Analysis - One of the usual natural seed characteristics of species that have not been subjected to intensive breeding or domestication is the presence of deep dormancy. Deep seed dormancy is an important survival mechanism for most of these species and also one of the reasons these species are desirable for the revegetation of many hostile sites. However, seed analysts are disturbed by dormancy. Many of us can only think of viability as germination and tend to equate the two terms. The terms are not the same. Viability means only the state of being alive. Germination is the resumption of active growth and is one expression of being alive. Deeply dormant seeds are also alive but cannot germinate under the conditions that we are able to provide. Many seed analysts go to great pains to get all alive seeds to express their viability by germination regardless of how deeply they are dormant. I believe that this is a mistake so we take a different tack at the Colorado Seed Laboratory. We proceed by subjecting the seed to normal germination environments for a reasonable length of time. We record the percentage of germinated seeds at that time and then subject the remaining ungerminated seeds to the tetrazolium test to determine the percentage of viable seeds in the ungerminated group and designate them as dormant. We then report the percentage of germinated seeds, the percentage of dormant seeds and the sum of these two percentages as total viable seed. This report gives the owner of the seeds some idea about how much of his seed lot will germinate rather soon after planting and how much may germinate later. We believe this to be more accurate and usable information and avoids the pitfall of someone planting these seed lots expecting an immediate seedling stand. Buyers of seeds to be planted in wild or hostile conditions must begin to recognize the value of dormancy in seeds.

Pure Live Seed - Buyers and sellers should recognize that seed quality standards have not been established for all of these revegetation species. It is adviseable for them to consider the quality of seeds on a pure-live-seed basis. If specifications would state the number of pounds of pure-live-seed to be delivered the chances of finding a supplier would be increased considerably. Even though many suppliers may have the seed for sale, their seed may not meet narrow specifications. The bulk size of the lot may vary considerably to achieve the same pounds of pure-live-seed, but the buyer would be assured of the proper amount of the product he is really after. This attitude would prevent the possible over processing of some tender seed lots just for the purpose of meeting unrealistic specifications. So until we really know how to handle seeds of these unfamiliar species, let'sjust take it easy.

For those who wish to have publications on how to handle seeds of species not familiar in the general seed commerce I would recommend (but not always agree with) the information in these two publications.

1. Collecting, Processing, and Germination Seeds of Western Wildland Plants. A USDA publication available from the Science and Education Administration Renewable Resource Center, 920 Valley Road, Reno, Nevada 89512.

2. Seeds of Woody Plants in the United States. Agriculture Handbook No. 450. Available from the U.S. Government Printing Office.

GEOLOGIC PROCESSES IN THE HIGH ALPINE ENVIRONMENT
FOURTH HIGH ALTITUDE REVEGETATION WORKSHOP, FEBRUARY 27, 1980

JOHN W. ROLD, DIRECTOR
COLORADO GEOLOGICAL SURVEY

As I was attempting to gather my thoughts for this talk, a question came to my mind as just what is meant by "high altitude", or "alpine", or "high alpine", and how would geologic processes in that environment differ from the more usual environment we see in Colorado? In order to stress those geologic processes occurring in the alpine environment, I will address that environment occurring at the elevation of near-timberline to above-timberline. If I were successful in explaining conditions in the near-timberline and higher elevation environment, you yourselves could see how these same principles would apply in varying degrees as one progressed downward in elevation to that level of 8,000 feet.

Those geologic factors that I visualize in that high alpine environment, which are markedly different from Colorado's more usual environment are: climate, topography, bedrock, age of features, weathering, soil development, and slope stability.

As the geologic aspects of these natural processes are discussed, many of you may feel disappointed that you are not gaining any broad new insights into the problem. Many will feel that as a geologist I'm giving only a small new wrinkle or slightly different insight into subjects that many of you have observed over long periods of time in many different areas. If you have observed and studied these processes and their impacts, you can easily grasp my preferred definition or derivation of "GEO-LOGIC"; "GEO" from the root words for earth and earth processes, and "LOGIC", which is a system of applied reasoning or "common sense". Today I'd like to examine briefly with you those GEO-LOGIC factors which particularly relate to reclamation in the alpine environment.

Climate

Temperatures provide a major control on climate, and in the alpine environment, the climate is definitely cold. In fact, most of the surface is snow-covered over long periods of the year. Most of the soils and rock are frozen during much of the year. In some scattered areas, on steep north slopes we encounter permafrost. Precipitation in most of those areas is quite high, particularly during the wintertime as snowfall. Because of this, high water saturations occur in the soils and the rock, particularly in the spring during and after snowmelt. The freeze-thaw cycle, and its attendant geologic effects, predominate over a much longer period of the year at these elevations than in most areas. A long, late spring can continue even into mid-summer. A very early fall can begin the day after spring ends. Winds, except in sheltered areas, can reach extremely high veolocity. Yet in the alpine environment, eolian or wind deposits are quite scarce. This is probably due to the type of material available for the wind to work on. Those materials are usually moist or wet, and they are often bound together by vegetative cover. High wind veolocities, however, could provide serious problems to revegetation efforts.

Topography

The topography in the alpine areas is normally quite steep. Relatively high relief usually occurs from ridge top to valley bottom.

Geologic Bedrock

The bedrock in Colorado's alpine regions is usually quite hard. In fact, the causal factor common to all alpine bedrock is its resistance to erosion. It is most often composed of granitic rocks, metamorphic rocks, or highly resistant volcanics. Usually, the bedrock encountered is quite old because we are often looking at the exposed core of the mountain ranges. Exceptions do occur in areas of volcanic terrain, but even there a thin, volcanic cap rock may overlay the roots of an old mountain uplift.

Age of Geomorphic Features

Predominant features are quite young, at least in terms of geologic time. The Ice Age, or the Pleistocene as called by geologists, ended only some 10,000 years ago. During the middle of the Pleistocene period, or approximately 600,000 years ago, most Colorado areas above timberline were covered by widespread ice caps or snow fields. These ice sheets, or major snow fields, fed valley glaciers which extended down most of the major valleys. As a result, the major shapes of most alpine geomorphic features are less than 600,000 years old. That represents only a moment's time when you're talking with a geologist. Glaciation left its stamp on much of the area in the form of cirques, tarn lakes, oversteepened U-shaped valleys, and glacial deposits such as discreet moraines and widespread deposits of glacial drift. In the alpine environment, most pre-existing structural features and topographic features were greatly modified by glacial action.

Weathering

Weathering in the high alpine environment is very definitely related to the freeze-thaw cycle, and freeze-thaw is one of the major weathering phenomena active in the alpine areas. Chemical weathering is usually quite slow, particularly because of the short period during each year when the ground is unfrozen. Waters are usually mildly acidic because of the types of minerals in the rocks, and also from decaying plants. The larger-scale weathering phenomena, or major geologic processes, will be discussed somewhat later.

Soils

The combination of climatic and weathering factors provides soils which are nearly all young and quite weakly developed. As soil scientists understand probably even better than most geologists, the soils in the alpine environment are apt to be quite similar to Arctic soils many thousands of miles away, and quite different from soil types only a few miles away and a few thousand feet lower in elevation. Again, one should realize that high altitude soils are frozen for a large portion of the year. The generally lower temperatures in these soils inhibit the growth of microorganisms. Those microorganisms which aid in soil development are much less well developed and quite sparse compared to warmer soils Soils contain a high percentage of rock fragments, and even the fine materials in the soil are apt to be rock flour rather than true soil particles. Soils are apt to be quite low in organic matter, except for a thin surface layer or in scattered peatbog situations. The soils are likewise quite variable in thicknes. Although they are thin in most areas, the soil thickness can range from zero over bare rock and in the piles of rock fragments or boulders to considerable thickness in the relatively low, flatter areas where highly organic, peaty-type soils can develop.

Slope Stability

The stability of slopes can again be extremely variable and can range from solid bedrock, which is quite prevalent, to highly unstable deposits of talus, glacial flour, or peat muck. Again, because of the steep slopes, the high topographic relief and high moisture saturation of materials, the stability problems of any loose material can be greatly accentuated. Although the high percentage of rock fragments may tend to produce well-drained soils, the high water table and extremely high saturations provided in the spring of the year may cause even materials which are normally considered as well-drained to be highly saturated and quite unstable during the spring and early summer. Likewise, the presence of peaty material and highly organic soils can also contribute to stability problems even in areas of moderate slopes.

Predominant Major Geologic Processes

Because of the steep topography and severe cold climate, certain large scale geologic processes predominate in the alpine environment. In that environment, one certainly expects major impacts from snow avalanches, landslides, mudflows, debris flows, rockfall, solifluction (soil creep), and frost heaving. Depending upon the specific site in question, each of these processes could have a distinct, significant, and separate impact on reclamation efforts. Each process by itself could provide a separate talk. Reclamation people should recognize the likelihood of these processes and call upon experienced engineering geologists to suggest mitigation procedures designed for each specific site situation.

In summary, those geologic processes that aid reclamation -- that is, those that relate to soil formation -- work very slowly. Those that work against reclamtion, particularly those related to stability, could work very fast and quickly wipe out reclamation efforts. In the alpine environment, reclamationists must pay particular attention to soil types and to slope stability problems. Successful reclamation efforts must work with geologic processes, and not against them.

