Effects of topsoiling and other reclamation practices on nonseeded species establishment on surface mined land at Colstrip, Montana
by Lyle Andrew King

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Range Science
Montana State University
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Abstract:
The purpose of this study was to determine the extent to which reclamation practices, especially topsoiling, aided nonseeded species establishment on revegetated mined land. Nonseeded species are desirable because of their potential to increase diversity with species not readily available from commercial sources. Fifteen topsoiled, thirteen nontopsoiled, and one native range study area were sampled at or near a coal strip mine at Colstrip, Montana, in May and June 1979, using frequency data and Domin-Krajina cover-abundance estimates .

Results indicated that properly handled topsoil, especially direct-take, increased numbers of total species and numbers and frequency of nonseeded native species on mined land. Perennial native species in the 0-20 percent frequency range and in the rare, less than I percent, and 1-5 percent cover classes were increased if smooth bromegrass (Bvomus inermis) was not abundant. Topsoiling also increased numbers and frequency of warm season perennial grasses and warm season forbs if smooth bromegrass was not abundant.

The exclusion of aggressive perennial grasses, especially smooth bromegrass from seeding mixtures was a major factor in encouraging nonseeded species establishment.

Proper grazing of revegetated mined land communities also increased total numbers and cover of nonseeded species.

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Date December 24, 1980

EFFECTS OF TOPSOILING AND OTHER RECLAMATION PRACTICES ON NONSEEDED SPECIES ESTABLISHMENT ON SURFACE MINED LAND AT COLSTRIP, MONTANA

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

Range Science

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ABSTRACT

The purpose of this study was to determine the extent to which reclamation practices, especially topsoiling, aided nonseeded species establishment on revegetated mined land. Nonseeded species are desirable because of their potential to increase diversity with species not readily available from commercial sources. Fifteen topsoiled, thirteen nontopsoiled, and one native range study area were sampled at or near a coal strip mine at Colstrip, Montana, in May and June 1979, using frequency data and Domin-Krajina cover-abundance estimates.

Results indicated that properly handled topsoil, especially direct-take, increased numbers of total species and numbers and frequency of nonseeded native species on mined land. Perennial native species in the 0-20 percent frequency range and in the rare, less than 1 percent, and 1-5 percent cover classes were increased if smooth bromegrass (*Bromus inermis*) was not abundant. Topsoiling also increased numbers and frequency of warm season perennial grasses and warm season forbs if smooth bromegrass was not abundant.

The exclusion of aggressive perennial grasses, especially smooth bromegrass from seeding mixtures was a major factor in encouraging nonseeded species establishment.

Proper grazing of revegetated mined land communities also increased total numbers and cover of nonseeded species.

INTRODUCTION

Montana's Strip and Underground Mine Reclamation Act of 1977 requires "a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area" to be established on coal strip mined land before it is legally reclaimed. The Montana reclamation regulations require each operator to establish at least one unmined reference area in good range condition, based on Soil Conservation Service range condition guides, for each native plant community type to be mined. Success of revegetation is determined at the end of a ten year bond period by comparing revegetated areas to unmined reference areas. At that time, revegetated areas must be composed of at least 51 percent native species (based on production and canopy cover) with diversity (the number of species with more than one percent ground cover) comparable to that of reference areas. In addition, revegetated areas must be comparable to reference areas in current annual production, ground cover for each morphological class, and seasonality of species. Revegetated areas must be grazed during the last two bonding years. To meet these criteria, it will be necessary to understand the modified successional patterns resulting from cultural attempts to speed up plant succession on coal mined areas.

Montana reclamation regulations require topsoil to be spread on

graded and contoured spoil prior to seeding. Topsoiling has potential to encourage native species establishment, but the degree of such establishment has not been adequately documented (Howard and Samuel, 1979). Proper handling, stockpiling, and spreading of topsoil are important in determining its ability to add nonseeded native species to revegetated plant communities. However, ambiguous regulatory definitions of topsoil have resulted in the mixing and dilution of soil horizons, often destroying soil structure, microorganism populations, seed reservoirs, and other reproductive plant parts (Miller, 1978; Robbins, 1980).

Regulations require the use of genotypically adapted seed and seedlings when available in sufficient quality and quantity. Since commercial sources of native plant species are limited or nonexistent, topsoiling is a potential source of species that cannot be obtained commercially (Beauchamp et al., 1975). It is important to identify which nonseeded species can be established by topsoiling and to identify their ecological roles.

The purpose of this study was to determine the extent to which topsoil aids nonseeded species establishment in revegetated mined land communities. Other reclamation practices were also investigated to determine their effect on nonseeded species establishment. This research project is associated with an existing study on surface mined land in eastern Montana (Sindelar and Plantenberg, 1977, 1978, 1979).

Objectives of this study on mined land were to:

1. Determine the role of topsoil in establishment of nonseeded species.
2. Determine the effects of cultural practices on nonseeded species establishment.
3. Identify successfully established nonseeded plant species and define their ecological roles.

LITERATURE REVIEW

FACTORS INFLUENCING SEED NUMBERS AND GERMINATION IN TOPSOIL

The number and type of viable seed present at any one time in the soil depends on many factors. Major and Pyott (1966) examined a California bunchgrass type and found grazed plots to have higher numbers of seed (12,290 seed/m^2) than ungrazed plots (8,230 seed/m^2). Brown (1943) measured seed yield in central North American grasslands and found considerable variation within each type over a three year period. In blue grama-buffalograss *(Bouteloua gracilis-Buchloe dactyloides)* dominated grassland seed yields were 720-53,200 mg/m^2, while little bluestem *(Schizachyrium scoparium)* and big bluestem *(Andropogon gerardi)* grassland seed yields varied between 4,510-40,100 mg/m^2 and 0-118,900 mg/m^2 respectively. Rabotnov (1955) reported smooth bromegrass meadowland in the USSR to have between 280-2,450 seed/m^2. Blake (1935) and Lippert and Hopkins (1950) observed low numbers of buried viable seed in the Great Plains, with native perennial grasslands yielding 300-800 seed/m^2. The majority of seed were annual grasses or forbs.

Because of their methods of dispersion, reproductive outputs, and seed longevities, colonizing and pioneering species tend to leave large seed reserves in the soil (Harper, 1977). However, a large number of seed in the soil does not insure a reliable source of potential plant material. Many factors affect the number and type of seed that will

germinate. Weaver and Clements (1938) stated that certain characteristics of the seed or of the embryo itself can cause germination failure even under favorable external conditions.

McMinn (1952), May et al. (1971), and Dwyer and Aguirre (1978) found moisture to be the most critical factor limiting germination in arid and semiarid land. Weaver and Himmel (1931) found water content of the soil and air humidity to be major influencing factors in the prairie environment. Soil moisture in the surface 15 cm of unplowed soil often varied ten percent or more during a single week. Moore and Wein (1977) stated that numbers of seed present in the soil were much greater than numbers germinating. Knipe and Springfield (1972) found natural reproduction from seed of alkali sacaton *(Sporobolus airoides)* in New Mexico subject to high loss by wind, water, and unfavorable conditions for seedling establishment, thus limiting natural reseeding of disturbed land. Roberts (1972) found that viable seed could be lost from a site by germination, predation, and fungal pathogens.

The number of seed remaining viable in a soil depends on the species, length of time seed are buried, number of seed produced, durability of the seed coat, and the seed's response to moisture (Bookhout, 1958). Hull (1973) reported that some seed will remain viable up to several hundred years. Hard-coated seed (especially legumes) retain their viability longer than soft-coated seed. Longevity of most seed is greatest when stored at low temperatures, low

moisture content, low humidity, and in the absence of oxygen (Crocker, 1945; Barton, 1953 and 1961; Hafenrichter, et al., 1965; Windle et al., 1966).

Rate of germination is a species characteristic, but within a species, younger seed emerge faster than older seed (Hull, 1973). Deeply buried seed are generally older and have a lower germination rate than those from upper soil layers. Rabotnov (1958) found that deep burial induced seed dormancy and decreased viability. He found 64.0-99.6 percent of all seed in a pasture to be in the top 10 cm of soil. In the type he classified as "meadow", the number of seed buried 2 to 10 cm deep was greater than the number of seed at depths less than 2 cm.

Excessive litter accumulations can retard both seedling germination and the development of established plants (Heady, 1975; Redmann, 1975). Successful germination and establishment occurs at proper soil depths. Seed must be covered with soil to permit germination and establishment (Weaver and Clements, 1938). When seeds germinate in the litter of dry environments, seedlings are suspended above the moisture supply of mineral soil. Their survival depends on rapid elongation of the radicle because the porous litter and duff dry out rapidly. Thick surface layers of organic debris restrict the number of species, contributing to floristic simplification (Daubenmire, 1968).

Both Olmsted and Curtis (1947) and Weaver and Rowland (1952) found excessive accumulations of litter and duff to reduce soil temperature to levels which inhibit seedling germination and growth. Weaver and Rowland found these conditions to favor dominance by a single species. Blake (1935) found that seed falling in dense vegetation were caught and held in crowns of old plants, inhibiting placement in proper seed beds.

Beauchamp (1973) found the season of seed collection affected the number and type of seed germinating in a greenhouse study. Grass seed are generally better able to respond to available moisture and germinate faster than forb seed (Major and Pyott, 1966; Dwyer and Aguirre, 1978).

Prince and Hodgdon (1946) and Lippert and Hopkins (1950) found that seed buried in soil does not necessarily bear a close relationship to compostion of the vegetation present. Of ten perennial species found on a site by Prince and Hodgdon, none had germinable seed in the soil.

Golubeva (1962) working on a meadow-steppe found only two percent of the viable buried seed to be those of dominant, perennial grass species. He attributed this small number to yearly variations in fruiting, rapid seedling germination, and short viability in most perennial species.

Harper (1965 and 1977) suggested the availability of suitable

microsites on a soil surface may regulate the number of plants establishing from seed because the surrounding environment determines whether proper environmental conditions, resources, and stimuli are received for germination. Because species' germination requirements for "safe sites" showed a considerable subtlety, he concluded the ability of the ecosystem to provide microsites can determine the number and variety of seedlings that are recruited from a seed bank into a population of growing seedlings.

SOURCES OF NONSEEDED SPECIES ON MINED LAND

Topsoil

Literature dealing with the potential of topsoil to provide viable seed and vegetative parts is limited. Kohnke (1950) found species volunteering on overburden to be predominantly those with seed which are easily carried by wind or introduced in the original topsoil. In a study conducted in southwestern Wyoming, Beauchamp (1973), after one growing season, found seedling density on overburden seeded with crested wheatgrass *(Agropyron cristatum)* greater (290 seedlings/m^2) than nonseeded overburden left to naturally revegetate (11 seedlings/m^2). In greenhouse studies involving seed collected from the top 5 cm of topsoil at various native range sites in Wyoming, he found it not advisable to depend solely on viable seed in the soil for revegetation. Although each sample contained enough viable seed to

revegetate an area much greater than his original quadrat size, lack of precipitation limited germination. Of those species germinating, most were common to early secondary succession in the area (Beauchamp et al., 1975).

Studies conducted in Wyoming and Colorado by Howard and Samuel (1979) showed several species present in nonseeded topsoiled plots after 14 months of treatment, despite drought conditions. They concluded that direct-take topsoil spread in early spring can be an important source of rhizomes and other vegetative parts from useful reclamation plants in arid regions. In North Dakota, Wali (1980) found that regardless of species seeded, initial vegetation was determined by the diversity of viable seed present in the topsoil.

Natural Migration

The primary factor influencing a species' migration is its means of mobility (Praeger, 1923). Mobility is determined by size, weight, surface characteristics, and amount of disseminules produced. The fertility of seed is greatest in typical "polyanthous" species which produce one seed per flower as observed in grasses, composites, and other achene bearing families. This is shown by the large number of successful invaders (weeds) produced by these groups. The perfection of the migratory device and the distance of migration determine which pioneer species will enter, as well as when other species will appear (Clements, 1916). Daubenmire (1968) stated, "survival of

pioneer species depends on their ability to produce highly mobile disseminules in great quantities and at an early age, permitting them to avoid intense competition by taking advantage of newly created bare areas." In contrast, climax plants have heavier disseminules and spread slowly into new territory. Salisbury (1942) and Daubenmire (1968) found seed size increased in higher successional stages, while the number of viable seed per plant decreased. Rice et al. (1960) showed that seed of prairie threeawn *(Aristida oligantha)*, an early successional plant, were carried long distances by wind, whereas fruits of little bluestem, a species of later successional stages, were carried only short distances from parent plants. Although natural migration would eventually supply invading plant species on seeded mine spoil, one potential value of topsoil may be its ability to supply these heavier, less mobile disseminules of climax species earlier.

OLD FIELD SUCCESSION ON GRASSLANDS

Once present, the potential of a species to establish itself is influenced by many environmental factors. Succession studies quantify this potential and relate it to predictable patterns. Old field succession has been thoroughly researched in much of the United States (Haug, 1970). Although not totally applicable to succession on seeded mine spoil, some aspects of the patterns, functions, and

interactions of "normal" successional stages apply.

Bazzaz (1975) described secondary succession as "a process of systems repair through which the attributes of a mature ecosystem are restored, including: high species diversity, structural complexity, closed mineral cycling, balance between community productivity and respiration and perhaps, system stability."

Several authors have documented the general pattern of old field succession (Smith, 1940; Booth, 1941; Costello, 1944; Keever, 1950; Bazzaz, 1975; Tramer, 1975). It is initiated with an annual forb invasion by species adapted for migration because of tumbling habits, spines and prickles on fruits, prodigious seed production, early germination, and a short life cycle (Smith, 1940; Costello, 1944).