ALPINE SOIL FACTORS IN DISTURBANCE AND REVEGETATION

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INTRODUCTION

For the past three years a study has been conducted investigating the soils of the Indian Peaks region of the Colorado Front Range. It is part of a larger, multi-disciplinary project that it to produce an environmental atlas of this region. The soils have been mapped at 1:24,000 in a 3rd order soil survey that has been supervised by the Soil Conservation Service. Approximately 57,000 hectares (140,000 acres) have been mapped with about 14,000 hectares (35,000 acres) being in the alpine zone. The second part of the project has been to explain the distribution of these soils based on the factors of soil development. The third part of the project is to develop land use planning ideas for the alpine zone based on the results of the factors of soil development. This paper summarizes the mapping part of this project, looks at how the factors of alpine soil development affect soil characteristics, and then applies these principles to alpine soil disturbances and revegetation.

The conclusions from this project concerning alpine soils can be applied to most North American alpine soils formed on metamorphic and igneous intrusive bedrock. Most alpine mining disturbances occur on rock of this type. Alpine soils of areas with volcanic and sedimentary bedrock have same processes occuring, but the chemistry of the soils is slightly different (for example, pH's are higher and cation concentrations are different).

It is the purpose of this paper to clarify and organize alpine soil characteristics and processes so they can be used for better alpine revegetation.

INDIAN PEAKS STUDY AREA

The Indian Peaks region of the Colorado Front Range lies directly to the south of Rocky Mountain National Park along the Continental Divide. Bedrock of the area is primarily biotite schist and gneiss with some large intrusions of granite. The valleys have been heavily glaciated and about 10 active glaciers still exist in the cirques of some of these drainages. At the center of this region lies Niwot Ridge which has been an alpine research site for many years.

I have divided the tundra into three provinces: high alpine which is composed of the steep alpine slopes of bedrock outcrops and talus with some thin and young soils; rolling tundra which is composed of the large ridges and high plateaus of the region that have gentle, undulating topography; and valley bottoms which have been glaciated, and their soils are formed mainly on till and scoured bedrock. Soils of the rolling tundra are thick and moderately developed. Soils of the high alpine and valley bottoms tend to be thin and poorly developed for they have been glaciated in the past 15,000 years thus providing little time for adequate development of "moderate" soil characteristics.

FACTORS AFFECTING SOIL DEVELOPMENT

Soil characteristics change through time and this change in soil profile characteristics is called soil development. Soil development is marked by an increase in the: number of horizons, size of each horizon, amount of clay and iron oxides translocated into the B horizons, organic matter in the A horizon, and depth of the soil to the unweathered parent material.

The characteristics of all soils are controlled by five factors that influence their development (Jenny, 1941).: climate, parent material, vegetation, time, and topography. In the Indian Peaks alpine zone, the climate is basically uniform if one considers macroclimate. (Microclimatic influence is great, but it is controlled by topography which is mentioned later.) Overall, the cold temperatures and the lack of moisture slow down development considerably. Parent material is generally the same for it is either gneiss, schist, or granite of similar mineral composition, and therefore has little effect on soil distribution. This bedrock does control the pH and gives the characteristic low pH's found in the area (as opposed to the pH's found on volcanic or sedimentary rocks). Loess (eolian debris) is also another parent material that provides essential nutrients for the A horizons where plants grow. Vegetation is primarily affected by the same factors that control soil development, so in essence, plant succession develops in a manner parallel to that of soil development. Alpine plant communities are excellent indicators of different soils and amounts of winter snow cover. Time is difficult to analyze because there are few dating controls on the tundra. Topography controls snow distribution in the alpine and under various snow cover sites, different soils are found. I feel that topography, through its control of snow distribution, is the most important factor in controlling soil distribution on the alpine tundra and may also be very important in controlling development of soils. At this symposium, Dr. Kay Everett mentioned that soil moisture is the most important factor in controlling arctic soil development. In the alpine, topography controls snow distribution which in turn controls soil moisture. The next section discusses alpine soil distribution and development in relation to topography.

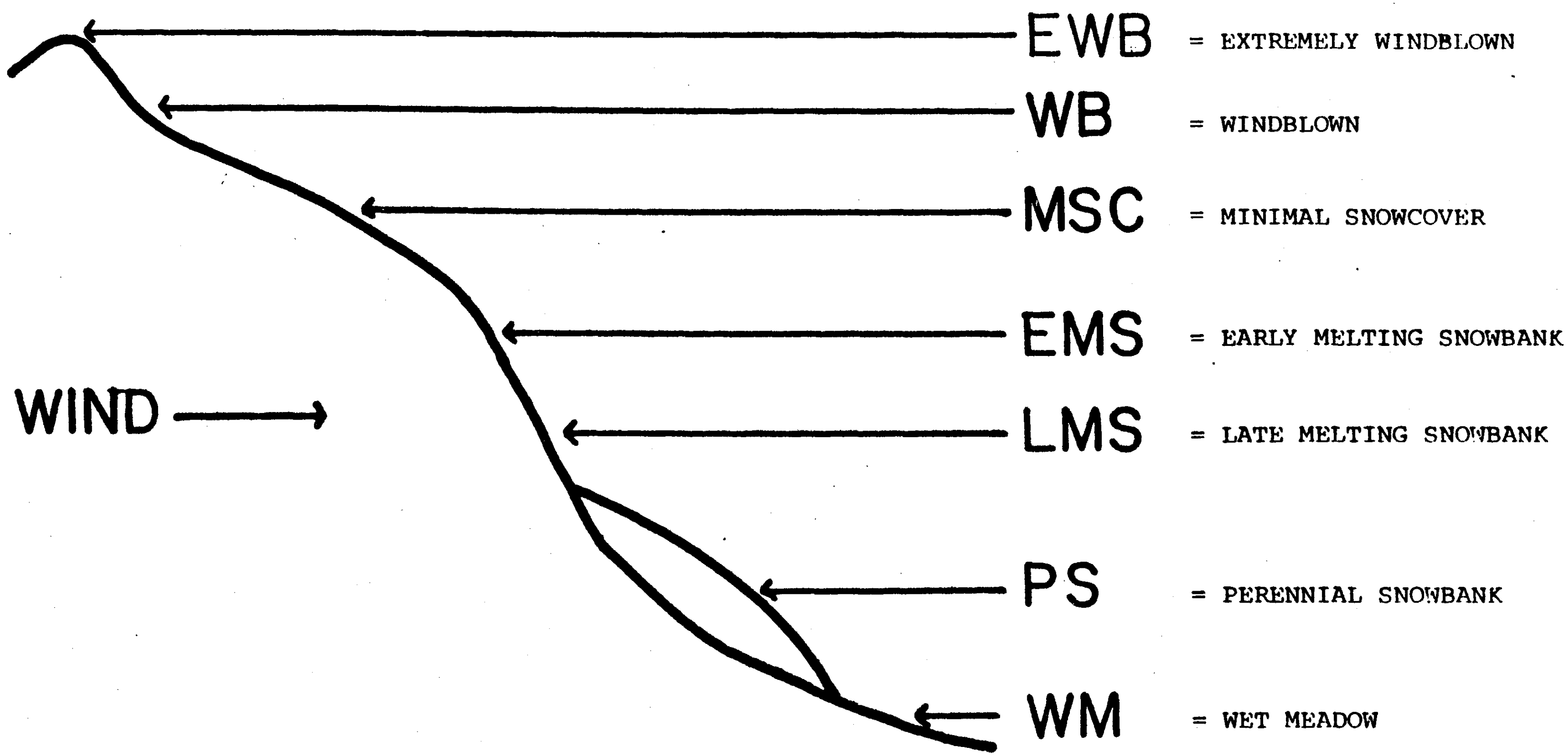
THE THEORETICAL ALPINE SLOPE: ORGANIZATION

During the mapping of these soils, it became apparent that alpine soils are extremely variable, but there was an order to their distribution based on snow cover. A theoretical slope organized around snow accumulation on the leeward side of a slope (Figure 1) was then constructed and subsequently revised many times. It is similar to the mesotopographic unit of Billings (1973, 1978), but it has been modified into more specific components. Nowhere in the alpine has this slope been found, but most slopes contain portions of it. This Theoretical Alpine Slope (TAS) has been constructed based on personal observations which were used to modify the measurements recorded by Diane May (1973).

The extremely windblown (EWB) and windblown (WB) sites are found on the alpine ridge tops and knolls and rarely have any snow cover. Vegetation is sparse because these sites are extremely dry. These areas are characterized by constant wind erosion. On the minimal snow cover (MSC) portions of the slope one gets the greatest loess deposition on the alpine tundra. These sites are usually in the cols and on the large plateaus. They are the most common soils in the study area. Early melting snowbank sites (EMS) are generally found at the lower elevations of the tundra and these snowbanks generally melt out by June. The alpine revegetation plots of Brown and Johnston (1978b) are of this slope position. Many times these are the sites of solifluction activity. Late-melting snowbank (LMS) sites normally melt out in July or August. Under perennial snowbanks (PS) there is no vegetation for these snowbanks rarely melt out completely. All 3 of these snowbank sites (EMS, LMS, PS) continually undergo downslope movement. Below these different snowbank sites there is a wet meadow (WM) where meltwater from above snowbanks accumulates.

Table 1 describes each portion of the slope by giving the indicator plant species used to identify the soils and slope positions, the number of snow free days per year, and the mean annual soil temperatures at 10 cm. depth on the slope. The slope basically has the same construction on the windward side, too, but generally lacks the late-lying snowbank and the perennial snowbank portions as the windblown portions extend further down the slope.

THEORETICAL ALPINE SLOPE PORTIONS



<u>FIGURE 1: THEORETICAL ALPINE SLOPE:</u> Positions on the slope are determined by snow cover. The windward slope has the same sequence but lacks the perennial snowbank and the late-melting snowbank.

TABLE 1: CHARACTERISTICS OF THE THEORETICAL ALPINE SLOPE: The snow free days are based on personal observations and May (1973). The soil temperatures are taken from May and Webber (1975). The indicator plant species associated with each slope position are from Komarkova and Webber (1978). The mapping unit numbers are those used by Komarkova and Webber (1978) to map alpine vegetation.

Slope Position	Approximate Snow Free Days Per Year	Mean Annual Temperature at 10cm depth	Mapping Unit #	Associated Indicator Plant Species
Extremely Windblown	300	-	4	Silene acaulis Paronychia pulvinata
Windblown	225 - 300	- 0.86 °C	2, 7 5	Carex rupestris Dryas octopetala
Minimal Snow Cover	150 - 200	- 1.37 °C	6 3 1 -	Kobresia myosuroides Trifolium dasyphyllum Carex elynoides K. myosuroides/Acomastylis
Early Melting Snowbank	100 - 150	- 1.15 °C	9 10 11, 8 12, 13 20(dry)	Acomastylis rossii Trifolium parryi Deschampsia caespitosa Vaccinium scoparium/cespitosum Salix planifolia/villosa
Late Melting Snowbank	50 - 100	+ 1.04 °C	14, 15 16 17	Sibbaldia procumbens Carex pyrenaica Juncus drummondii
Perennial Snowbank	0	below 0°C	-	no vegetation
Wet Meadow	About 100	+ 0.41 °C	18,19,21 20(dry)	Carex scopulorum Pedicularis groenlandica Salix planifolia/villosa

THEORETICAL ALPINE SLOPE: SOIL CHARACTERISTICS AND OVERALL SOIL DEVELOPMENT IN THE COLORADO FRONT RANGE

Tables 2A and 2B give a detailed look at seven soils that represent the portions of the Theoretical Alpine Slope. These soils are found mainly on the rolling tundra province. Soils of the high alpine and valley bottom alpine provinces are mapped mainly from their geomorphology. Neoglacial (last 5000 years) and late-Wisconsin (about 10,000 years B.P.) till deposits are common in the valley bottom assemblage. High alpine soils are composed of thin, moderately developed soils on rock ledges of steep slopes with many poorly developed Entisols on talus slopes. Avalanche chutes also contain a catena of the same soils as found on the steep slopes. Patterned ground soils are mainly found on the rolling tundra. Four mapping units (not listed here) have also been developed for soils of the forest-tundra ecotone. The soils of all three provinces are listed along with their taxonomic names in Table 3.

One can see from Tables 1 and 2 that it is impossible to give a brief description of the "average" alpine soil, for there are many types of alpine soils. When considering alpine soils, one first must ask which slope position soil is to be discussed. Soils of the alpine do have two common characteristics though: mostly they are extremely rocky (or skeletal using S.C.S. terminology), and they are extremely variable, even over short distances. As an example, in the summer of 1978 a pit was dug on Niwot Ridge on a "windblown" slope surface that could be classified in three different ways on different sides of the pit. This variability is associated with the differences in the rockiness of the soils which probably is a relic of past, colder climates of the Wisonsin age glaciations.

Figures 2 through 6 show how certain soil characteristics change on the Theoretical Alpine Slope.

Figure 3 shows how the depth of the A horizon (evaluated by depth to a chroma of 2 or less thus eliminating the sites that might be overthickened by pocket gophers reworking the upper horizons). It shows that the A horizons increase downslope until the MSC sites after which the size of the A horizon begins to decrease to the bottom of the slope. The size again increases in the wet meadows.

Figure 4 shows how the clay content in the B horizon increases to a maximum at the MSC site and then decreases downslope from there. The anomaly under the perennial snowbank is probably from unexplained nivation processes.

The deposition of loess (Figure 5) generally follows the curve of the clay content in the B horizons. This shows that loess might have something to do with clay movement for this eolian debris is adding clay to the system. This means the greater the surface loess deposit, the greater the supply of clay to move through the system. Loess is

Table 2A: Soil descriptions of representative soils for each position on the Theoretical Alpine Slope. Some cation data was not available at time of print.

Soil Type	Horizon	Depth (cm.)	Moist Color	Percent Volume greater than 2mm	Texture	pH (1:1 water)	CEC meq/100g (sum of cations)	Percent Base Saturation	Percent Organic Matter
Extremely	A	0- 5	7.5YR 2/1	45%	sandy loam	4.4	-	-	10.1%
Windblown	B	5- 28	7.5YR 3/4	50%	sandy loam	4.5	-	-	5.1%
Soil	C	28- 58+	7.5YR 4/3	50%	sandy loam	4.8	-	-	1.7%
Windblown	A	0- 5	7.5YR 2/1	10%	loam	5.6	24.8	48%	14.0%
Soil	B	5- 50	7.5YR 5/6	40%	sandy loam	5.9	6.6	58%	1.3%
	C	50-107+	10 YR 4/4	40%	sandy loam	5.5	5.3	67%	.6%
Minimal	A11	0- 14	7.5YR 2/1	15%	loam	5.5	29.8	53%	16.7%
Snow	A12	14- 24	7.5YR 3/2	40%	sandy loam	5.0	19.7	26%	3.9%
Cover	B1	24- 46	7.5YR 4/6	45%	sandy loam	5.1	16.4	12%	2.1%
Soil	B2	46-110	7.5YR 5/6	45%	sandy loam	5.2	9.2	11%	.9%
Early	A11	0- 6	7.5YR 2/1	20%	loam	4.9	-	-	18.4%
Melting	A12	6- 30	7.5YR 3/2	35%	sandy loam	4.5	-	-	1.7%
Snowbank	A13	30- 93	7.5YR 3/3	50%	sandy loam	5.0	-	-	1.6%
Soil	IIBb	93-160+	7.5YR 4/4	20%	sandy clay loam	5.4	-	-	.6%

Table 2B: Soil descriptions of representative soils for each position on the Theoretical Alpine Slope. Some cation data was not available at time of print.

Soil Type	Horizon	Depth (cm.)	Moist Color	Percent Volume greater than 2mm	Texture	pH (1:1 water)	CEC meq/100g (sum of cations)	Percent Base Saturation	Percent Organic Matter
Late Melting Snowbank Soil	A	0- 13	7.5YR 3/2	70%	sandy loam	4.5	19.6	14%	6.7%
	B21	13- 48	10 YR 4/4	70%	sandy loam	4.8	8.4	8%	1.6%
	B22	48- 90	10 YR 4/4	50%	sandy loam	5.1	4.4	55%	.7%
Perennial Snowbank Soil	A11	0- 18	10 YR 3/3	30%	sandy loam	4.7	-	-	2.2%
	A12	18- 28	7.5YR 3/4	30%	sandy loam	4.7	-	-	1.4%
	B	28- 34	7.5YR 3/4	30%	sandy loam	4.8	-	-	1.3%
	II A b	34- 39	7.5YR 1/1	10%	sandy clay loam	4.9	-	-	-
	II B2b	39- 56	7.5YR 3/3	50%	sandy clay loam	4.9	-	-	1.7%
	II B3b	56- 79	7.5YR 4/4	50%	sandy loam	4.9	-	-	1.5%
Wet Meadow Soil	Oe	0- 25	7.5YR 1.7/1	5%	clay loam	4.6	62.7	23%	51.4%
	A	25- 39	7.5YR 2/2	75%	clay loam	4.7	22.5	15%	13.4%
	B	39- 66	10 YR 4/5	65%	sandy loam	4.8	2.6	28%	3.6%

TABLE 3: Alpine soils mapped in the Indian Peaks region of the Colorado Front Range

MAPPING UNIT NAME	TAXONOMIC NAME
1) Extremely Windblown Soil	1) Dystric Pergelic Cryochrept
2) Windblown Soil Complex	2) Pergelic Cryochrept Dystric Pergelic Cryochrept
3) Minimal Snow Cover Soil Complex	3) Pergelic Cryumbrept
4) Early Melting Snowbank Soil Complex	4) Typic Cryumbrept Pachic Cryumbrept
5) Late-Melting Snowbank Soil	5) Dystric Cryochrept
6) Perennial Snowbank Soil Complex	6) Lithic Pergelic Cryorthent Pergelic Cryoboralf over a buried Pergelic Cryoboralf
7) Wet Meadow Soil Complex	7) Histic Pergelic Cryaquept Pergelic Cryaquept
8) Soil on Patterned Ground	8) Pergelic Entic Cryumbrept
9) High Alpine Steep Soil Complex and the Avalanche Chute Soil Complex	9) Pergelic Cryorthent Lithic Pergelic Cryochrept Dystric Pergelic Cryochrept Lithic Pergelic Cryoboroll
10) Late-Wisconsin Surficial Deposit Soil	10) Dystric Pergelic Cryochrept
11) Neoglacial Surficial Deposit Soil	11) Pergelic Cryorthent