Several adaptations aid the competitive advantage of pioneering species, including earliness of taproot penetration, ability to garner nutrients in short supply, and ability to withstand drought or poor soil aeration. In addition, pioneers tend to be xerophytic, light demanding, heat demanding, frost hardy, deep rooting, and not exacting as to soil. They are generally intolerant of conditions that arise as a dense plant cover develops so their tenure is usually limited to one generation (Daubenmire, 1968).

First year communities consist of scattered individuals of pioneer species, which become more uniform in distribution the second year. Soon after, these pioneers begin to die due to competition for

soil moisture and decreased production of viable seed (Booth, 1941; Costello, 1944).

With normal weather, perennial forbs replace annuals and become progressively more important through time. They dominate the community earlier and more completely each successive year (Costello, 1944; Tramer, 1975). The perennial forb stage is followed by either annual grasses or short lived perennial grasses, depending on climate and other environmental factors. The final stage is dominance by more permanent, long lived perennials.

General tendencies of old field succession on a mixed prairie grassland in northeastern Colorado were summarized by Costello (1944):

1. Replacement of annuals by perennials.
2. Gradual reduction in percent compositon contributed by forbs.
3. Increased abundance of grasses.
4. Increased density of ground cover as climax associations are approached.
5. Increased numbers of species as climax is approached.

Most species were retained throughout several seral stages but in differing amounts as each sere reached maximum development (Costello, 1944). Smith (1940) found 30 percent of the species listed in early stages to be present through all stages of succession. The later in succession a species appeared, the greater its chance of surviving in the climax vegetation.

Keever (1950) suggested that because of life cycle event timing of early invaders, the season of the year that secondary succession

was initiated influenced the eventual dominant species more than environmental changes brought on by those invaders. Although the influence of a species on its environment may produce conditions which keep it from surviving, those conditions do not always favor the next invader. Secondary invaders may attain dominance in spite of and not because of changes in environment brought about by the first dominant (Keever, 1950). The habitat determines both when the seed will germinate during the season and if dormant seed will remain viable (Clements, 1916).

ROLE OF COMPETITION IN ESTABLISHMENT

Odum (1971) defined interspecific competition as an interaction between two or more species' populations which adversely affect their growth and survival. Competition was defined by Weaver and Clements (1938) and Harper (1977), as changes in the environment that are brought about by the proximity of individual plants.

Competition begins early in succession. In herbaceous species, danger arises from excess competition immediately after germination (Clements, 1916). Clements found that once a seedling became established it was fairly certain to develop, especially with herbaceous plants. When dense stands of seedlings of several species start growth at the same time, any initial advantage may lead to a lasting

superiority in growth (Daubenmire, 1968; Mueller-Dombois and Ellenberg, 1974). In sparse stands, competition becomes noticeable later in the life cycle. Braun-Blanquet (1951) observed competition in the early life history of many species to be so drastic that few individuals survived. Competition among mature plants was of secondary importance so far as survival of a taxonomic unit in an ecosystem was concerned.

Life form duration (annual versus perennial), rapid growth rate, efficient uptake of nutrients, rate and amount of germination, vegetative reproduction, a species' capacity to maintain its presence, and genetic variability and plasticity all help a plant to accommodate a severe condition (Clements et al., 1929; Braun-Blanquet, 1932; Daubenmire, 1968).

The competitive exclusion principle between closely related species results in equilibrium adjustments in which one species replaces another or forces it to occupy another space and yields ecological separation of related species (Odum, 1971).

It is characteristic of competition in all plant communities to increase along with increases in population numbers until the climax or subclimax is reached (Clements, 1916). The inherent capacity of plants for growth and reproduction leads to competition for available niches in each habitat, resulting in a tendency for all plant communities to become closed. Closed plant communities with established stands of vegetation fully utilizing the habitat are not

readily invaded. Plant communities populated by few species are more readily invaded because plants are unable to monopolize the limiting factor, usually moisture, through the entire growing season (Clements, 1916; Robertson and Pearse, 1945). The number of stages of succession is largely determined by this increasing difficulty of invasion as the area becomes stabilized (Clements, 1916). Stabilization results when the entrance of invaders capable of influencing community structure is no longer possible (Clements et al., 1929).

FACTORS INFLUENCING FLUCTUATIONS IN STABLE PLANT COMMUNITIES

Humphrey (1958) found radical changes in plant community floristics to be dependent on: (a) developmental changes in endemic or nearby exotic vegetation which is usually too slow a process to consider on a short term basis for plant community change; (b) introduction of new species or varieties; (c) marked changes in such environmental factors as climate, grazing, and plant competition. Strip mining can also be added. Robertson and Pearse (1945) found that marked departures from normal patterns in arid or semiarid climates can open communities to invasion.

Species composition of natural grasslands fluctuates much more in response to environmental influences than does that of woody shrublands and forests. Seasonal fluctuation of relative species abundance in grassland increases with degree of fluctuation in the environment.

Yet, it is probable that homogeneity of plant cover as a whole is increased by environmental fluctuation as species which are not adapted to surviving extremes are excluded from the community (Coupland, 1974).

Because the ecological response of a species also depends upon that of its competitors, the response cannot be constant. Wherever main competitors differ in the range of a species, its ecological or sociological response will differ also. Therefore, ecological behavior and competitive ability of a plant species are rather complex. They are the result of both morphological structure and physiological requirements as matched with the environmental resources available in the habitat and modified by competing plant species (Mueller-Dombois and Ellenberg, 1974).

Competition is keenest when individuals are most similar. Therefore competition among plants of different species varies directly with their similarity in growth or life form. This is of primary importance in competition arising between occupants and invaders in different stages of succession. Invaders so unlike the occupants that they enter with a clear advantage or disadvantage establish themselves readily, in one case as a result of reaction, in the other by taking a subordinate position (Clements, 1916). The tendency to limit species to a group with matched abilities under a particular type and intensity of competition makes competitive elimination a

major unifying force responsible for much of the similarity among stable vegetation units in similar habitats. As succession advances and competition intensifies, a species may be eliminated from certain habitats where in early seral stages it grew well, if not at its best, and the areas characterized by its success or failure become more sharply differentiated (Daubenmire, 1968).

Because soil texture and surface topography are not uniform, vegetation patterns are created along moisture gradients. Working in the northern Rocky Mountains, McMinn (1952) found distinct differences among plant associations in the amount of soil drought they could tolerate, with soil drought being earliest and deepest in grassland communities. He concluded that the spread of plant associations into dry areas was prevented because of soil drought. If this idea is extended to include the spread of individual species then drought will also be limiting in revegetated mined land communities.

POTENTIAL SPECIES INVASION AND SUCCESSION ON STRIP MINED SPOIL

Wali (1980) stated that succession on topsoiled strip mined spoil will resemble secondary succession more than primary succession because topsoil provides organic matter, nutrients, seed, and propagules from original vegetation. Old field succession patterns differ from that on strip mined land in that spoil areas are often seeded. Competition from seeded species becomes a primary factor in determining

which species will be able to establish in a mined land plant community. Nonseeded native species have several inherent disadvantages:

1. There are generally more seed of seeded species properly placed for ideal germination in the prepared seedbed. Nonseeded species may be found at any depth or location.
2. Seeded introduced species gain a competitive advantage by germinating and establishing faster, making use of available nutrients and moisture before natives (Depuit et al., 1978).

Research dealing with succession and species invasion of strip mined spoil in the arid and semiarid West has been limited. Hall (1957) and Leisman (1957) found that pioneer vegetation invading strip mined areas was usually determined by characteristics and configuration of the spoil, nature of adjacent vegetation, and habitat requirements of the vegetation. Hodder et al. (1970) claimed that slope exposure significantly affected invading species on spoil, with north and east exposures having more surface moisture for establishment. Meyn et al. (1976) found that weedy invaders offered some degree of protection to seeded species from wind and water, but if allowed to grow without competition, probably increased the length of time necessary to establish diverse and self-sustaining plant communities. Sindelar and Plantenberg (1978) found that competition resulted in population replacement and structural changes in most seeded communities on mined land. Life forms characteristic of early succession were seldom abundant for more than two years following seeding. Golley

(1965) found that rate of change within or between seral stages of a community may be influenced by size of the disturbed area and invasion ability of species on adjacent land. Old, naturally revegetated level spoil communities at Colstrip generally had greater species diversity than seeded mine spoil; their diverity was equal to or greater than diversity of grazed native range (Sindelar and Plantenberg, 1978). On steep seeded spoil in North Dakota, Williams (1978) concluded diversity was affected by age and was much lower on mined land than on unmined land, regardless of age.

DePuit et al. (1978) found competitive inhibition of native species when they are seeded in mixtures containing even a low proportion of naturalized introduced species. They concluded that adequate and diverse native species establishment may be enhanced if naturalized introduced species, especially crested and tall wheatgrasses *(Agropyron elongatum)* are eliminated from seeding mixtures.

In a study of native species best adapted to seeding and establishment on coal strip mined land in southeastern Montana, Eddleman (1978 and 1979) determined that initial seedling survival, rates of root and shoot growth, and resistance to moisture stress determine the degree of success exhibited by a species. He found a wide variety of germination requirements and ideal seed ages in the native species he investigated. It is probable that there is no ideal length of time

for topsoil storage or treatment for all native species.

Sindelar and Plantenberg (1978) found plant establishment and succession on seeded spoil to be influenced by species seeded, weather conditions, cultural practices and postmining management. Although advanced life forms such as perennial grasses, forbs, and shrubs were readily established by seeding, the use of aggressive introduced species, especially smooth bromegrass, had limited community diversity and native species invasion. The inability of native species to establish and become dominant on seeded sites was due to unsuitability of cultural practices and the often limited ability of native species to become established by seeding. The eventual effect was dependent upon the type of cultural practice, climate, and degree of management. They concluded that topsoiling as a cultural practice has great potential to increase species numbers and diversity on seeded mined land but improper use of topsoil has limited its effectiveness.

METHODS AND PROCEDURES

SITE SELECTION

Site selection was based on availability of historical information from research reports and coal company records and was completed during late April and early May of 1979.

To determine how cultural practices affected presence and abundance of nonseeded species on revegetated mined land communities, as many site treatments and ages as possible were included. Fifteen topsoiled sites and thirteen nontopsoiled sites were chosen. In addition, one native range area in good condition was sampled for comparative purposes.

SAMPLING PROCEDURES

Frequency

Sites were sampled within a short time to minimize environmental variability. Frequency was chosen as a fast method of determining differences among sites. It is not an absolute measure because results obtained depend in part on quadrat size and shape. Proper quadrat size is a function of plant size and species richness per unit area (Mueller-Dombois and Ellenberg, 1974). Daubenmire (1968) regarded ideal quadrat size as consistently yielding two or three species at or near 100 percent frequency.

A review of the previous year's data from an associated study on six of the sites (Sindelar and Plantenberg, 1979) indicated that a 2x5 dm rectangular quadrat (Daubenmire, 1959) approached Daubenmire's criterion. However, a few sites had greater than three species at or near 100 percent frequency. This relatively large quadrat size was chosen over a point frequency method in order to maximize the area covered within a minimum number of samples. Species area curves indicated that 20, 2x5 dm quadrats per site was an efficient sample number, with all but three sites leveling in species numbers with 20 or fewer quadrats.

Sampling was conducted early in the 1979 growing season (May 1 to May 16) to give consideration to early maturing species, especially forbs, which might have been overlooked with later sampling dates.

A central location was chosen on each site and each sample quadrat was located by pacing northward or southward from this center point. The direction and number of steps were determined from a random numbers table. Frequency was recorded for all species, alive or dead, which were overhanging or rooted in the quadrat. In addition, species lists were made for each site to record species not encountered in frequency data.

Cover

Because frequency does not reveal dominance of a site, cover-

abundance estimates were made for each species on each site using the Domin-Krajina method. These estimates were made two to four weeks after frequency sampling to allow for additional growth of early and midseason species. This is a quick, visual estimate of cover which is not accurate on absolute scales, but good for relative comparisons among sites (Mueller-Dombois and Ellenberg, 1974).

Six sites were simultaneously monitored in a mined land succession study. Extensive species lists had been constructed for these sites and detailed cover estimates had been made using a modified Daubenmire technique (Daubenmire, 1959; Sindelar and Plantenberg, 1977, 1978, and 1979). In addition, detailed cover estimates and species lists were made for the native range area by Munshower et al. (1978) and DePuit (unpublished data, 1979). Cover data derived from the Daubenmire procedure were classified into Domin-Krajina categories (Table 1), but included only those species encountered in 40, 2x5 dm quadrats per site. Therefore, these are minimum estimates of the number of species present on these sites.

Frequency and cover were compared among sites to determine effects of reclamation practices on nonseeded species establishment. Cover estimates provided a basis for comparing percent composition of individual species and groups of species among sites. Differences in species ecological roles as a result of site treatments were evaluated.

Table 1. Domin-Krajina cover-abundance categories

Category Number	Percent Cover	Description
10	100	-
9	>75	-
8	50-75	-
7	33-50	-
6	25-33	-
5	10-25	-
4	5-10	-
3	1-5	-
2	<1	Scattered individuals with cover under 1/20
1	0.1	Seldom present, with insignificant cover
+	Rare (R)	Solitary individual with insignificant cover

The Chi-square test of significance was used to determine differences in frequencies among sites. Analysis of variance and Student t-tests were used for determining site differences in species numbers and cover values. All statistical tests were made at the 0.05 level of significance.

Cluster analysis used similarity indices determined from frequency data (Sokal and Sneath, 1963) to look for groupings of sites by species similarity.

STUDY AREA

COLSTRIP AREA

The Colstrip area has been strip mined for coal since the early 1920's. Early mined areas were left to revegetate naturally. Since 1968 mined areas and old spoil ridges have been reshaped and seeded. Vegetation in the Colstrip area is primarily mixed prairie grassland interspersed with ponderosa pine *(Pinus ponderosa)* on scattered sandstone outcrops.