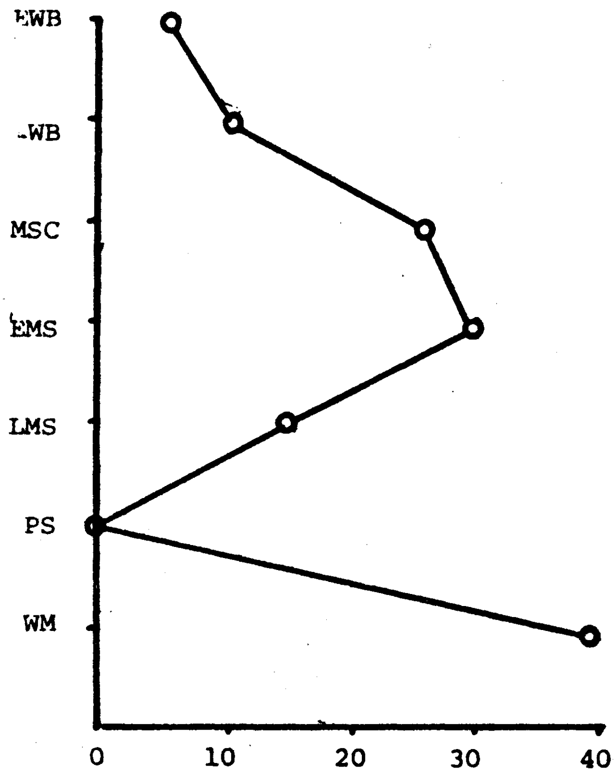


FIGURE 2: DEPTH (CM.) OF DARK COLORS (CHROMA 2)

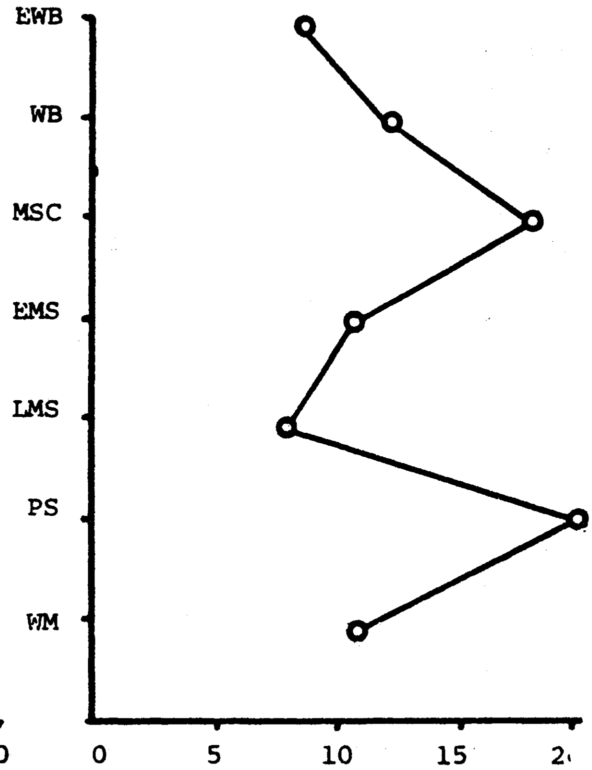


FIGURE 3: MAXIMUM CLAY PERCEN IN "B" HORIZON

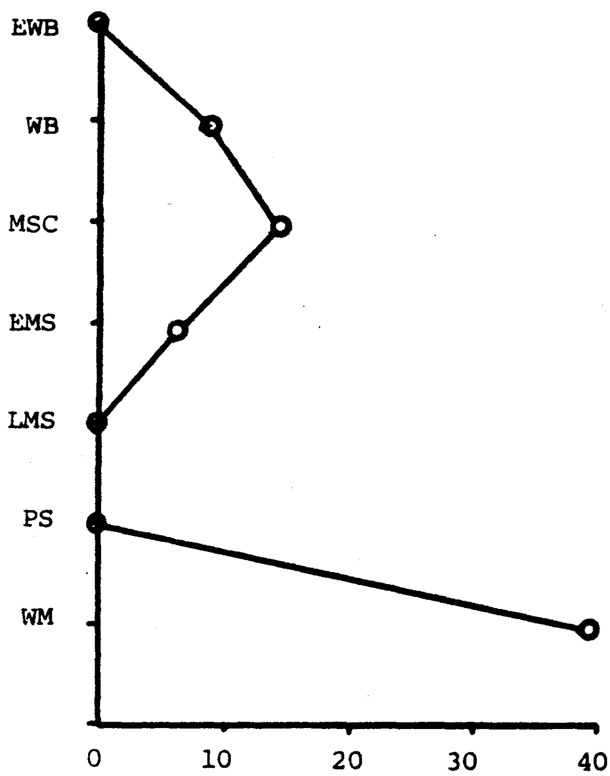


FIGURE 4: DEPTH (CM.) OF LOESS

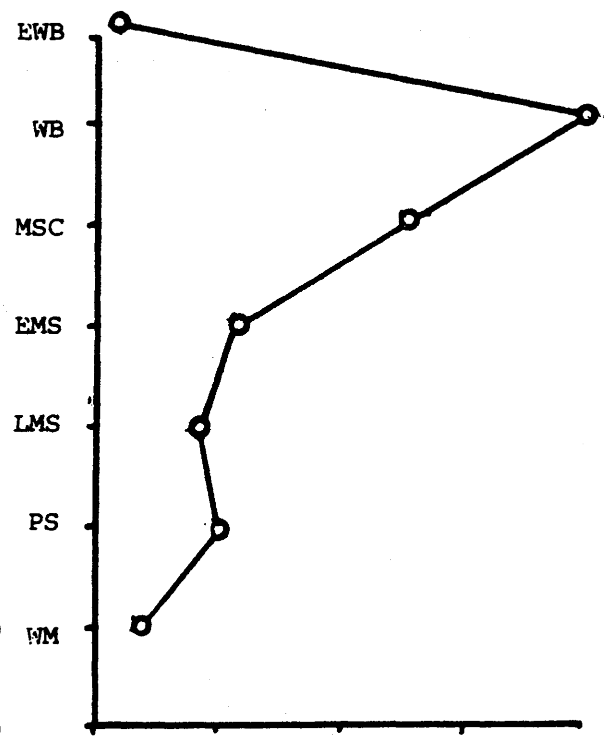


FIGURE 5: AVERAGE PROFILE pH

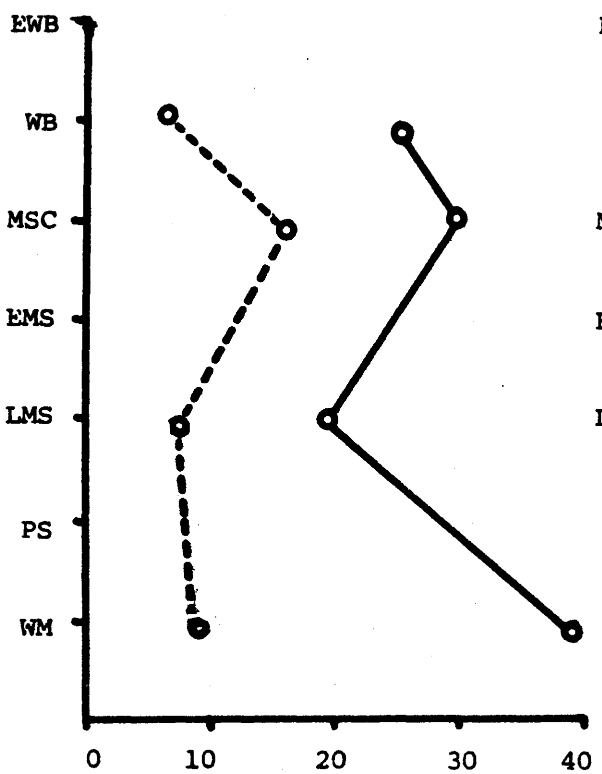


FIGURE 6: CATION EXCHANGE CAPACITY
(Solid line is for surface horizon)
(Dashed line is for B horizon)
(Data not available for all sites)

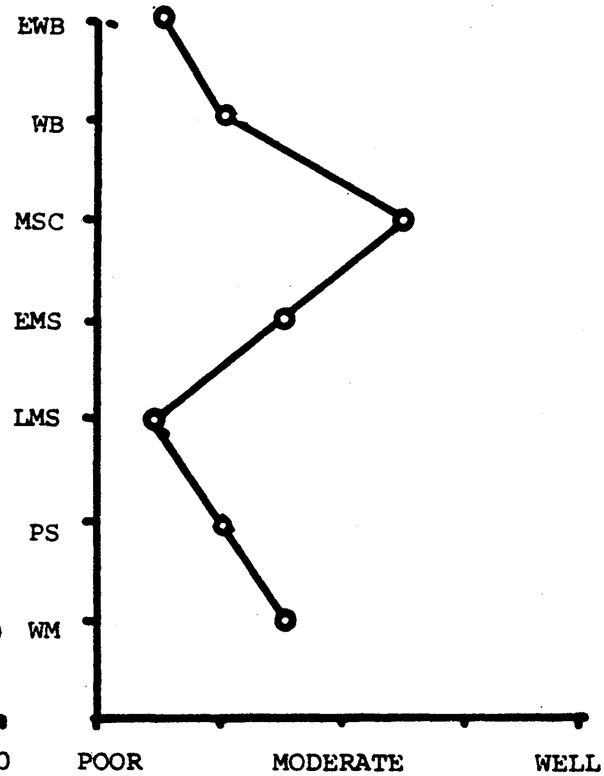


FIGURE 7: GENERAL DEVELOPMENT

extremely important to vegetation growth for it adds needed calcium and magnesium ions that are not present in the subsoil. (Calcium and magnesium are the major components of the positive cations other than hydrogen that are reported as CEC in Tables 2A and 2B.)