The growing season extends from April to October with a frost free period of 120-140 days. Summers are hot, dry, and often windy. Annual precipitation averages 40 cm with most falling as rain in April, May, and June (Sindelar and Plantenberg, 1978). Several detailed descriptions of vegetation, topography, climate, physiography, soils, and geography have been previously reported (Sindelar et al., 1974; Meyn et al., 1976; Sindelar and Plantenberg, 1978; Skilbred, 1979).

Precipitation for 1979 was 14.8 cm with 11.0 cm falling during the growing season. Although one of the driest years on record, stored soil moisture from the previous fall allowed near normal spring growth.

SITE DESCRIPTIONS

Twenty-eight study sites were located on revegetated spoil at Western Energy Company's Rosebud Mine and Peabody Coal Company's Big

Sky Mine near Colstrip (Figures 1 and 2). In addition, one native range area near Colstrip was sampled for comparison. Except for native range and Cape Oliver, topsoiled and nontopsoiled sites were further divided by smooth bromegrass abundance as described in results and discussion. These categories were used for assigning names to 27 revegetated mined land sites. Complete species lists for each site and percent frequency and cover of each species from 1979 data appear in the appendix. In addition, a summary is given of seeded species, native species, and seasonality of species present.

Topsoiled Sites

I-A. This site was located on the Peabody Big Sky Mine approximately 9.6 km south of Colstrip. It was mined in February, then reshaped and topsoiled during the spring of 1974. Although the area was a nonseeded study plot for Arnold and Dollhopf (1977), it is probable the site was seeded to an eight species mixture along with the adjacent area in January of 1975. It is difficult to tell if the abundance of those species in 1979 was the result of seeding or invasion from the adjacent seeded area (Figure 3).

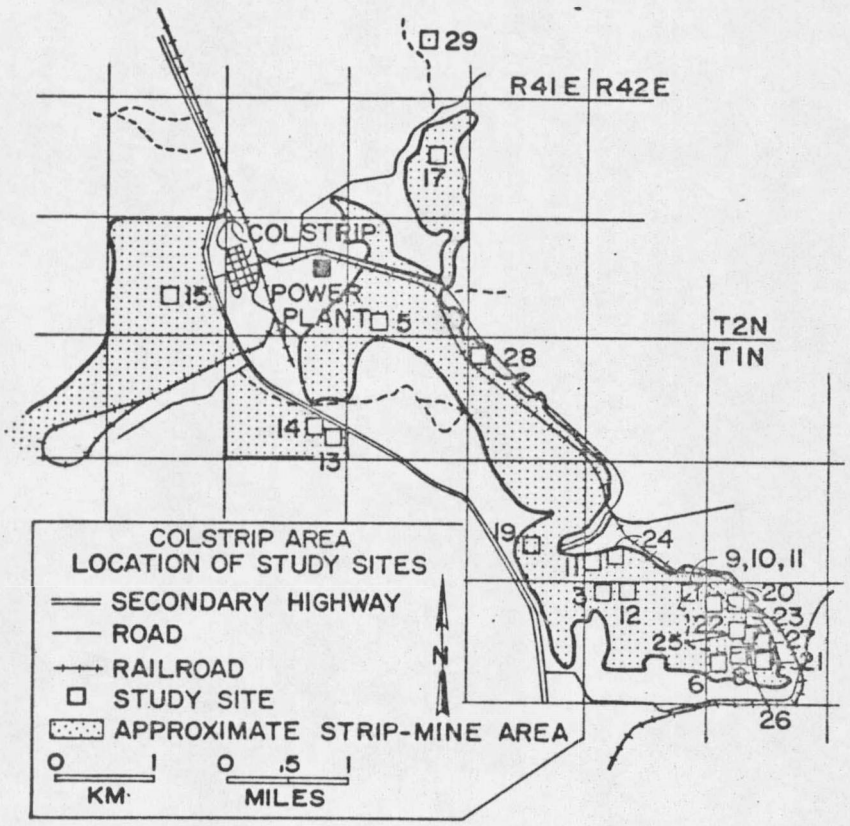


Figure 1. Study sites located on the Rosebud Mine near Colstrip, Mt. Corresponding site numbers are listed in Table 6. (From Sindelar and Plantenberg, 1978)

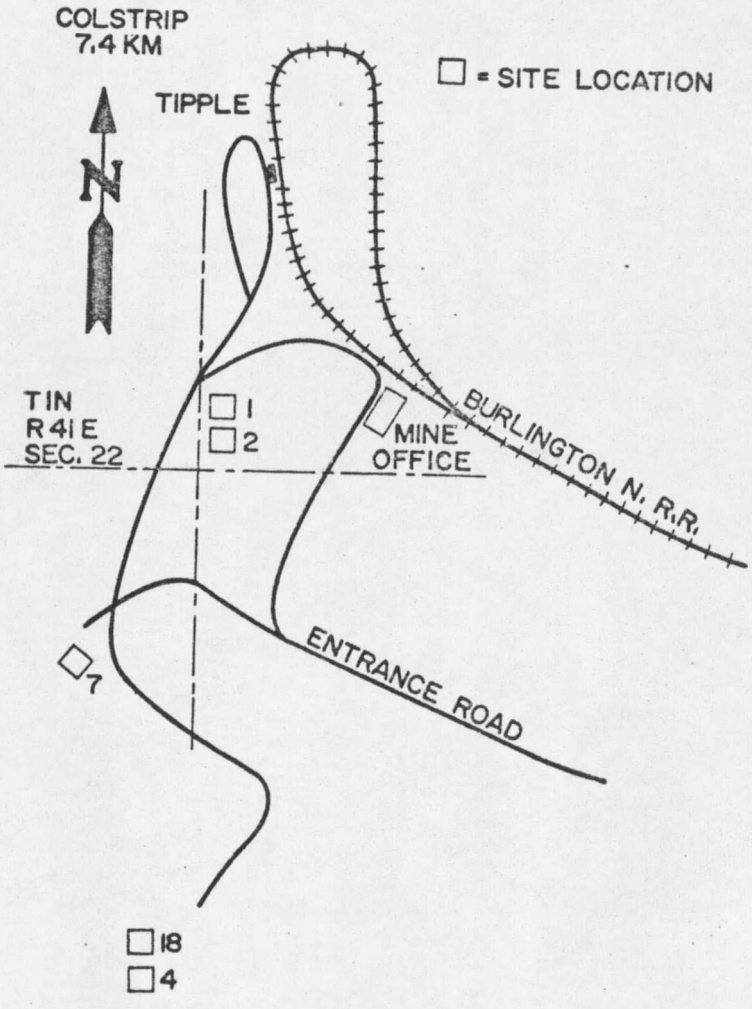


Figure 2. Study sites located on the Big Sky Mine near Colstrip, Mt. Corresponding site numbers are listed in Table 6. (From Arnold and Dollhopf, 1977)



Figure 3. Site I-A.

I-B. This site was immediately adjacent to I-A. In 1974, it was seeded to sideoats grama *(Bouteloua curtipendula)* to establish a local seed source for the mining company. The attempt failed and a mixture of eight species was seeded in January 1975. The site had 52 total species present and was similar in appearance to site I-A (Figure 4).



Figure 4. Site I-B

I-C. This site was located 6.5 km southeast of Colstrip, on a gentle west slope. It was shaped, topsoiled, and drill seeded with a broad mixture in the fall of 1975. It was also drill seeded with annual grains for temporary stabilization. Extreme wind erosion during winter and water erosion from spring and summer thunderstorms damaged the site in 1976. A large number of species was present on the site.

I-D. This site, located at the Peabody Big Sky Mine, had topsoil spread and abandoned during the spring of 1977 for a topsoil

depth research site. It was not seeded or manipulated in any way. The area was level and dominated by Russian thistle *(Salsola kali)*, cheatgrass brome *(Bromus tectorum)* and Japanese brome *(Bromus japonicus)* (Figure 5). Many nonseeded native species were also present.



Figure 5. Site I-D located in the center foreground.

I-E. This area was located 1.6 km southeast of Colstrip. It was treated with direct-take topsoil. The slope varied from being nearly level to having a slight northeast exposure (Figure 6). It was disced and seeded in April 1979 to 16 grasses, forbs, and shrubs and then fertilized. An annual cover crop was planted. In the spring of 1979, 53 species were found on the site.



Figure 6. Site I-E with direct-take topsoil.

I-F. This site was approximately 8 km southeast of Colstrip. It was reshaped, ripped, topsoiled, disced, cultipacked and harrowed in October 1973. A portion was subdivided for species trials. In the fall of 1973 and spring 1974, 26 grasses and 1 forb were broadcast seeded. Plots were cultipacked immediately after seeding. Wind erosion caused excessive seed blowout. Thirty-nine nonseeded species were found on the site.

II-A. This site was mined in October 1970, then reshaped and topsoiled in the winter of 1972. It was seeded with eight species the following spring. It was located on a level crest of a small knoll

at the Peabody Big Sky Mine and was dominated by smooth bromegrass.

II-B. This site was located approximately 8 km southeast of Colstrip. It was on a southwest facing slope which was covered with a 15 cm layer of topsoil in April 1972. The site was chiseled on the contour and seeded in May 1972 with a simple mixture of sudangrass *(Sorghum sudanense)*, smooth bromegrass, and fourwing saltbush *(Atriplex canescens)* and then fertilized. It was dominated by smooth bromegrass with only a few nonseeded species present.

II-C, II-D, II-E. Site II-C was located on a gentle west slope 6.5 km southeast of Colstrip. The site was covered with an irregular layer of topsoil 15-20 cm thick, deep-chiseled, and then broadcast seeded with a mixture of grasses, forbs, and shrubs in May 1972. Wheat *(Triticum aestivum)* and sudangrass were drill seeded for temporary stabilization. Located downwind from a coal loader, the soil surface was covered with a 0.5-1.0 mm layer of coal dust.

Site II-D had identical treatment except that it was burned to remove excess litter in April 1978.

Site II-E had treatment identical to II-C except that it was grazed in 1978.

II-F. Site II-F was located 6.5 km southeast of Colstrip, on a moderate north slope. It was topsoiled, gouged and broadcast seeded with a mixture of perennial grasses, forbs, and shrubs and then fertilized in the spring of 1973. It was dominated by smooth bromegrass.

II-G. This site was topsoiled and seeded in May 1977 to a mixture of 15 species of grasses, forbs, and shrubs (Field notes of B. Sindelar, Range Science Department, Montana State University at Bozeman, 1979). It was located approximately 3.2 km from Colstrip on a moderate northeast exposure.

II-H. This site was adjacent to the one above, on a moderate northeast exposure. The site was topsoiled, chiseled and broadcast seeded to a mixture of 16 grasses, forbs, and shrubs in April 1978. It was then cultipacked and fertilized. Fifty-seven species were present on the site in 1979 (Figure 7).



Figure 7. Site II-H in foreground.

II-I. Site II-I was located 0.8 km southwest of Colstrip on a gentle north slope. Clay textures dominated the soil profile. It was shaped, topsoiled, and drill seeded to a mixture of 16 grasses, forbs, and shrubs in the spring of 1977. Barley *(Hordeum vulgare)* was also seeded for temporary stabilization. It was fertilized in April 1978 and during the first growing season 45 species were present. Portions of the site were cut for hay in the fall of 1978 in order to remove excess material and minimize litter accumulation.

Nontopsoiled Sites

III-A. This site was located along a moderate northeast slope approximately 5 km southeast of Colstrip. It was reshaped old spoil, seeded in the fall of 1973. A simple mixture of three wheatgrasses, sweetclover *(Melilotus officinalis)*, alfalfa *(Medicago sativa)*, and winter wheat was seeded and fertilized in the fall of 1973. Some erosion was apparent on the site (Figure 8) and no postseeding management had been practiced.

III-B. This site was located approximately 1.5 km north of Colstrip. It was unique in that several cottonwood trees *(Populus deltoides)*, which had established at the base of the steep spoil, were partly buried during reshaping of old spoil piles (Figure 9). The site was seeded in 1974 to a simple five species mixture, and had subsequently been regularly grazed. It had 35 species present on the site.



Figure 8. Erosion rills in vegetation on Site III-A.



Figure 9. Site III-B with cottonwood trees established in swales of old reshaped spoil.

III-C. Mining activity began on this site in September 1970. It was located on Peabody's Big Sky Mine approximately 9.6 km south of Colstrip. The site was recontoured several times, the last which was in the winter of 1974. It was seeded in the spring of 1975 with an eight species mixture. The blue shale spoil provided a harsh environment and very little vegetation was present on the site (Figure 10).



Figure 10. Site III-C with sparse vegetation.

III-D. This site was located on a slight northwest exposure, 4 km southeast of Colstrip. Although the spoil was exposed in 1975, it was still in an active mining area and had not yet been topsoiled or seeded. The site was dominated by Russian thistle and had 15

species on the species list.

III-E. Site III-E was located 6.5 km southeast of Colstrip on a gentle southeast slope. It was created by reshaping 13-17 year old spoil in 1969. The seedbed was prepared and drill seeded in November 1969 with thickspike wheatgrass *(Agropyron dasystachyum)*. The next spring, areas between plots were drill seeded with a mixture of native and introduced perennial grasses, legumes, and shrubs. Broadcast fertilizing occurred in spring 1970 (Sindelar and Plantenberg, 1978). Results from 1979 showed the site had a large number of non-seeded species including rubber rabbitbrush *(Chrysothamnus nauseosus* var. *glabratus)*, the dominant species on the site.

IV-A. This site was located approximately 8 km southeast of Colstrip along a gentle southeast slope. In November 1970 the narrow strip of raw spoil was treated with a specially designed offset lister-drill that produced a series of staggered elongated trenches to reduce wind and water erosion and increase water accumulation and infiltration. The area was broadcast seeded with a mixture of 17 species and fertilized the following spring and periodically thereafter.