Figure 6 shows the changes in pH (1:1 distilled water) on the slope. The average pH of the profile has been plotted here. The values in Table 2 indicate that there are big pH differences within the profiles too. Again, the maximum pH values are at the WB and MSC sites.

Only a few values of CEC are available now, but they have been plotted in Figure 7. Values for the surface horizons and the B horizons are both given. Again, the values follow the slope trends of the previous five figures.

Generalizing from the above 6 curves, an overall development curve has been constructed as a summary (Figure 8). It shows that development increases downslope to its maximum at the MSC site and then decreases downslope to the perennial snowbank where it again begins to increase. It shows that the most stable alpine soils are found in the zone of minimal snow cover.

I tend to look at the MSC soils as being close to the "climax" developed soils with all other sites being physiographic climaxes (to use plant succession terms, Oosting, 1956) in soil development. Snow and wind are the limiting factors. Downslope from the MSC sites, increasing snow cover decreases soil development. The climax soils of the alpine tundra, which are probably alfisols, are mostly buried today. (I have found some of these in pits deeper than a meter.) I would imagine that I would discover extremely old buried soils if I would dig deeper soil pits. The physical environment through snow distribution not only controls vegetation growth patterns, but it may control soil development.

Compared to arctic soils, alpine soils show more diversity. The alpine soils that most resemble arctic soils are the wet meadow soils of the TAS. Their moisture regimes and horizontality are similar to a majority of arctic brown soils (Tedrow, 1977).

DISTURBANCE AND REVEGETATION OF ALPINE SOILS

Disturbance of soils on the tundra continuously occurs in nature on a small scale, but the systems recover. Pocket gophers, for instance, are a major erosive agent on the alpine tundra (Burns, 1979), but their sites sometimes can recover within 5 years. Larger disturbances by man are much slower to recover in this cold environment. If

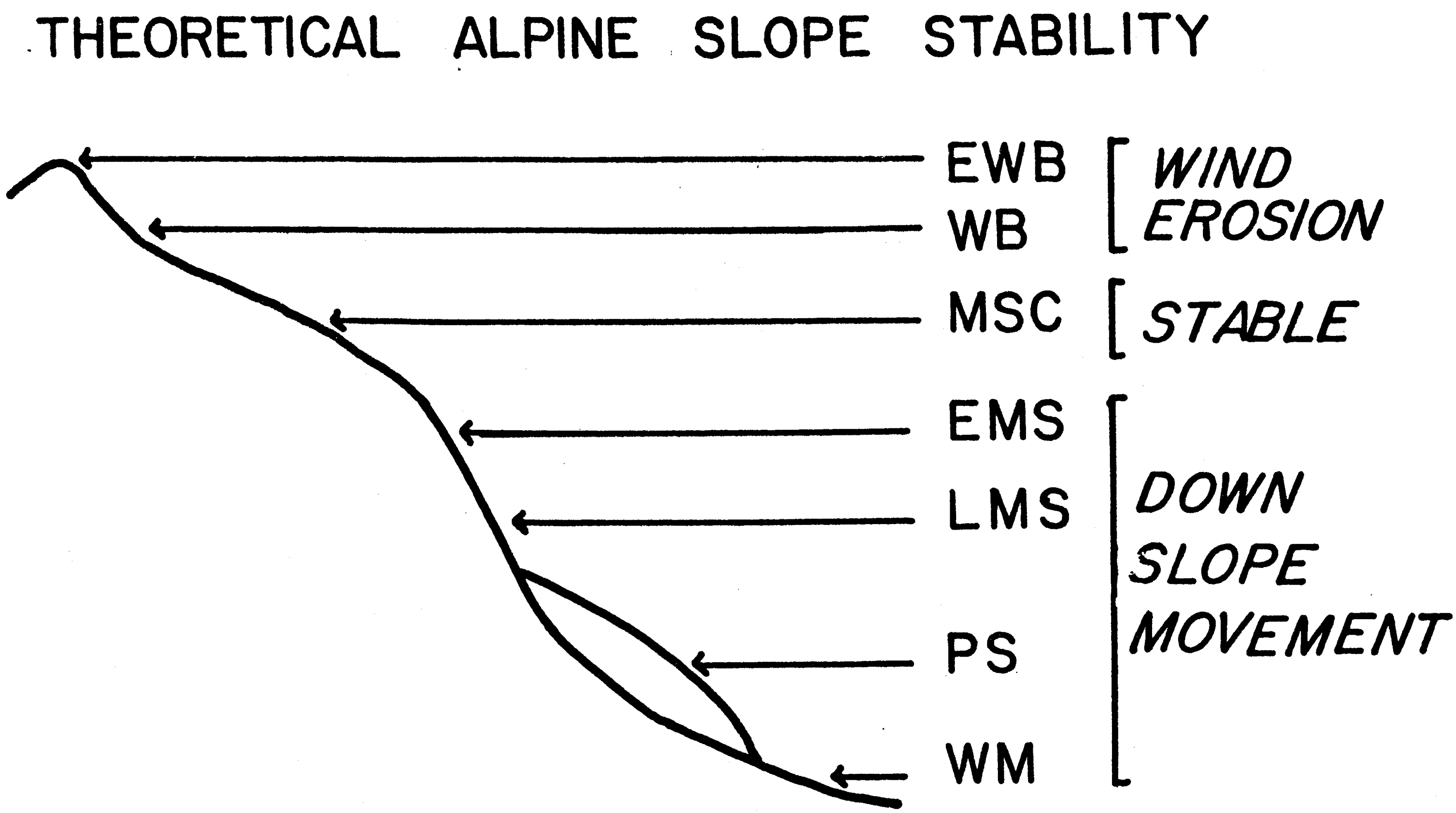


FIGURE 8: Zones of stability on the Theoretical Alpine Slope.

man does not help nature revegetate the area, extensive soil erosion and subsequent water pollution can further devastate the environment.

An alpine disturbance removes the most important portion of the soil, the A horizon. Most of the nutrients, the fine particles from the loess, and the higher pH are needed by the alpine vegetation, especially the seral and climax stages of vegetation, for proper growth. The thickest A horizons seem to have the thickest vegetation. New vegetation has to grow on a sterile, more acidic, sandy regolith.

One particular part of the ecosystem is extremely fragile and may never recover from man's destruction. The forest-tundra ecotone is the transition zone between the subalpine forest and the alpine tundra composed of krummholz forms of trees and alpine vegetation. Kathy Hansen-Bristow (1979) has recently found that these trees are not regenerating (little seed production) and that there are very few seedlings becoming establised. Therefore, the treeline was probably established at an earlier, warmer climatic period. This means that after the destruction of this beautiful vegetation, these trees can not restore themselves under the present climate and only alpine vegetation is able to revegetate there. The upper limit of trees rises and falls with the climate and now may be decreasing in elevation.

The question of shaping and grading slopes that are to be revegetated is extremely important for it controls snow distribution which is the most important physical factor on the tundra controlling soils and plant development. Based on the principles discussed in the section on the Theoretical Alpine Slope, one would want to imitate either the minimum snow cover or the early melting snowbank sites of the TAS to attain the most stable site (least erosion), the best conditions for soil and plant development, and therefore healthy tundra vegetation. Figure 8 summarizes these zones of erosion and stability on the TAS. This slope position offers enough snowcover for plant moisture but not too much to shorten the growing season. It also provides the best environment for loess deposition. The partial snow cover also reduces winter frost processes in the soil.

This type of uniform slope grading prevents ridges that are barren in winter and very dry in summer. It also prevents big depressions for large snow accumulations which have short, very wet growing seasons and therefore are subclimaxes of vegetation. Brown and Johnston (1978) also point out that these depressions seem to collect the acids that wash into them if soils containing pyrite are in the area. If the slope cannot be graded into this form, the site should be revegetated with plant communities that are adapted to the particular snow cover (TAS) class into which the slope falls.

Bob Johnston (personal communication, 1980) said that one of the most destructive soil processes that he and Ray Brown encountered in alpine revegetation was frost heave. This freeze-thaw cycle literally pops seedlings out of the soil. On a sparsely vegetated site on Niwot Ridge in June, 1973, there were 9 freeze-thaw cycles alone at a 10 cm depth in the soil, which is below seedling depth (May and Webber, 1975). One would expect many more of these cycles closer to the surface. Brown and Johnston (1978b) recommend the use of mulches to reduce this effect of frost heave and also dessication.