IV-B. This site was located approximately 6.5 km southeast of Colstrip. It was a one acre block with a strongly sloping north aspect that had been gouged. It was broadcast seeded in December 1971 with a mixture of 23 species and fertilized. Data collected in 1979

indicated smooth bromegrass dominated the site (Figure 11).



Figure 11. Site IV-B with abundant smooth bromegrass.

IV-C. Site IV-C was on old spoil that had been reshaped to a rolling topography approximately 7 km southeast of Colstrip. The sample area was the relatively level crest of a small hill. Seeded in the fall of 1971 to a simple mixture of three perennial grasses and two legumes, it had been contaminated by aerial seeding of adjacent spoil and was dominated by smooth bromegrass and crested wheatgrass. Diversity was low, with only ten species being present.

IV-D. History of this site was difficult to obtain, so descriptions are speculative. It was located 5 km southeast of Colstrip along a northeast exposure on old reshaped spoil that was terraced on the contour by Burlington Northern in 1971. It was probably seeded the fall of 1971 to a mixture of three wheatgrasses, sweetclover, and alfalfa and fertilized. Although no smooth bromegrass or crested wheatgrass was seeded, the subsequent aerial broadcast seeding of nearby pastures by Western Energy Company in 1972 apparently contaminated the area, allowing smooth bromegrass and crested wheatgrass to become uniformly established on the site. The site was very diverse for a nontopsoiled site with many nonseeded native species present.

IV-E and IV-F. These sites were located in the extreme northern portion of pit six at Rosebud mine approximately 7 km southeast of Colstrip. They are part of the first land disturbed by Western Energy Company in that pit. Shaping of the spoil was completed in 1971, creating a rolling terrain of knolls and swales with north facing slopes of 3:1 or less. Steeper slopes were treated by dozer basins and lesser slopes were chiseled or gouged. The seedbed was prepared in May 1972, and aerial seeded to a mixture of 17 grasses, shrubs, and legumes and fertilized in 1972 and 1974.

Site IV-E was grazed in the spring and late summer of 1976 by yearling steers as part of an eight pasture grazing study (DePuit

et al., 1977). Only a small number of nonseeded species were found on either site.

IV-G. This site was located approximately 8 km southeast of Colstrip adjacent to site IV-A. Initially, portions were topsoiled in alternate strips. However, the site was reworked, gouged, and seeded in the fall of 1971 with 23 species. This activity mixed topsoiled areas with nontopsoiled areas to the point where topsoil was effectively nonexistent. For purposes of this study, the site was considered nontopsoiled.

Cape Oliver. This site was located 3.2 km southeast of Colstrip. It was created when excessive overburden was removed from the mine area between July 1929 and May 1931 and used to form a nearly level 15 ha dump nearby. It was leveled during formation and then abandoned. Spoil texture varied from sandy loam to clay.

The site was naturally revegetated without being topsoiled, seeded, or fertilized. It has been periodically grazed since 1931 and was leased for spring and fall cattle use from 1955 to 1973. Portions of the site were also used for recreation. The study area was dominated by bluebunch wheatgrass *(Agropyron spicatum)* and ponderosa pine (Figure 12). In 1977 it was in excellent range condition (Sindelar and Plantenberg, 1978).



Figure 12. Cape Oliver

Native Range

This site was located 2.3 km northeast of the Colstrip power plants. The vegetation was predominantly mixed prairie grassland (*Stipa-Carex* type) which is an important and widespread plant community in the Colstrip area. It was located on a lightly grazed level hilltop in good range condition (Munshower et al., 1978) (Figure 13).



Figure 13. Native range (*Stipa-Carex* type).

RESULTS AND DISCUSSION

Extensive coal mining has occurred in the Colstrip area since mining resumed in 1968. Due to changes in mining techniques, reclamation laws and practices, and climatic variations, the seeded plant communities produced on mine spoil since that time vary greatly in species composition, dominance, structure, and age (Sindelar and Plantenberg 1977, 1978, and 1979). The major objectives of this study were designed to analyze possible causes of these differences.

THE ROLE OF TOPSOIL IN ESTABLISHMENT OF NONSEEDED SPECIES

Topsoil aids establishment of nonseeded species on mined land by: (a) supplying seed or other reproductive plant parts of species that may not be obtained elsewhere; (b) improving the physical structure and chemical properties of the rooting medium.

Topsoiling may decrease erosion and sloughing by promoting more rapid vegetation establishment (Hodder, 1973; Dollhopf et al., 1977). Arnold and Dollhopf (1977) found that organic matter in topsoil tends to stabilize soil aggregates, thus decreasing soil crusting. This improves water infiltration, percolation, and emergence and growth of vegetation. They found infiltration rates to be greater on native range than on topsoiled sites, and greater on topsoiled than on non-topsoiled sites. These differences were attributed to differences in amounts of vegetation and topsoil.

Frequency data and species lists were used to compare numbers of total species, nonseeded species, and native nonseeded species among different aged topsoiled and nontopsoiled sites. No attempt was made to determine whether nonseeded species were supplied by topsoil or simply encouraged by improved physical and chemical characteristics of the rooting medium.

Data show average numbers of total species, nonseeded species, and nonseeded native species to be significantly greater on topsoiled than on nontopsoiled sites (Table 2). However, numbers of nonnative volunteer species did not differ significantly.

Topsoiled sites had a significantly greater proportion of nonseeded native species than nontopsoiled sites. In addition, the average frequency of nonseeded native species was greater on topsoiled sites (12.8 percent) than on nontopsoiled sites (7.3 percent), but this difference was not significant (Table 3).

Table 2. Average numbers of species on topsoiled and nontopsoiled sites from species lists and frequency data.

	Topsoiled (Average 15 sites)	Nontopsoiled (Average 12 sites)
From species list		
Nonnative, nonseeded species	11.8[a]	8.0[a]
Native nonseeded species	18.7[a]	9.5[b]
Total nonseeded species	30.5[a]	17.8[b]
Total species	40.3[a]	25.4[b]
From frequency		
Nonnative, nonseeded species	7.1[a]	6.1[a]
Native nonseeded species	6.6[a]	2.0[b]
Total nonseeded species	13.8[a]	8.1[b]
Total species	20.0[a]	14.2[b]

Numbers within rows followed by the same letter are not significantly different at the P = 0.05 level.

Table 3. Average percent frequency and average proportion of nonseeded native species on topsoiled and nontopsoiled sites.

		Topsoiled	Nontopsoiled
Average percent frequency of nonseeded native species		12.8[a]	7.3[a]
Average proportion of nonseeded native species	from species list	57.1[a]	41.1[b]
	from frequency	43.9[a]	16.6[b]

Numbers within rows followed by the same letter are not significantly different at the P = 0.05 level.

Total cover, nonseeded species cover, nonseeded native species cover, and cover composition of nonseeded native species were not significantly different between treatments (Table 4).

Table 4. Average total cover, average cover of all nonseeded species, and average cover and percent composition of nonseeded native species on topsoiled and nontopsoiled sites.

Average percent cover	Topsoiled	Nontopsoiled
Nonseeded native species	4.8[a]	4.0[a]
Nonseeded species	26.3[a]	11.4[a]
Total species	66.4[a]	63.8[a]
Percent composition of native species by cover	7.5[a]	6.2[a]

Numbers within rows followed by the same letter are not significantly different at the P = 0.05 level.

Montana regulations require separate stripping, storage, and replacement of topsoil and subsoil on mined areas (Figures 14 and 15).

The ability of topsoil to provide species or aid in their establishment depends in part on how it is handled. Organic matter content and source of desirable species will depend on premining vegetation, land use, and dilution of the upper soil horizons during the mining operation.

Stockpiling topsoil for any period of time between removal and replacement decreases its potential as a seed reservoir (Miller, 1978). Topsoil that has not been stockpiled but is replaced directly after removal (direct-take topsoil) is most effective as a supplier of nonseeded species.



Figure 14. Depth of topsoil and subsoil removal.



Figure 15. Stockpiled topsoil.

Only site I-E could be documented as a direct-take topsoil site (E. Murray, Western Energy Company at Colstrip, Montana, *personal communication*, 1980). This site had more total species, nonseeded species, and nonseeded native species than the average of 15 topsoiled sites (Table 5). In addition, the frequency of nonseeded natives was higher on this site than the average of all topsoiled sites. Although other factors were involved, such as site age, direct-take topsoil was partly responsible for these differences.

Table 5. Species numbers and average frequency of nonseeded native species on site I-E compared to the averages from 15 topsoiled sites.

From species list	Site I-E	Average from 15 topsoiled sites
Nonseeded native species	30	12
Nonseeded species	45	21
Total species	53	40
Frequency		
Nonseeded native species	16	4
Nonseeded species	27	11
Total species	35	20
Average frequency of nonseeded native species	29.4%	12.8%

High frequencies of Sandberg bluegrass *(Poa sandbergii)* and prairie junegrass *(Koeleria cristata)*, both nonseeded native perennials, and the occasional presence of other nonseeded natives (e.g. *Carex filifolia)* that were rare on other sampled sites indicated the value of direct-take topsoil in supplying and aiding establishment of nonseeded species of later successional stages in revegetated mined land communities.

These data indicate that properly handled topsoil can increase the number of total species and the number of frequency of nonseeded native species on revegetated mined land. However, total cover, cover of nonseeded species, and cover and composition of nonseeded native species were not significantly increased by topsoiling.

THE EFFECTS OF CULTURAL PRACTICES ON NONSEEDED SPECIES ESTABLISHMENT

Sindelar and Plantenberg (1978) stated that unsuitability of cultural practices was a major factor influencing the ability of native species to establish and become dominant on seeded sites. The eventual effect was dependent upon the type of cultural practice, weather, and degree of management.

Cluster analysis, using frequency data and the Sokal and Sneath linkage method (1963) revealed no distinct relationships between topsoiled and nontopsoiled sites when all species, all nonseeded species, and nonseeded native species were considered.

In addition, wide variations among sites within each treatment (topsoiled or nontopsoiled) suggested that factors other than topsoiling influenced species similarity among sites. Several cultural practices had potential for producing this effect: seeding temporary cover crops, varying season of seeding, use of vigorous introduced perennial grasses in seeding mixtures, burning, grazing, surface manipulation, method of seeding, fertilizing and varying the seeding rates (Table 6). Investigation of the significance of seeding rates and fertilization was limited by a lack of data and by variations in the reporting methods used by different sources. However, heavy fertilization resulted in stagnation of seeded vegetation, helped to maintain dominance of introduced species, and was a major factor in the inability of native species to establish on seeded sites (Sindelar and Plantenberg, 1978).

Table 6. Summary of cultural practices used on study sites.

Site No.	Site	Topsoiled	Time of seeding	Cover crop seeded	Grazed	Surface manipulation
1	I-A	yes	--	no	no	no
2	I-B	yes	--	no	no	no
3	I-C	yes	fall	yes	no	no
4	I-D	yes	not seeded	no	no	no
5	I-E	yes	spring	yes	no	--
6	I-F	yes	spring & fall	no	no	--
7	II-A	yes	spring	no	no	--
8	II-B	yes	spring	yes	no	--
9	II-C	yes	spring	yes	no	no
10	II-D	yes	spring	yes	no	no
11	II-E	yes	spring	yes	yes	no
12	II-F	yes	spring	no	no	gouged
13	II-G	yes	spring		no	--
14	II-H	yes	spring	yes	no	--
15	II-I	yes	spring	yes	no	no
16	III-A	no	fall	yes	no	no
17	III-B	no	fall	no	yes	no
18	III-C	no	spring	no	no	no
19	III-D	no	not seeded	no	no	no
20	III-E	no	fall & spring	no	no	no
21	IV-A	no	fall	no	no	no
22	IV-B	no	fall	no	no	gouged
23	IV-C	no	fall	no	no	no
24	IV-D	no	fall	--	no	terraced
25	IV-E	no	spring	no	yes	chiseled & gouged
26	IV-F	no	spring	no	no	chiseled & gouged
27	IV-G	no	fall	no	no	gouged
28	Cape Oliver	no	not seeded	no	yes	no
29	Native Range	--	--	--	--	--

Influence of Smooth Bromegrass on Community Structure

In analyzing cover and frequency data, differences became apparent between those sites with substantial smooth bromegrass populations and those without. To determine if smooth bromegrass inhibited establishment of nonseeded species, the sites were separated into four groups. These were topsoiled, smooth bromegrass nonabundant; topsoiled, smooth bromegrass abundant; nontopsoiled, smooth bromegrass nonabundant; nontopsoiled, smooth bromegrass abundant.

Smooth bromegrass abundance was measured using percent frequency, Domin-Krajina cover-abundance estimates, and percent composition based on cover.

The correlation coefficient showed 33 percent of the variability in the number of nonseeded native species among sites was explained by frequency of smooth bromegrass. With only two exceptions, revegetated mined land sites had either high (greater than 75 percent) or low (less than 15 percent) smooth bromegrass frequency. Therefore, 50 percent frequency was used for dividing sites into abundant or nonabundant smooth bromegrass populations.

To place the two exceptions and to verify placement of other sites, percent cover and composition of smooth bromegrass were considered. Sites with less than one percent cover and less than five percent composition tended to have low frequencies and were placed in

the nonabundant smooth bromegrass groups. Sites with more than one percent cover and five percent composition tended to have high frequencies and were placed in the abundant smooth bromegrass groups.

Site III-E had marginal smooth bromegrass abundance with all three parameters. It was eventually placed in the smooth bromegrass nonabundant group because of obvious visual dominance by rubber rabbitbrush, a native shrub, and thickspike wheatgrass, a native perennial grass (Figure 16).



Figure 16. Site III-E.