Aggregation and loss of soil structure have also been a concern in revegetation. Most alpine soils have weak structure anyway (and at the most development, one finds moderate structure) so some alpine plants could probably adapt to the sandy, structureless spoil heaps. Pioneer species are especially adapted to growing in structureless, very sandy soils.

SUMMARY

How long does it take for "total ecosystem recovery" (Billings, 1978) of a disturbed site that has been reclaimed in the alpine?

A good analogy of man's reclamation processes in the alpine is nature's revegetation of glacial moraines. Glaciers grind up rock and deposit it in large piles in cirques in a fashion similar to that of men in mining operations. Mahaney (1970) found that soil development on moraines of the Triple Lakes glacial stage (Benedict, 1973) showed B horizons (Inceptisol development) whereas younger moraine soils had only A/C profiles (Entisols). The ages of these Triple Lakes moraines have been recently recalculated to be at least 5400 years old (Davis et al, 1979) and may be up to two thousand years older. From this data, I would infer that it takes 5-7000 years for Entisols to develop into weak Inceptisols. I feel that the Inceptisol stage of development is the minimum requirement needed for alpine soils to be considered as recovered for all soils of the Theoretical Alpine Slope are at least Inceptisols in development.

Since soils are probably the slowest parts of the ecosystem to recover from disturbance, total ecosystem recovery can be estimated from soil recovery. Based on this, I would consider that it takes about five to seven thousand years for total ecosystem recovery to occur naturally on alpine spoil deposits in the Colorado Front Range. Other alpine areas in mid-latitude North America should have similar recovery rates. Revegetation efforts by man should reduce this amount of time by 1000 - 2000 years if extensive topsoiling is used.

The Triple Lakes moraine site would be equivalent to the WB site of the Theoretical Alpine Slope mentioned earlier. Soil development on other portions of the TAS might occur at different rates with EWB and MSC sites possibly developing slower and the EMS, LMS, and WM sites taking perhaps less time to develop to their minimum characteristics given for the TAS.

These long recovery times should not discourage people from revegetation for establishment of a vegetative cover is necessary to reduce soil erosion. Bovis (1974) showed that erosion can be up to 1000 times greater on alpine slopes with little vegetation as opposed to well-vegetated slopes. Revegetation is essential to reduce this erosion and keep the valuable soil constituents on the tundra. In these revegetation efforts, care should be taken to replicate the minimal snow cover or upper early melting snowbank site characteristics of the TAS.

Alpine soils are extremely variable and their characteristics depend on the yearly snow cover of the site where they are developed. This paper has outlined these characteristics for different alpine snow cover sites for the Colorado Front Range in the discussion of the TAS. Because of this great diversity of alpine soils and sites where they develop, it should be stressed that it is dangerous to adapt one uniform method of revegetation on the entire tundra. A different method should be developed for each particular snow cover site on the Theoretical Alpine Slope.

ACKNOWLEDGEMENTS

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IMPACT OF ELK ON ALPINE TUNDRA IN ROCKY MOUNTAIN NATIONAL PARK

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Introduction

About one-third of Rocky Mountain National Park is above 3,300 meters elevation, with 14,000 ha covered by alpine tundra vegetation. Most of the alpine area, including Trail Ridge, has been found to be elk (*Cervus canadensis nelsoni*) range at some time of year. In recent years, elk wintering on the alpine tundra appears to have increased. Marr (1964) considered this behavior to be of rather recent origin as a result of human population pressures at lower elevations. These areas are also important habitat for other species, such as bighorn sheep (*Ovis canadensis*) and ptarmigan (*Lagopus leucurus*). In the past, a concern has been shown for the possible competitive effect of elk on bighorn (Capp, 1967).

It was believed that since elk can have a major ecological influence on their habitat under certain circumstances, their effect on the alpine needed to be assessed. These effects must also be considered when planning tundra revegetation projects, since certain techniques such as fertilization have been shown to attract ungulates (Smith, 1958). In the National Park, management of the alpine tundra resource requires a complete knowledge of all influences so that the human impact can be minimized and, if necessary, the damage restored.

The objective of this paper is to examine the relationships of elk and the alpine tundra and assess effects. The data were gathered in conjunction with an elk ecology study of 1968 to 1979.

The Study Area

The study area (Figure 1) is in Rocky Mountain National Park, an area of 106,700 ha, lying along the Continental Divide in northcentral Colorado. Elevations range from 2,329 meters to 4,345 meters, with about one-third of the total area over 3,300 meters above sea level. The mountains are formed by a series of granitic batholiths, intruded into precambrian micaschists and pegmatite. The physiography of the East Slope is characterized by steep cliffs and U-shaped valleys, as altered by local Pleistocene glaciation. The generally more level, rolling alpine tundra areas were apparently not glaciated. On the west, the mountains fall off less steeply to the Colorado River valley at about 2,740 meters elevation.

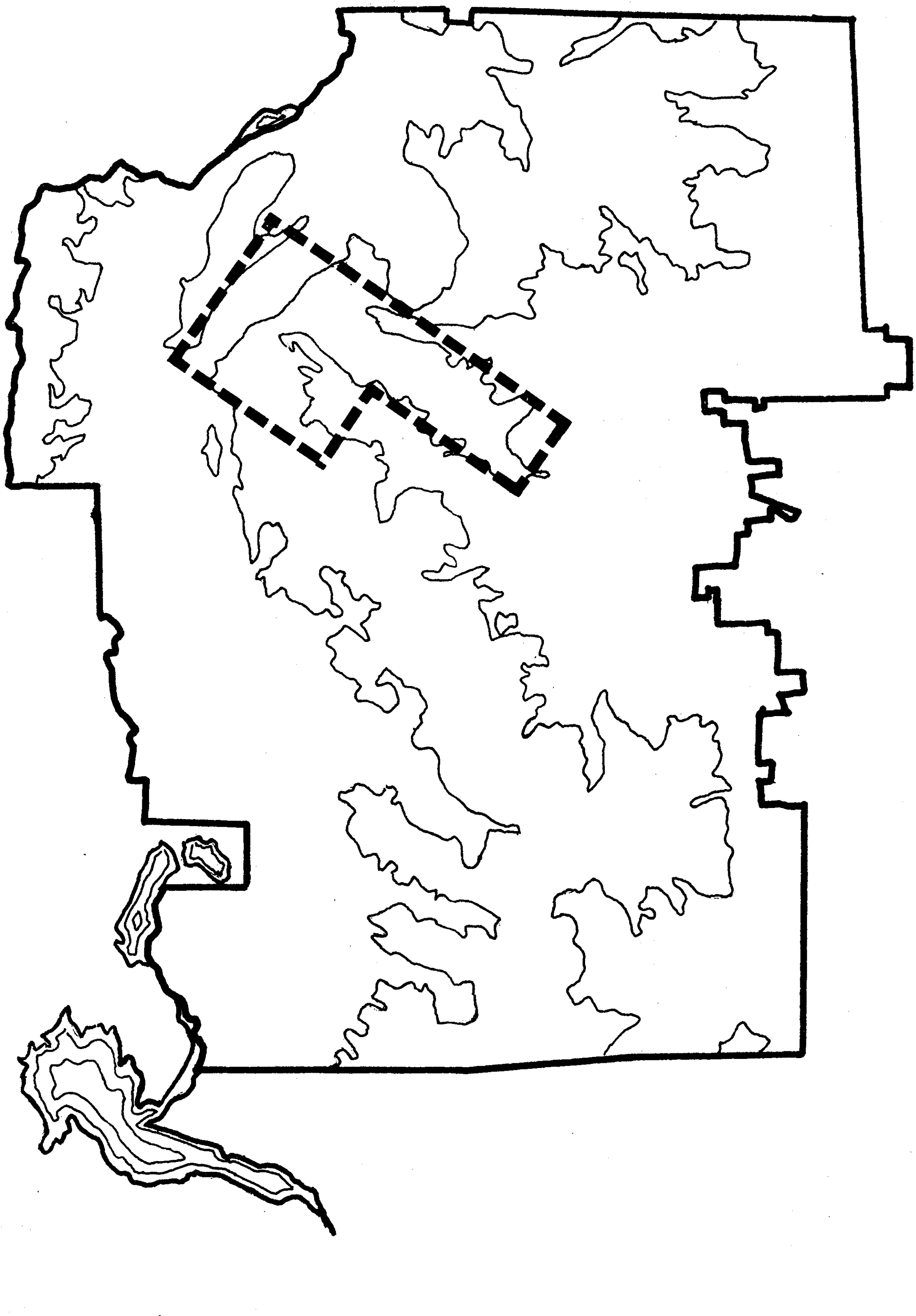

Figure 1. The study area in Rocky Mountain National Park

The vegetation is characterized by three climax regions, well described by Marr (1961). The upper montane region occurs from 2,300 to about 2,740 meters elevation and is characterized by a ponderosa pine (*Pinus ponderosa*) savannah with various shrub and grassland understories. Big sagebrush is common on some of the larger openings. The valley bottoms show indications of past disturbance of grazing and cultivation. Willow (*Salix* spp.) and meadow types dominate the vegetation.

Above the montane forest, from 2740 meters to 3500 meters, is the subalpine forest region. The primary cover is an Engelmann spruce (*Picea engelmannii*)/subalpine fir (*Abies lasiocarpa*) type. With a sparse understory, primarily of huckleberry (*Vaccinium* spp.), arnica (*Arnica cordifolia*), and various mosses and lichens, it appears to be the climatic climax in these areas. The fire sere to the climax is primarily the lodgepole pine (*Pinus contorta*) type, which may almost occur as a pure stand, with a very sparse understory.

Openings in the subalpine forest are common and may be covered by the willow type or an herbaceous grass/forb type. Characteristic willow species are *Salix brachycarpa* and *Salix planifolia*, bog birch (*Betula glandulosa*), huckleberry, hairgrass (*Deschampsia caespitosa*) and currant (*Ribes montigeum*). The ecotone (krummholz) between the subalpine and the alpine tundra shows similar vegetation with scattered dense stands of conifer intermixed with tundra vegetation.

Above the subalpine region is the alpine tundra climax region. Several studies have described the vegetation of the alpine tundra in the park. These include Keiner (1939), Griggs (1956), and Willard (1979). The tundra vegetation is characterized by a complex mosaic of vegetation communities related to physiography, snow accumulation, moisture availability, exposure, temperature, and substrate. For the purposes of this discussion, five vegetation types were considered. Fellfields were on exposed sites and characterized by cushion plants such as moss campion (*Silene acaulis*), nailwort (*Paronychia sessiliflora*), alpine sandwort (*Minuartia obtusiloba*), and dwarf clover (*Trifolium nanum*). Alpine turf type was characterized by kobresia (*Kobresia myosuroides*), alpine avens (*Geum rossi*), sedge (*Carex rupestris*), bistort (*Polygonum bistortoides*), and Rocky Mountain sage (*Artemisia scopulorum*). The snowbed types were characterized by hairgrass (*Deschampsia caespitosa*), rush (*Juncus drummondii*), sibbaldia (*Sibbaldia procumbens*), and arctic mountain sage (*Artemisia arctica*). Alpine marsh type was characterized by sedge (*Carex scopulorum*), marsh marigold (*Caltha leptosepla*) and Parry primrose (*Primula parryii*). The willow type was characterized by several willow species (*Salix planifolia, Salix brachycarpa,* and *Salix glauca*). Understory was hairgrass, sedges (*Carex* spp.), and narcissus anemone (*Anemone narcissiflora*).

It is recognized that this is a very simplified classification of the tundra vegetation.

The climate of the alpine has been described by several authors, including Marr (1960), Willard (1960), and Bell (1974). The summers are short and cool with frequent thunderstorms. Fall days are clear, dry and cold. The winters are long, cold, and very windy. Glidden (1974) measured wind speeds of greater than 74 mph on 44 per cent of the days from January to May 1974. The spring is cool and wet. Annual precipitation is 25-35 inches, with mean annual temperatures of 25-28°F. The climate can be characterized as severe, when compared to the lower elevations of the park.

Elk in the Estes Park area were extirpated by 1880 through market hunting and competition with domestic livestock for winter range. In 1913 and 1914, 49 elk were reintroduced from Yellowstone Park. Records show that by 1930, 430 elk were counted on the winter range. Migration routes over the alpine tundra were reestablished. The first elk wintering on the alpine tundra were recorded in 1933 (Annual Wildlife Report). At that time, 23 elk were observed on Trail Ridge and 6 bull elk above Lost Lake. Summer range areas were noted in the head of Forest Canyon and in the North Fork of the Big Thompson River.

By 1943 the herd was considered too large for the low elevation winter range, and a reduction program was initiated. Since 1968, direct control has been discontinued and the population allowed to increase toward the ecological carrying capacity of the range. The only population control buffering an increase in numbers is hunting outside the park boundaries.

Other ungulates utilizing the alpine are mule deer (*Odocoileus hemionus*) and bighorn sheep, along with numerous smaller herbivores. No major predators, except possibly mountain lions (*Felis concolor*), are present but coyotes (*Canis latrans*) are common.

Methods

Both ground and aerial observation trips were conducted. All observed elk were noted as to sex, age, activity, vegetation type, elevation and location. Where possible, feeding sites were examined to determine plants eaten and relative frequency.

Eight agronomy cages (4' x 4' square wire mesh) were established on Trail Ridge on representative vegetation types. Use on these was annually described and photographed.

At each study site, transects using a 20 x 50 cm. plot frame (Daubenmire, 1959) were established in 1971 to show long-term trends. Twenty-one plots were mechanically distributed along a 100-foot line. These were sampled the second time in 1976 and again in 1979.

Fecal group counts were made in the spring on the Trail Ridge sites to determine relative use by ungulates at these sites.

To determine similarities between transect measurements, a modified "coefficient of community" was calculated according to the formula

$$C = \frac{2w}{a + b} \times 100$$

(Grieg-Smith 1964:137); "a" is the sum of the cover values for the stand at one time, and "b" is the sum for the stand at the time to which it is to be compared; "w" is the sum of the lowest value for each species common at both times. The closer this percentage is to 100%, the more similar the communities are considered.

Distribution and Range Use

Tundra use data was tabulated on 2391 elk in 135 groups observed by ground observation. In addition, 1291 elk were observed on the alpine tundra on 19 helicopter flights. As determined by aerial observation over ten winters, an average of 27 percent of the elk population (Table 1) remaining within the Park boundaries utilize the alpine tundra. Most of the remainder migrate to the lower elevation ranges on the East Slope of the park. The most heavily used alpine ranges are all in the north half of the park on Trail Ridge, Mount Ida Ridge, Mummy Mountain, and Mount Dickinson. Trail Ridge was most heavily used, averaging 38 per cent of the total observations for the alpine. The total number of elk using the alpine was high in 1968 and 1969--178 and 193 elk, respectively, then remained fairly constant, averaging 105 until 1976. Recently an increase has been noted with the highest number ever recorded--316 elk--on the alpine tundra in March 1976. In 1979, 172 elk were counted on the alpine. This increase, however, was not reflected by the fecal group counts on Trail Ridge.

The mean sex and age composition of these elk for the period was 20 per cent adult males, 6 per cent yearling males, 59 per cent females, and 15 per cent calves. In 1979, the composition of elk parkwide was 7 per cent males, 4 per cent yearlings, 66 per cent females, and 23 per cent calves.

Vegetation types on which elk were observed in the winter reflect the importance of areas blown free of snow by wind. Of the 1714 elk classified as to vegetation used, 65 per cent were on tundra turf and 32 per cent were on fellfield. Both willow and marsh areas were used, but because of the relative size of these sites, the observed use was less. The actual degree of use was indicated by pellet group counts. An average of 7 elk days use per acre was recorded on the tundra turf sites, but 18 elk days use per acre was found on the willow sites. Elk used all elevations from treeline at about 3500 meters to the tops of the mountains in winter.

In winter, elk use the alpine sites primarily for feeding but, during good weather, will also bed there. Of 243 elk observed undisturbed from the ground, 38 per cent, or 93, were bedded. During inclement weather, elk move down into the tree cover of the krummholz to rest.

Table 1. WINTER ELK DISTRIBUTION BY VEGETATION ZONES AS DETERMINED BY AERIAL OBSERVATION

Year	Upper Montane		Subalpine		Tundra	
1968	174	(36)*	136	(28)	178	(36)
1969	447	(69)	9	(1)	193	(30)
1970	306	(73)	10	(2)	103	(25)
1971	396	(79)	0		105	(21)
1972	484	(80)	10	(2)	115	(18)
1973	286	(74)	1	(tr)	101	(26)
1974	413	(80)	0		103	(20)
1976	547	(63)	0		316	(37)
1978	572	(70)	0		240	(30)
1979	543	(76)	0		172	(24)
Mean	417	(70)	17	(3)	163	(27)

*Percentage is in ( ).

As vegetation begins to green up in the low country and snow crusts over in the subalpine forest, the elk appear to move down to lower elevations. In 1968, a flight April 30 showed only 63 elk on the alpine, while in February, 177 elk had been observed. They probably do not return to the alpine until mid-May, when the annual migration back to the summer range begins (Gill, 1967). Much of the elk use of alpine areas in June is while en route to summering areas. Trail Ridge receives heavy use during this period. The vegetation type most used was tundra turf, where 73 per cent of the observations, or 661 elk, were made.

Use of alpine as summer range is related to major summering areas. Summer concentration areas were Mirror Lake-Mummy Pass area, Flatiron Mountain-Mount Chapin area, Specimen Mountain, Forest Canyon Pass-Gorge Lakes, and the Snowdrift Peak-Nakai Peak area. Other areas where large summer elk populations have been noted were the head of West Creek, Fairchild Mountain, and the Cony Creek drainage in Wild Basin. Observations in July, August, and September indicated the most important habitat types for feeding elk were right at treeline, in the krummholz. An average of 52 per cent of the elk were observed in this type from 1968 to 1975. Only 23 per cent of the observations were made on the alpine tundra, and this was in close association with the krummholz. Of 930 elk recorded on the alpine, 64 per cent were on tundra turf type and 22 per cent on alpine marsh sites. Moist areas with lush vegetation appeared to be preferred. The only area where it was believed that the tundra was key vegetation type for summering elk was on the southeast ridge of Mount Fairchild.