Table 7 shows 27 sites placed into four smooth bromegrass groups using frequency, cover, and composition of smooth bromegrass.

Table 7. Twenty-seven revegetated mined land sites placed into four smooth bromegrass groups and percent frequency, cover, and composition of smooth bromegrass on each.

	Site	Percent frequency smooth bromegrass	Percent cover smooth bromegrass	Percent composition smooth bromegrass	
Group I	I-A	0	<1	0.6	topsoiled smooth brome-grass non-abundant
	I-B	15	0.1	0.1	
	I-C	10	<1	1.4	
	I-D	0	0	0.0	
	I-E	5	R	0.0	
	I-F	0	1-5	5.9	
Group II	II-A	85	5-10	11.6	topsoiled smooth brome-grass abundant
	II-B	100	25-33	99.5	
	II-C	100	5-10	54.7	
	II-D	100	10-25	13.4	
	II-E	100	10-25	17.6	
	II-F	100	5-10	28.9	
	II-G	100	10-25	47.0	
	II-H	80	1-5	4.1	
	II-I	75	1-5	10.8	
Group III	III-A	0	0	0.0	nontopsoiled smooth brome-grass non-abundant
	III-B	10	0.1	0.1	
	III-C	45	<1	3.1	
	III-D	0	0	0.0	
	III-E	60	1-5	5.2	
Group IV	IV-A	100	5-10	14.2	nontopsoiled smooth brome-grass abundant
	IV-B	100	10-25	26.9	
	IV-C	100	5-10	12.0	
	IV-D	100	10-25	52.9	
	IV-E	95	10-25	17.7	
	IV-F	100	25-33	27.1	
	IV-G	80	5-10	7.2	

Average numbers of total species, nonseeded species, and nonseeded native species were compared among the four groups using both frequency data and species lists. Group I (topsoiled, smooth bromegrass nonabundant) had consistently higher averages of all three parameters than the other three groups (Table 8). Group I also had a higher average percent frequency of nonseeded native species than the other groups.

Topsoiled sites without abundant smooth bromegrass developed greater cover of nonseeded native species than the other three groups (Table 8). This increase was significant between groups I and II and between groups I and IV indicating smooth bromegrass abundance reduced cover of nonseeded native species. In addition, the percent composition, by cover, of nonseeded native species in smooth bromegrass group I was significantly greater than that of groups II, III, or IV, (16.2, 1.6, 2.8, 10.8 percent, respectively) (Figure 17).

Table 8. Comparisons among four smooth bromegrass groups from frequency and species lists using average numbers of total species; average numbers of nonseeded species; and average numbers, frequencies, and cover of nonseeded native species.

Group	I	II	III	IV
from species list	Topsoiled smooth bromegrass nonabundant	Topsoiled smooth bromegrass abundant	Nontopsoiled smooth bromegrass nonabundant	Nontopsoiled smooth bromegrass abundant
ave. no. nonseeded native species	30[a]	12[b]	13[b]	7[b]
ave. no. nonseeded species	45[a]	21[b]	24[b]	14[b]
ave. no. total species	56[a]	30[b]	30[b]	22[b]
from frequency				
ave. no. nonseeded native species	10[a]	4[b]	2[b]	2[b]
ave. no. nonseeded species	18[a]	11[b]	9[b]	7[b]
ave. no. total species	25[a]	17[a]	14[a]	14[a]
average percent frequencies of nonseeded native species	18[a]	10[a]	9[a]	6[a]
average percent cover of nonseeded native species	11[a]	1[b]	6[a]	2[b]

Numbers within rows followed by the same letters are not significantly different at the P = 0.05 level using analysis of variance tests of significance.

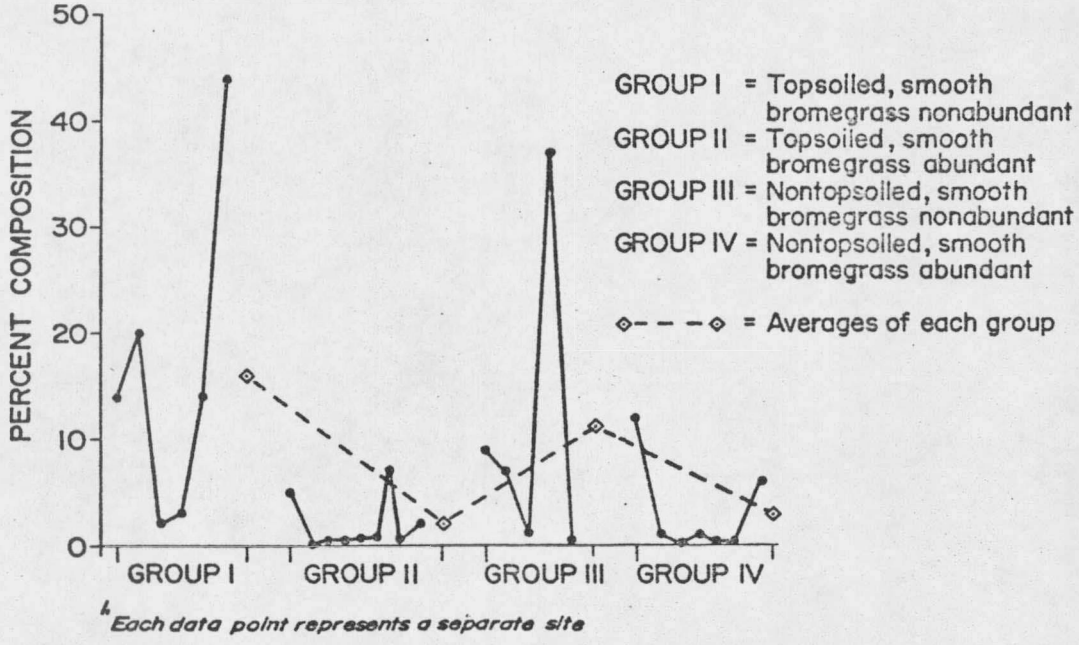


Figure 17. Percent composition (cover) of nonseeded native species on revegetated spoil with varying amounts of smooth bromegrass.

Excessive Litter Accumulations. Herbage production of revegetated mined land communities dominated by vigorous introduced grass species has been greater than that of native range in the Colstrip area (Sindelar and Plantenberg, 1978, 1979; Sindelar, 1980). This excessive vegetation, coupled with the lack of decomposition of plant material has resulted in excessive accumulations of litter (Figure 18). DePuit et al. (1978) working in the Colstrip area, found litter to increase five-fold from the fourth to the sixth growing season.

Literature suggests that large amounts of litter, such as those on revegetated mined land communities dominated by smooth bromegrass and crested wheatgrass, can inhibit seedling germination and establishment and limit invasion by nonseeded species. Working at Colstrip, Skilbred (1979) found excessive litter accumulations reduced perennial grass seedling establishment. Mueller-Dombois and Ellenberg (1974) stated that established plants can only be replaced by competitors that are able to grow in their shade, or that grow at a faster rate through canopy openings. Successful competitors withdraw more light, water, and nutrients from local environments to the disadvantage of associated plants. Simple occupation of growing space plays a role. It is doubtful that topsoil supplied species which are adapted to native conditions can meet these criteria. In dense stands of smooth bromegrass at Colstrip, seed and vegetative plant

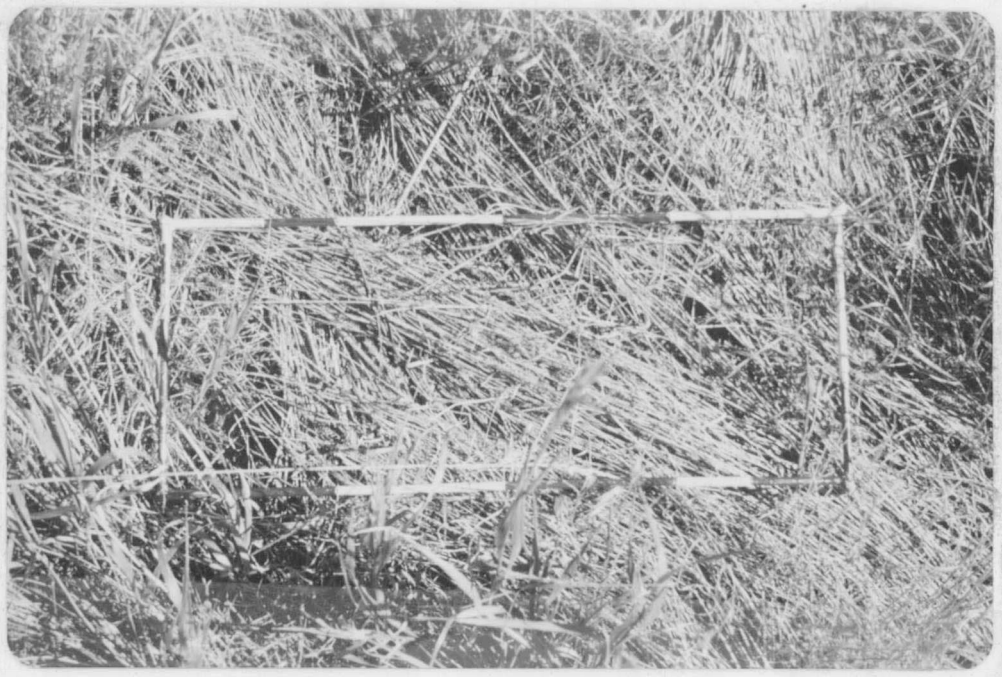


Figure 18. Litter accumulation on revegetated mined land.

parts from topsoil probably do not readily germinate or establish because conditions are unsuitable due to shading, limited growing space, excessive litter accumulation, cool temperatures, and competition for nutrients and water. This is supported by the lower numbers of nonseeded species on these sites compared to sites where smooth bromegrass was not abundant.

Benedict (1941) found that smooth bromegrass may produce a substance from its dead roots which inhibits its own growth. This substance may inhibit growth of other species as well, enhancing the competitive ability of smooth bromegrass.

In general, analyses of the four smooth bromegrass groups revealed that significantly greater numbers, cover, and composition of nonseeded native species were present on topsoiled sites without abundant smooth bromegrass. A larger number of individuals of each nonseeded native species was also present. The potential of topsoil to aid in nonseeded species establishment can be negated by including smooth bromegrass in seeding mixtures. Other vigorous species, such as crested wheatgrass, tall wheatgrass, and pubescent wheatgrass *(Agropyron trichophorum)* may also produce this effect (Depuit et al., 1978; B. Sindelar, Range Science Department, Montana State University at Bozeman, *personal communication*, 1980).

Season of Seeding

Range seedings should be made prior to the period of the longest favorable growing conditions, giving primary consideration to the distribution of precipitation and temperature (Vallentine, 1971). Working in the Colstrip area, DePuit et al. (1978) reported initial superiority of spring versus fall seeding, mostly due to higher rates of establishment of naturalized introduced species. Those same introduced species did not germinate as well in the fall, enabling native plant species to establish a more diverse, although less productive, plant community.

Time of seeding could be determined for twenty-three sites (13

spring, 10 fall). Despite the fact that only three fall sites were topsoiled and only three spring sites were nontopsoiled, no significant differences were revealed in numbers or frequencies of nonseeded native species between them (Table 9).

Table 9. Average numbers and frequencies of nonseeded native species on spring and fall seedings.

	Average frequencies %	Average numbers
Spring seeded	10.4	4.2
Fall seeded	12.1	4.3

Student's t-test showed a significant difference in the average percent cover of nonseeded natives between fall (6.7 percent) and spring (0.9 percent) seedings. However, spring seedings included 11 smooth bromegrass abundant sites and fall seedings only five. This resulted in wide variability within each category and may have masked the results.

Seeding Temporary Cover Crops

Annual cover crops are seeded for temporary stabilization, to decrease wind and water erosion, decrease weed competition, and to protect seedlings from wind and severe temperatures (Vallentine, 1971). Vigorous initial stands may compete excessively with seeded perennial grasses and nonseeded native species (DePuit et al., 1978; Sindelar and Plantenberg, 1978).

This study showed no significant differences in numbers or

frequencies of nonseeded native species among sites seeded with temporary cover crops and those without, regardless of the age of the seeding (Table 10).

Table 10. Average numbers and frequencies of nonseeded native species on sites with and without temporary cover crops.

	Average frequencies %	Average numbers
Cover Crop	11.6	4.3
No Cover Crop	10.9	4.1

Surface Manipulation

Vallentine (1971) and Sindelar et al. (1973) found that creating fissures, pits, and depressions on the soil surface tended to increase water infiltration and plant survival, and limited erosion from wind or water. Some soil surface preparation is needed on mined land to promote infiltration and improve conditions for germination. This problem can be acute on mined land in eastern Montana due to limited precipitation and dry, hot summers (Meyn et al., 1976).

Surface manipulation was completed on site IV-D before seeding. The moderately sloping northeast face was terraced on the contour into a series of microridges and swales. Diversity, percent frequency, and cover of nonseeded natives were high on this site, despite absence of topsoil and abundance of smooth bromegrass. Smooth bromegrass apparently established better in microswales due to moisture accumulation while more open, drier microridges of the terraces had more native plant species (Figure 19).



Figure 19. Site IV-D showing relatively bare microridges and smooth bromegrass dominated swales.

The wide variability in species numbers on sites with surface manipulation indicated that factors other than surface manipulation influenced these sites (Table 11). Surface manipulation was generally not effective in enhancing nonseeded species establishment if smooth bromegrass was included in the mixture.

Table 11. Numbers of total species, nonseeded species, and nonseeded native species on sites with surface manipulation.