Generally, the elk will bed in the spruce fir forest and move into the more open types to feed. Feeding elk were observed at almost all times of the day on the alpine, but the most common time was early morning and evening. During mid-day, most of the elk would bed near the feeding sites, often using solifluction terraces unless disturbed. Calves would be bedded in groups as the females fed. The solifluction terraces were often so heavily used that concentration of urine killed the vegetation in bedding sites.

During the breeding season, in early September, some of the elk begin to move to lower elevations. A reduction of elk on the alpine was clearly evident at that time. However, many elk were still observed in the alpine, especially on Trail Ridge, as they began to migrate back to the winter range. The alpine tundra was believed to be very important to migrating elk, since it represented the most easily traveled routes in many cases.

Most of the elk that were to winter in the low elevations had arrived on these areas by mid-October.

Food Habits

To determine forage used, 11 feeding sites, recording 1,162 instances of use, were examined during the winter period (Table 2). All were from

Table 2. FOOD HABITS OF ELK ON ALPINE TUNDRA AS DETERMINED BY FEEDING SITE EXAMINATION

Taxa[1/]	Winter	Summer
Browse		
Salix spp.	3/18[2/]	4/8
Forbs		
Arenaria obtusiloba	3/36	2/16
Anemone narcissiflora	-	3/25
Artemisia spp.	tr/9	7/42
Caltha leptosepla	-	7/25
Polygonum spp.	-	4/33
Trifolium spp.	6/18	46/83
Other forbs	5/82	18/83
Total	14/82	87/100
Grass and Grass-like Plants		
Carex rupestris	29/54	-
Carex spp.	12/71	5/75
Kobresia myosuroides	19/36	1/8
Poa spp.	16/64	tr/16
Other grasses	7/14	3/16
Total grasses and grass-like	83/100	9/100

[1/] Only Taxa amounting to at least 2% during one season are listed.

[2/] Percent/frequency of sites.

Trail Ridge. These data indicated that grasses and sedges, including kobresia, make up the major portion of the winter diet (83%). They were used on all the sites examined. Forbs, primarily represented by cushion plants, alpine sandwort and clover, made up 14 per cent of the use. The only shrub to appear on the feeding sites was willow, with 3 per cent. No other studies of winter foods for elk on the alpine are known.

Summer food habits on the alpine sites were determined by examining 12 feeding sites and recording 1,325 instances of use. During this time, forbs formed 87 per cent of the use. Clover represented by three different species, formed the major portion of this with 46 per cent of the total. Other important items were marsh marigold and sageworts (*Artemisia* spp.), both with 7 per cent. Grasses and other grass-like plants made up only 9 per cent of the use. Again, willow was the only shrub, with 4 per cent.

On one feeding site examined by Capp (1976), 72 per cent of the use was forbs, of which 49 per cent was clover (*Trifolium dasphyllum*) and 28 per cent were grasses or sedges. Nichols (1957) studied elk on an 11,000-ft. elevation park in the White River Area. He found the most important items in the elk summer diet to be hairgrass, miscellaneous forbs, marsh marigold and Baltic rush (*Juncus balticus*). Harrington (1978) also found grasses and grass-like plants to form the bulk of the diet on Specimen Mountain.

Impact on Vegetation

On Trail Ridge, eight agronomy cages, established in 1968, were used as protected sites, to estimate annual plant utilization.

On the four tundra turf sites dominated by kobresia, sedge/alpine avens and alpine clover/bluegrass associations, utilization was very light and almost nondiscernible after ten years of protection. Various species of bluegrass (*Poa* spp.) showed the most use. The most obvious difference inside and outside was the accumulation of litter. An average of seven days use per acre had been measured on these sites.

On the three sites dominated by willow associations, use was more obvious each year. On all three sites, the willow protected from browsing was about 1/3 taller after ten years. An average of 18 elk days use per acre had been measured on these sites.

In 1976 and again in 1979, quantitative data was collected on vegetative cover and frequency along the 100-foot line transects established near the cages in 1971. Data from four transects on the upland sites (Table 3) indicated no significant changes, and the calculated coefficient of community indicated 87% similarity between the 1971 and the 1979 measurements. Species appearing to increase were sedge (*Carex rupestris*), kobresia and Parry's clover. Decreasers were bluegrasses, arctic sage, bistort, and alpine avens.

Table 3. Canopy Cover and Frequency of Key Plant Species on upland and willow vegetation types on tundra winter range 1971 and 1979.

Taxa[1/]	Upland tundra (4)[2/]		Willow tundra (3)	
	1971	1979	1971	1979
S. brachycarpa			24/40[3/]	22/40
S. planifolia			25/51	19/54
Deschampsia caespitosa	4/20	3/11	27/90	18/76
Carex rupestris	14/61	19/86		
Carex scopulorum			4/35	2/32
Kobresia myosuroides	20/64	26/63		
Poa spp.	2/37	1/20		
Anemone narcissifolia			6/21	5/22
Arenaria obtusiloba	4/34	3/48		
Artemisia scopulorum	11/81	7/63	12/68	11/71
Caltha leptosepla			14/65	14/67
Geum rossii	32/99	31/95	25/86	23/87
Polygonum spp.	8/82	2/46	2/50	4/51
Potentilla spp.			6/53	4/41
Sedum rosea			4/46	3/40
Trifolium spp.	8/36	8/49		
Trifolium parryi	4/23	7/41		
Bare ground	4/42	2/37	1/10	1/5

1/ Taxa listed form at least a mean of 2% total cover.

2/ Number of line transects with 21 plots (20 x 50 cm.) each.

3/ Mean percent Canopy Cover/Mean Frequency.

In the willow areas, changes in cover were greater, although the coefficient of community still showed the associations to be 86% similar. *Salix brachyocarpa* declined in cover from 24% to 22% and remained at 40% frequency. *Salix planifolia* declined from 25% to 19% cover but increased in frequency. Other decreasing species were hairgrass, sedge (*Carex scopulorum*), alpine avens and cinquefoil (*Potentilla* spp.). The only species to show much of an increase was bistort, with most of the other species on the plots remaining fairly stable.

In 1971, four transects were established on the elk summer ranges on Specimen Mountain and the upper end of Forest Canyon. These sites were willow krummholz and determined to be elk summer concentration areas by observation. Elk use was considered heavy. The transects were similar to those on the winter range. They were remeasured in 1975 and again in 1979 to determine trend in composition and cover (Table 4). Major cover and intercept changes were only noted on willow species. *Salix brachycarpa* decreased an average of 55% on three of the four transects, with an overall decline from 20% cover to 9%. *Salix planifolia* declined from 37% to 29% cover. Other species appearing to decrease were low huckleberry, arnica, anemone, and trollius (*Trollius laxus*). The primary increaser was hairgrass, from 11% to 16%, and bluegrass, from 3% to 5%. Bare ground was insignificant in the plots.

Summary and Discussion

The use of alpine tundra by elk as winter range has been reported in other areas by Schwan and Costello (1951) and Houston (1976). In Rocky Mountain National Park, elk were first reported wintering on the alpine in 1933, and probably they have used these areas historically. It would appear that, as the elk population in the park increased, the elk wintering on the alpine also increased. Ratcliff (1941) reported elk increasing on the alpine in 1939 to 1941 during a period when the overall elk population reached its peak prior to direct reduction. Although adult male groups are common, the sex and age classification is not dissimilar to the low elevation winter range areas.

This study tends to indicate that elk utilization of the alpine tundra has an influence on the vegetation cover. On the tundra turf sites, however, the vegetation appears to be stable and in equilibrium with present elk use and other environmental factors.

On the willow sites, both alpine and krummholz, the data indicates a loss of willow cover and vigor. Although the cages could form a micro-environment favoring willow growth , the transect data also supports the findings. It is believed that the indicated impact of elk on this type is real. If these effects persist over the long term, influence on other faunal species that use the alpine tundra sympatrically could be expected. Reduction in the willow habitat on the alpine would probably affect white-tailed ptarmigan populations. Willow is the primary item in the diet of the ptarmigan (May, 1970). However, the level of change at present appears to be within tolerance and can be

Table 4. Canopy Cover and Frequency of Key Plant Species in subalpine willow type in 1971, 1975 and 1979.

Taxa[1/]	1971	1975	1979
Salix brachycarpa	20/38[2/]	21/34	9/28
Salix planifolia	37/52	29/56	29/54
Vaccinium scoparium	14/46	15/40	12/48
Deschampsia caespitosa	11/38	11/33	16/44
Carex spp.	7/32	5/30	7/33
Poa spp.	3/23	2/24	5/44
Phleum alpina	6/42	4/30	5/43
Arnica cordifolia	4/24	3/22	2/25
Aster spp.	7/35	3/32	6/60
Anemone narcissiflora	12/54	7/46	6/50
Delphinium barbeyi	5/34	1/11	4/33
Polemonium delicatum	tr/13	1/19	1/15
Senicio triangularis	2/18	1/11	3/19
Trollius laxus	2/28	4/41	2/31
Sedum spp.	2/22	1/18	1/21

[1/] Taxa listed form at least 2 percent cover in one year.

[2/] Percent Canopy Cover/Percent Frequency.

considered a natural ecological influence. Results of this study did not indicate that restoration projects were directly affected by elk use. These areas will continue to be monitored to obtain data on which future management will be based.

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