Site	Total species	Nonseeded species	Nonseeded native species
II-F	20	10	5
IV-B	12	5	0
IV-D	19	14	6
IV-E	9	1	0
IV-F	11	3	0
IV-G	23	16	6
Mean	16	8	3

Grazing

Of the twenty-seven seeded areas sampled, only four had been grazed. To determine effects of grazing on nonseeded species establishment, each of these sites was compared to an equal aged nongrazed site seeded with similar mixtures. Comparisons were based on evaluations of total species numbers, frequencies of nonseeded native species, cover of all nonseeded species, and cover of nonseeded native species.

III-B (grazed) versus III-A (nongrazed). These sites were seeded to the same simple seed mixture in 1973. Neither site was topsoiled. Numbers of total species, nonseeded species, and nonseeded native species were all greater on the grazed site (III-B) than on the nongrazed site (III-A) (Table 12).

Table 12. Numbers of total species, nonseeded species, and nonseeded native species on sites III-A and III-B using frequency data and species lists.

	Number of nonseeded native species		Number of nonseeded species		Number of total species	
	from frequency	from species list	from frequency	from species list	from frequency	from species list
Site III-A (nongrazed)	13	24	8	19	1	9
Site III-B (grazed)	20	35	15	30	3	15

Average frequencies of nonseeded native species were five percent on site III-A and ten percent on site III-B. Cover comparisons showed the grazed site with a total nonseeded species cover of 15.3 percent and a total nonseeded native species cover of 9.5 percent. Respective numbers on the nongrazed sites were 0.8 percent and 0.3 percent. In addition, proportions of nonseeded native species using frequency were 20 percent for the grazed site and 13 percent for the nongrazed site.

IV-E (grazed) versus IV-F (nongrazed). These two nontopsoiled sites were seeded at the same time with identical seed mixtures. Smooth bromegrass was abundant on both sites. Numbers of total species, nonseeded species, and nonseeded native species on the grazed site (IV-E) were 11(14), 3(4), and 0(1) respectively with parenthesis indicating numbers from species lists. Respective numbers for the nongrazed site (IV-F) were 9(11), 1(2), and 0(1). Average frequencies of nonseeded native species were zero for both sites. Cover values

for nonseeded species and nonseeded native species were 0.7 percent and 0.1 percent respectively for the nongrazed and 0.2 percent and 0.1 percent for the grazed sites. This suggested that there were no grazing influenced differences between sites. Figures 20 and 21 show similarities in appearance of the two sites.



Figure 20. Grazed site IV-E.



Figure 21. Nongrazed site IV-F.

II-C, II-D, and II-E. These topsoiled sites were seeded at the same time with identical mixtures, the only difference being in postseeding management when the site was six years old (Figure 22). There was little difference between grazed (II-E) and nongrazed (II-C) sites in total numbers of species present, nonseeded species, or nonseeded native species (Table 13). Average frequencies of seeded native species were essentially the same.



Figure 22. Nongrazed site II-C (on left) and grazed site II-E in 1978.

Table 13. Numbers of total, nonseeded, and nonseeded native species on sites II-C, II-D, and II-E.

Site	Nonseeded native species	Nonseeded species	Total species
II-C (nongrazed)	1	7	10
II-E (grazed)	0	6	9
II-D (burned)	5	11	15

Burning on site II-D slightly increased numbers of total nonseeded and nonseeded native species, but it did not improve the average percent frequency of nonseeded natives, total cover, or total cover of nonseeded natives.

Other research conducted at Colstrip indicated that grazing revegetated mined land communities decreased standing dead litter and ground litter, and increased the proportion of bare ground (Depuit et al., 1977). This may eventually prove beneficial to the plant community by opening the stand to invasion and allowing further successional changes. Both smooth bromegrass and crested wheatgrass had less cover on grazed sites than on nongrazed controls. They concluded that diversity of grazed spoil communities was slightly greater than diversity of nongrazed spoil communities but all were low compared to native range.

Data from this study indicated that grazing effects on nonseeded species establishment were related to accompanying treatments. On nontopsoiled sites without smooth bromegrass, grazing opened the community, increasing total species, nonseeded species, and nonseeded native species, with possible increases in cover of nonseeded species. However, on nontopsoiled sites with abundant smooth bromegrass, no significant differences were apparent in nonseeded species numbers or total cover. Topsoiling, grazing, or burning were not sufficient to significantly increase species numbers if the site was dominated by smooth bromegrass.

It is possible that grazing on sites without abundant smooth bromegrass can substantially increase total numbers and cover of

nonseeded species but not necessarily their frequencies.

An overview of cultural practices suggested that their ability to aid in establishment of nonseeded native species was dependent on the aggressiveness of the species seeded. The presence of smooth bromegrass proved a major factor limiting nonseeded species establishment. Excluding this factor, topsoiling and grazing proved most effective in aiding establishment of nonseeded species. The former served as a seed source and an excellent rooting medium, and the latter opened up communities to invasion and establishment of nonseeded species.

IDENTIFICATION OF SUCCESSFULLY ESTABLISHED NONSEEDED PLANT SPECIES AND DEFINITION OF THEIR ECOLOGICAL ROLES

Once it has been determined that topsoil can add native species in significant amounts, it is of interest to determine the ecological role of those species and their importance in overall community structure. Do they fill niches that would otherwise remain empty? Do they compete with seeded species for available niches? This knowledge may be used to encourage or discourage species within specific ecological boundaries through use of management or cultural practices.

Table 14 lists all native nonseeded species and the number of revegetated mined land sites each was found on. Of the 54 native species present in frequency data, 39 were perennial, 3 were biennial,

and 12 were annual. Of the 120 native volunteers present on species lists, 96 were perennial, 5 were biennial, and 19 were annual. Smooth bromegrass group I (topsoiled, smooth bromegrass nonabundant) was found to have a statistically greater number of nonseeded perennial native species than groups II, III, or IV. Differences between numbers of biennials and annuals were not significant.

Table 14. Nonseeded native species and the number of revegetated mined land sites they appeared on out of 28 possible.

Species	From Frequency	From Species Lists	Duration
Ambrosia psilostachya	9	15	P
Stipa comata	9	13	P
Oryzopsis hymenoides	6	10	P
Grindelia squarrosa	6	12	B
Gutierrezia sarothrae	7	18	P
Plantago patagonica	5	8	A
Lithospermum incisum	7	9	P
Agropyron dasystachyum	5	4	P
Androsace occidentalis	5	6	A
Artemisia frigida	5	13	P
Hedeoma hispida	4	5	A
Ratibida columnifera	5	11	P
Aster falcatus	4	9	P
Yucca glauca	4	11	P
Descurainia pinnata	4	12	A
Poa sandbergii	3	5	P
Lactuca pulchella	3	6	P
Festuca octoflora	2	8	A
Koeleria cristata	3	10	P
Erysimum asperum	3	10	B
Polygonum douglasii	2	3	A
Helianthus petiolaris	2	7	A
Cirsium undulatum	2	16	B
Agropyron trachycaulum	2	3	P
Achillea millefolium	3	3	P
Carex filifolia	1	3	P
Conyza canadensis	1	3	A

Table 14. Nonseeded native species and the number of revegetated mined land sites they appeared on out of 28 possible (continued).

Species	From Frequency	From Species Lists	Duration
Solidago missouriensis	2	7	P
Chrysopsis villosa	2	7	P
Artemisia dracunculus	2	11	P
Chenopodium leptophyllum	2	4	A
Sitanion hystrix	2	4	P
Linum perenne	2	2	P
Artemisia cana	2	6	P
Draba reptans	2	5	A
Chrysothamnus nauseosus var. *glabratus*	1	6	P
Chrysothamnus nauseosus var. *nauseosus*	1	2	P
Psoralea argophylla	1	11	P
Microsteris gracilis	1	2	A
Lepidium densiflorum	1	5	A
Petalostemon purpureum	1	3	P
Oenothera nuttallii	1	1	P
Physalis longifolia	1	1	P
Poa spp.	1	1	P
Psoralea esculenta	1	1	P
Leucocrinum montanum	1	4	P
Bouteloua curtipendula	1	2	P
Vicia americana	1	1	P
Hordeum jubatum	0	9	P
Gaura coccinea	0	9	P
Astragalus lotiflorus	0	8	P
Penstemon albidus	0	6	P
Mentzelia decapetala	0	4	B
Sphaeralcea coccinea	0	4	P
Eriogonum annuum	0	4	A
Opuntia fragilis	0	4	P
Populus deltoides	0	3	P
Stipa viridula	0	4	P
Agropyron spicatum	1	4	P
Astragalus adsurgens	1	3	P
Poa juncifolia	1	2	P
Aristida longiseta	1	1	P
Agropyron smithii	1	1	P
Panicum virgatum	1	1	P

Table 14. Nonseeded native species and the number of revegetated mined land sites they appeared on out of 28 possible (continued).

Species	From Frequency	From Species Lists	Duration
Lygodesmia juncea	0	3	B
Polygala alba	0	2	P
Astragalus gilviflorus	0	2	P
Calachortus nuttallii	0	2	P
Astragalus missouriensis	0	3	P
Amaranthus graecizans	0	2	A
Atriplex canescens	0	2	P
Rosa woodsii	0	3	P
Machaeranthera canescens	0	2	P
Tradescantia bracteata	0	2	P
Allium textile	0	2	P
Calamovilfa longifolia	0	2	P
Verbena bracteata	0	2	P
Petalostemon candidum	0	2	P
Pinus ponderosa	0	2	P
Cirsium flodmanii	0	2	P
Symphoricarpos occidentalis	0	2	P
Solanum triflorum	0	1	P
Psoralea tenuiflora	0	1	P
Helianthus annuus	0	1	A
Dyssodia papposa	0	1	P
Atriplex patula	0	1	A
Solidago mollis	0	2	P
Astragalus crassicarpus	0	1	P
Asclepias viridiflora	0	1	P
Zigadenus venenosus	0	1	P
Euphorbia glyptosperma	0	1	A
Amaranthus albus	0	1	A
Ambrosia trifida	0	1	A
Cleome serrulata	0	1	P
Linum rigidum	0	2	P
Oenothera serrulata	0	2	P
Aster spp.	0	1	P
Artemisia tridentata	0	1	P
Echinacea pallida	0	2	P
Liatris punctata	0	2	P
Polygonum spp.	0	1	
Amaranthus spp.	0	1	
Erigeron spp.	0	1	

Table 14. Nonseeded native species and the number of revegetated mined land sites they appeared on out of 28 possible (continued).

Species	From Frequency	From Species List	Duration
Schizachyrium scoparium	0	2	P
Oxytropis sericea	0	1	P
Cenchrus longispinus	0	1	P
Schedonnardus paniculatus	0	1	P
Artemisia ludoviciana	0	2	P
Ranunculus glaberrimus	0	1	P
Antennaria microphylla	0	1	P
Asclepias speciosa	0	1	P
Campanula rotundifolia	0	1	P
Carex pensylvanica	0	1	P
Muhlenbergia cuspidata	0	1	P
Microseris cuspidata	0	1	P
Kuhnia eupatorioides	0	1	P
Juniperus scopulorum	0	1	P
Cryptantha celosioides	0	1	P
Coryphantha missouriensis	0	1	P
Phacelia linearis	0	1	P
Phlox alyssifolia	0	1	P
Poa compressa	0	1	P
Rhus trilobata	0	1	P
Solidago rigida	0	1	P
Viola nuttallii	0	1	P

Raunkiaer Comparisons

A Raunkiaer J-curve (Raunkiaer, 1934) was constructed for smooth bromegrass groups I through IV to determine if their averages conformed to this standard. The J-curve postulates that any natural community will have more species in both the higher and lower frequency ranges than in the middle ranges. Although some individual sites did not conform, all four smooth bromegrass group averages formed J-curves (Figure 23). Because the J-curve has been found to

be consistent for a wide variety of natural communities, it can be stated that revegetated mined land communities approximate natural communities in this regard.

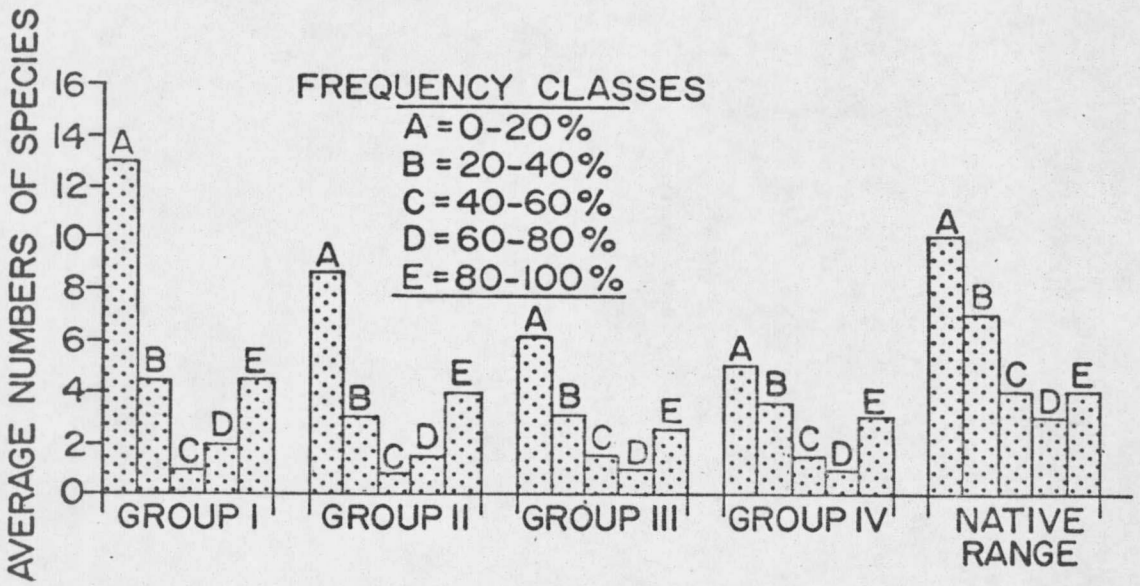


Figure 23. Average numbers of species in five frequency classes from four smooth bromegrass groups and native range.[1]

Average numbers of nonseeded native species per frequency class were compared. For the 0-20 percent frequency class, smooth bromegrass groups I through IV averaged 7.8, 3.2, 1.8, and 1.8 nonseeded native species respectively. This difference was significant but differences in the other four frequency classes were not. Topsoiled

[1]Used for Raunkiaer analysis.

sites without smooth bromegrass abundance provided nonseeded native species in primarily the 0-20 percent frequency range.

Seasonality Comparisons

A major reclamation deficiency has been the inability to establish warm season species, especially grasses, to a level comparable with native range reference sites (Sindelar, 1980). Smooth bromegrass group I showed a statistically greater number and frequency of warm season perennial grasses (Table 15). Both groups I and III (topsoiled and nontopsoiled, smooth bromegrass nonabundant) showed significantly higher frequencies of warm season forbs. Numbers of cool season forbs were fairly consistent among sites while perennial cool season grasses varied widely within all four groups.

Cover Comparisons

Smooth bromegrass group I had significantly greater numbers of nonseeded native species than the other three groups in the "rare," "less than one percent," and "one to five percent" cover classes (Table 16).

In general, topsoiling revegetated mined land communities has potential to provide native, perennial species in the 0-20 percent frequency range and in the "rare," "less than 1 percent," and "1-5 percent" cover classes, especially if smooth bromegrass is left out of seeding mixtures. In addition, the number and frequency of warm season perennial grasses and the frequency of warm season forbs may

Table 15. Average numbers and average frequencies of warm and cool season species among four smooth bromegrass abundance groups.

	Group I	Group II	Group III	Group IV
Warm season perennial grasses				
average number	1.5[a]	0[b]	0[b]	0[b]
average frequency (%)	29.7[a]	0[b]	0[b]	0[b]
Warm season forbs				
average number	6.0[a]	3.2[a]	3.0[a]	2.6[a]
average frequency (%)	38.4[a]	18.4[b]	34.2[a]	13.8[b]
Cool season forbs				
average number	6.8[a]	6.0[a]	4.4[a]	3.6[a]
average frequency (%)	26.9[a]	28.2[a]	19.5[a]	28.2[a]
Cool season perennial grasses				
average number	7.0[a]	5.2[a]	5.2[a]	6.6[a]
average frequency (%)	30.0[a]	68.0[a]	35.0[a]	51.0[a]
Cool season annual grasses				
average number	1.5[a]	1.0[a]	0.8[a]	0.9[a]
average frequency (%)	extreme variation within groups			
Shrubs and half shrubs				
average number	1.3[a]	1.0[a]	0.6[a]	0.4[a]
average frequency (%)	extreme variation within groups			

Numbers within rows followed by the same letter are not significantly different at the P = 0.05 level.

Table 16. Average numbers of nonseeded native species in each cover class among the four smooth bromegrass abundance groups.

Group	Rare	0.1%	<1%	1-5%	5-10%	10-25%[1]
I	15	7	4	2	t[2]	0
II	3	3	1	0	0	0
III	5	3	1	t	0	t
IV	2	2	1	t	0	0

[1] There were no nonseeded native species present in the higher cover classes (25-100 percent) on any site.

[2] Trace (less than 0.5%).

be significantly increased by topsoiling if smooth bromegrass is excluded from the sites.

COMPARISONS OF NATIVE RANGE AND REVEGETATED MINED LAND COMMUNITIES

Comparing revegetated mined land communities to both native range from the Colstrip area and Cape Oliver provided insight into how topsoiling can aid community development on revegetated mined lands.

Although topsoiling increased numbers of both total species and nonseeded native species over nontopsoiled sites, it still did not provide as many native species as found on native range or on naturally revegetated spoil (Table 17). However, topsoiled sites were comparable to native range in total species numbers.

Life form analysis indicated mined land communities had numbers approximately equal to native range in annual grasses, biennial forbs, and shrubs and half shrubs. However, the native range area had few shrubs and half shrubs and was not typical of all native range types in the Colstrip area. Average numbers of perennial grass species on revegetated mined land communities were 6.0 on nontopsoiled sites, and 8.5 on topsoiled sites compared to 10.0 on native range. In addition, both topsoiled and nontopsoiled sites averaged fewer perennial forbs (4.2 and 2.8 respectively) than either native range (7.0) or Cape Oliver (9.0).

Table 17. Topsoiled and nontopsoiled sites compared with native range and Cape Oliver in total species numbers, species numbers by vegetation class, and diversity.

	Native Range	Cape Oliver	Smooth bromegrass nonabundant	Smooth bromegrass abundant	All topsoiled
			TOPSOILED		
Total species numbers in frequency	28	32	25	17	20
Nonseeded natives in frequency	22	24	11	4	7
Perennial grasses	10	10	9	5	7
Annual grasses	1	1	2	1	1
Annual forbs	6	4	5	4	5
Biennial forbs	3	4	3	2	3
Perennial forbs	7	9	6	3	4
Shrubs and half shrubs	1	4	1	1	1
Number of species with greater than one percent cover	10[1]	10	7	5	6
Shannon-Weiner diversity	3.0518	3.0657	2.5634	2.1517	2.3164

	Smooth bromegrass nonabundant	Smooth bromegrass abundant	All nontopsoiled
	NONTOPSOILED		
Total species numbers in frequency	14	14	14
Nonseeded natives in frequency	2	2	2
Perennial grasses	7	5	6
Annual grasses	1	1	1
Annual forbs	1	3	2
Biennial forbs	1	2	2
Perennial forbs	4	2	3
Shrubs and half shrubs	t[2]	1	1
Number of species with greater than one percent cover	6	4	5
Shannon-Weiner diversity	2.1223	1.7760	1.9780

[1] Average of 7 native range sites in Colstrip area (Sindelar, 1980).

[2] Trace (less than 0.5%).

Diversity

Diversity, as defined by Montana reclamation regulations, was useful in revealing differences between revegetated mined land communities and native range. Regulations indicate adequate diversity is reached when, "the number of species occupying one percent or more of the cover in the revegetated area is equal to or greater than the number of species occupying one percent or more of the cover in the reference area." Reference areas are defined as, "unmined areas of the same community types to be mined."

No significant differences in the number of species with greater than one percent cover were found among four smooth bromegrass groups or between topsoiled and nontopsoiled sites (Table 17). Topsoiling did not increase the likelihood of meeting the diversity requirements established by Montana regulations.

Topsoiled sites with low smooth bromegrass abundance were shown to have a significantly greater number of nonseeded native species in the one to five percent Domin-Krajina cover-abundance class. However, no significant difference was found in the total number of species with greater than one percent cover. It was assumed that nonseeded native species providing greater than one percent cover must replace both seeded species and nonseeded nonnative species of greater than one percent cover on topsoiled sites without smooth bromegrass abundance. The numbers of species with greater than one percent

cover on both topsoiled and nontopsoiled sites averaged only about half that of native range.

Technically, species diversity is a function of both species richness and equitability. Odum (1971) stated that species diversity tends to increase during early stages of community development. These "bloomstage" organisms tend to be small in size, with simple life histories. As succession advances, the trend to larger organisms increases the mean length and complexity of life histories, which increases interspecific competition and may reduce the number of species that can live in a given cell. Golley (1965), working on succession in a broomsedge *(Andropogon virginicus)* community in South Carolina, found two oscillations of diversity which appeared to be a function of the size of the abandoned area and life history of dominant plant species. Sindelar and Plantenberg (1979) and Sindelar (1980) found diversity to decline as the initial flush of weedy and nonadapted seeded species disappeared on revegetated mined land sites at Colstrip. Diversity was low on sites dominated by aggressive species, such as smooth bromegrass and crested wheatgrass, and no revegetated sites were comparable to native range by either State standards or Shannon-Weiner diversity indices.

Shannon-Weiner diversity index values in this study were similar to those of Sindelar (1980). Although smooth bromegrass group I had higher average diversity than groups II, III, or IV, no differences

were significant (Table 17). Only four sites had diversity values higher than native range and naturally revegetated mined spoil (Figure 24). Those sites were all topsoiled and were relatively young. Their high diversity values probably reflected the early influx of invader species.

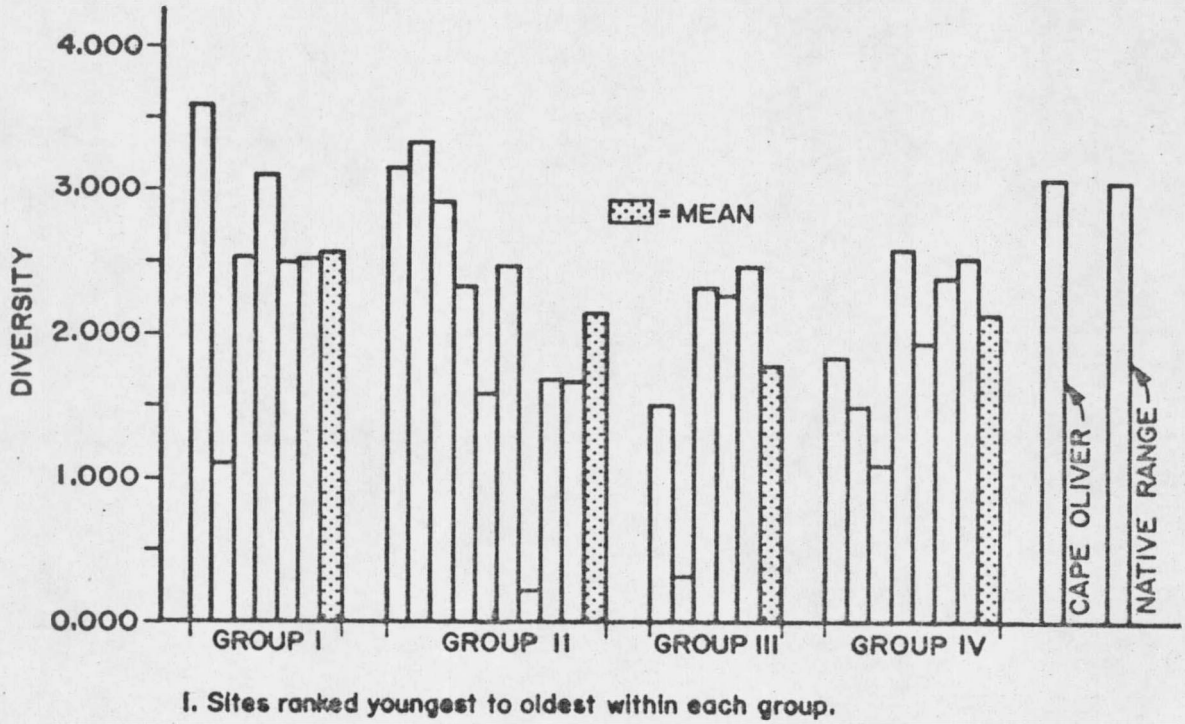


Figure 24. Shannon-Weiner diversity index values ($\log_2$) of 27 mined land communities placed in four smooth bromegrass groups compared to native range and Cape Oliver.

These results led to the conclusion that topsoiling does not increase diversity of revegetated mined land sites to a level comparable to native range as required by Montana reclamation regulations, nor does it increase the Shannon-Weiner diversity index values to a level comparable with native range, even though total species numbers may be significantly increased.

Permanence

Montana regulations use the proportion of native species present as an indication of vegetation permanence (Sindelar, 1980). They state that, "the operator shall establish a permanent diverse vegetative cover of predominantly native species."

Topsoiled sites had a significantly higher proportion of native species, both seeded and nonseeded, than nontopsoiled sites. Average proportions of native species present were 56 percent, 34 percent, 25 percent, and 27 percent for smooth bromegrass groups I to IV respectively, with group I being significantly greater. The proportion of native species on topsoiled sites without smooth bromegrass abundance (56 percent) compared favorably with the "predominantly native" requirements of the regulations. However, it was less than that of native range (79 percent) and Cape Oliver (75 percent). Topsoiled, smooth bromegrass nonabundant sites were superior to the other three smooth bromegrass groups in native species establishment and permanence as defined by Montana regulations.

Some postmining cultural practices are capable of improving conditions for nonseeded species establishment and improving revegetated mined land community structure. Among these, topsoiling and exclusion of aggressive introduced perennial grasses from seed mixtures, especially smooth bromegrass, appear most promising. However, benefits are limited to increased species numbers, cover of nonseeded native species, and vegetation permanence. Apparently, topsoiling and aggressive species exclusion did not improve diversity enough to contribute significantly to "adequate reclamation" at Colstrip. These procedures are not panaceas but additional steps to be used along with other ecological practices to achieve reclamation goals.

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the extent to which topsoiling and other reclamation techniques aid in nonseeded species establishment on revegetated mined land communities. Thirteen variously aged and treated nontopsoiled sites, fifteen variously aged and treated topsoiled sites, and a native range site were studied in the vicinity of Colstrip, Montana. Frequency, site species lists, and Domin-Krajina cover-abundance parameters were used for comparisons.

Literature revealed nonseeded species establishment to be dependent on seed supply, migration ability, climate, cultural practices, postmining management, and the characteristics and patterns of secondary succession.

Results showed that properly handled topsoil has potential to increase total species numbers and to provide significantly greater numbers and proportions of nonseeded native species on revegetated mined land. No significant differences were found between topsoiled and nontopsoiled treatments in total cover or frequencies of nonseeded species. Direct-take topsoil was found to be more effective than stockpiled topsoil in supplying nonseeded, less mobile, climax native species.

Cluster analyses indicated practices other than topsoiling influenced community development. Of those practices analyzed, grazing

and exclusion of aggressive introduced grasses from seed mixtures were most beneficial in nonseeded native species establishment. Both practices decreased competition from seeded species and increased the amount of resources available to nonseeded native species. Surface manipulation, use of temporary cover crops, and varying the time of seeding did not appear to influence nonseeded native species development. However, terracing on the contour provided microtopographic variation which appeared to increase establishment of nonseeded native species.

Sites were classified into four groups based on frequency, cover, and composition of smooth bromegrass. Those sites with topsoil and limited amounts of smooth bromegrass had consistently greater numbers of total species, nonseeded species, nonseeded native species, greater frequencies of nonseeded native species, greater cover of nonseeded native species, and higher percent composition of nonseeded native species than groups without topsoil or with abundant smooth bromegrass or both. Differences were due to inhibiting effects of excessive litter accumulation on seedling establishment and the competitive ability and possible allelopathic effects of smooth bromegrass.

One hundred and twenty nonseeded native species were found on 27 mined land sites. Among nonseeded native species, perennials outnumbered biennials or annuals. Topsoiled sites without abundant

smooth bromegrass had significantly greater numbers of nonseeded perennial native species. Revegetated mined land communities conformed to Raukiaer's J-curve, with topsoiling providing primarily perennial native species in the 0-20 percent frequency range and in the "rare," "less than 1 percent", and "1-5 percent" cover classes, especially if smooth bromegrass was not present. Topsoiling had potential to increase the number and frequency of warm season perennial grasses and the frequency of warm season forbs if smooth bromegrass was not present.

The average number of native species on topsoiled sites did not approximate the number found on native range, although total species numbers were similar. Mined land communities were approximately equal to native range in numbers of annual grasses, biennial forbs, and shrubs and half shrubs, but had fewer perennial grasses and forbs. Topsoiled and nontopsoiled sites had lower diversity than native range, both as defined by Montana regulations and by Shannon-Weiner diversity indices.

Using proportion of native species as an indicator of permanence, smooth bromegrass group I compared favorably with the "predominantly native" requirements of Montana regulations.

The following conclusions are based on results of this study:

1. Use of direct-take topsoil increased number and frequency of nonseeded native species more than topsoil which had been stockpiled.

2. Topsoiling increased the proportion of native species to a level comparable to the "predominantly native" permanence requirement of Montana regulations.

3. Topsoiling increased numbers of total species and nonseeded native species over nontopsoiled sites but not to levels comparable to native range.

4. Topsoiling increased diversity (as defined by Montana regulations) and Shannon-Weiner diversity index values but not to levels comparable with native range.

5. Although migration would eventually supply the heavier, less mobile disseminules of climax species, topsoil may provide them sooner.

6. Exclusion of excessively competitive species, especially smooth bromegrass, from seed mixtures significantly increased the numbers, cover, and composition of nonseeded native species. Most nonseeded native species that became established were perennial, in the 0-20 percent frequency range and provided less than five percent cover.

7. Proper grazing increased numbers of all species, and numbers and cover of nonseeded native species on revegetated mined land without smooth bromegrass abundance.

8. Contour terracing of steeper slopes may provide a greater variety of microclimatic conditions and increase establishment of nonseeded species.

9. Seeding cover crops, using surface manipulation, and varying the season of seeding were not effective in encouraging nonseeded native species establishment, if smooth bromegrass was abundant on the site.

10. The following nonseeded native species were abundant on revegetated mined land communities at Colstrip: *Stipa comata, Oryzopsis hymenoides, Lithospermum incisium, Agropyron dasystachyum, Ratibida columnifera, Aster falcatus, Yucca glauca, Koeleria cristata, Erysimum asperum, Cirsium undulatum, Poa sandbergii* and *Psoralea argophylla*. Establishment of these and other useful reclamation species from topsoil should be encouraged.

11. Evaluations of cultural practices on revegetated mined land community development must consider treatment interactions, and not the effect of each treatment individually.

12. Further research is needed to determine the best reclamation practice or combination of practices to be used in each circumstance.

APPENDIX

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
SITE I-A					
Agropyron cristatum	5	<1	no	I	cool
A. dasystachyum	5	1-5	no	N	cool
A. elongatum	85	1-5	no	I	cool
A. spicatum		R	no	N	cool
A. smithii		<1	no	N	cool
Ambrosia psilostachya	85	5-10	no	N	warm
Artemisia cana		R	no	N	1
A. dracunculus	5	<1	no	N	
A. frigida	5	0.1	no	N	
Aster falcatus	5	0.1	no	N	warm
Bouteloua curtipendula	35	5-10	no	N	warm
B. gracilis		R	no	N	warm
Bromus spp.	100	<1	no	I	cool
B. inermis		<1	no	I	cool
Camelina microcarpa		0.1	no	I	cool
Cenchrus longispinus		R	no	N	warm
Cirsium arvense		0.1	no	I	cool
C. undulatum		0.1	no	N	warm
Gaura coccinea		<1	no	N	warm
Gutierrezia sarothrae		<1	no	N	
Hordeum jubatum		0.1	no	N	cool
Kochia scoparia	20	0.1	no	I	warm
Lactuca pulchella		0.1	no	N	warm
L. serriola	90	0.1	no	I	warm
Lygodesmia juncea		<1	no	N	warm
Medicago sativa	25	10-25	no	I	cool
Melilotus officinalis	30	25-30	no	I	cool
Opuntia fragilis		R	no	N	cool
Oryzopsis hymenoides	15	1-5	no	N	cool
Oxytropis sericea		R	no	N	cool
Physalis longifolia	5	R	no	N	cool
Poa pratensis		0.1	no	I	cool
Populus deltoides		R	no	N	
Psoralea argophylla		1-5	no	N	warm
Rumex crispus		R	no	I	cool
Salsola kali	35	0.1	no	I	warm

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Schizachyrium scoparium		R	no	N	warm
Sisymbrium altissimum		R	no	I	cool
Solidago missouriensis	5	R	no	N	warm
Sphaeralcea coccinea		R	no	N	cool
Stipa comata	30	<1	no	N	cool
S. viridula		0.1	no	N	cool
Taraxacum officinale	35	0.1	no	I	cool
Tragopogon dubius	75	1-5	no	I	cool
Yucca glauca	5	0.1	no	N	
SITE I-B					
Agropyron cristatum	20	5-10	yes	I	cool
A. dasystachyum	30	1-5	yes	N	cool
A. smithii	10	<1	yes	N	cool
A. trachycaulum	45	1-5	yes	N	cool
A. trichophorum	75	5-10	yes	I	cool
Ambrosia psilostachya	90	1-5	no	N	warm
Artemisia cana		R	no	N	
A. dracunculus		0.1	no	N	
A. frigida		0.1	no	N	
A. ludoviciana		R	no	N	warm
Aster falcatus		R	no	N	warm
Astragalus lotiflorus		R	no	N	cool
Bouteloua curtipendula	30	1-5	yes	N	warm
B. gracilis	10	<1	yes	N	warm
Bromus spp.	85	1-5	no	I	cool
B. inermis	15	0.1	yes	I	cool
Camelina microcarpa	5	0.1	no	I	cool
Cirsium undulatum	5	<1	no	N	warm
Festuca octoflora	15	0.1	no	N	cool
Gaura coccinea		0.1	no	N	warm
Grindelia squarrosa	50	<1	no	N	warm
Gutierrezia sarothrae	5	0.1	no	N	
Hordeum jubatum		1-5	no	N	cool

	% Frequency	Cover	Seeded	Native vs Introduced	Seasonality
Kochia scoparia	45	<1	no	I	warm
Koeleria cristata		R	no	N	cool
Lactuca pulchella	5	1-5	no	N	warm
L. serriola	80	1-5	no	I	warm
Leucocrinum montanum	5	R	no	N	cool
Lithospermum incisum	5	R	no	N	cool
Lygodesmia juncea		<1	no	N	warm
Medicago sativa	90	25-33	yes	I	cool
Melilotus officinalis	75	25-33	yes	I	cool
Oryzopsis hymenoides	10	<1	no	N	cool
Poa spp.	5	R	no		cool
P. pratensis		R	no	I	cool
P. sandbergii		R	no	N	cool
Populus deltoides		R	no	N	
Psoralea argophylla	5	<1	no	N	warm
P. esculenta	5	R	no	N	warm
Ratibida columnifera		R	no	N	warm
Rumex crispus		R	no	I	cool
Salsola kali	75	<1	no	I	warm
Schedonnardus paniculatus		R	no	N	warm
Sitanion hystrix		0.1	no	N	cool
Solidago missourienis		R	no	N	warm
Sphaeralcea coccinea		<1	no	N	cool
Stipa comata	35	1-5	no	N	cool
S. viridula	10	0.1	yes	N	cool
Taraxacum officinale	30	0.1	no	I	cool
Tragopogon dubius	85	5-10	no	I	cool
Ulmus pumila		R	no		
Yucca glauca	5	0.1	no	N	

	% Frequency	Cover	Seeded	Native vs Introduced	Seasonality
SITE I-C					
Agropyron cristatum	75	<1	yes	I	cool
A. dasystachyum	85	1-5	yes	N	cool
A. smithii	75	1-5	yes	N	cool
A. spicatum		<1	no	N	cool
A. trachycaulum	90	<1	yes	N	cool
A. trichophorum	15	<1	no	I	cool
Ambrosia psilostachya	20	<1	no	N	warm
Aristida longiseta		R	no	N	warm
Astragalus gilviflorus		R	no	N	cool
A. lotiflorus		R	no	N	cool
Avena fatua		R	no	I	cool
Bouteloua curtipendula		R	no	N	warm
B. gracilis		R	yes	N	warm
Brassica kaber		R	no	I	cool
Bromus spp.	10	<1	no	I	cool
B. inermis	10	<1	yes	I	cool
Calamovilfa longifolia	5	<1	yes	N	warm
Calochortus nuttallii		R	no	N	cool
Camelina microcarpa	20	0.1	no	I	cool
Carex filifolia		R	no	N	cool
Chenopodium album		R	no	I	warm
C. leptophyllum		R	no	N	warm
Chrysopsis villosa		R	no	N	warm
Convolvulus arvensis		R	no	I	cool
Descurainia pinnata	5	R	no	N	cool
Euphorbia glyptosperma		R	no	N	cool
Festuca octoflora		R	no	N	cool
Gutierrezia sarothrae	5	R	no	N	
Helianthus petiolaris	5	0.1	no	N	warm
Kochia scoparia		R	no	I	warm
Lactuca serriola	35	0.1	no	I	warm
Lithospermum incisum		1-5	no	N	cool

	% Frequency / % Cover		Seeded	Native vs Introduced	Seasonality
Medicago sativa	5	R	no	I	cool
Melilotus officinalis	100	10-25	yes	I	cool
Misc. annual forb		R	no		
Onobrychis viciaefolia	5	<1	yes	I	cool
Oryzopsis hymenoides		R	no	N	cool
Penstemon albidus		R	no	N	cool
Plantago patagonica		R	no	N	cool
Poa sandbergii		R	no	N	cool
Polygala alba		0.1	no	N	cool
Polygonum douglasii	10	0.1	no	N	cool
Psoralea argophylla		R	no	N	warm
Salsola kali	85	0.1	no	I	warm
Sisymbrium altissimum		R	no	I	cool
Stipa comata	10	<1	no	N	cool
S. viridula	20	1-5	yes	N	cool
Taraxacum officinale	15	0.1	no	I	cool
Tragopogon dubius		R	no	I	cool
Triticum aestivum		R	yes	I	cool
Vaccaria segetalis		R	no	I	cool
Verbena bracteata		R	no	N	cool
Yucca glauca		R	no	N	

SITE I-D

Ambrosia psilostachya		0.1	no	N	warm
Androsace occidentalis	5	R	no	N	cool
Artemisia frigida		0.1	no	N	
Astragalus adsurgens		R	no	N	cool
A. lotiflorus		R	no	N	cool
Bouteloua curtipendula	5	R	no	N	warm
Bromus spp.	90	33-50	no	I	cool
Camelina microcarpa	5	0.1	no	I	cool
Chrysopsis villosa		R	no	N	warm
Cirsium undulatum		0.1	no	N	warm

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Descurainia pinnata		R	no	N	cool
Draba reptans		R	no	N	cool
Erigeron spp.		R	no	N	
Festuca octoflora		R	no	N	cool
Grindelia squarrosa	10	R	no	N	warm
Gutierrezia sarothrae		0.1	no	N	
Hedeoma hispida	10	0.1	no	N	cool
Helianthus petiolaris		0.1	no	N	warm
Koeleria cristata		R	no	N	cool
Lactuca serriola	10	<1	no	I	warm
Lepidium densiflorum	5	0.1	no	N	cool
Lithospermum incisum		R	no	N	cool
Medicago lupulina		R	no	I	cool
Melilotus officinalis	5	1-5	no	I	cool
Misc. perennial forb	5	R	no		
Oryzopsis hymenoides	5	R	no	N	cool
Penstemon albidus		R	no	N	cool
Plantago patagonica	5	<1	no	N	cool
Poa pratensis		R	no	I	cool
Psoralea argophylla		<1	no	N	warm
Ranunculus glaberrimus		R	no	N	cool
Ratibida columnifera		R	no	N	warm
Salsola kali	100	50-75	no	I	warm
Sitanion hystrix		R	no	N	cool
Stipa comata		R	no	N	cool
S. viridula		0.1	no	N	cool
Taraxacum officinale	15	0.1	no	I	cool
Tragopogon dubius		0.1	no	I	cool
Vicia americana	5	R	no	N	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Season-ality
SITE I-E					
Agropyron cristatum	85	<1	yes	I	cool
A. dasystachyum	65	<1	yes	N	cool
A. smithii	25	0.1	yes	N	cool
A. trachycaulum	80	<1	yes	N	cool
A. trichophorum	75	<1	no	I	cool
Allium textile		R	no	N	cool
Ambrosia psilostachya	10	R	no	N	warm
Androsace occidentalis	50	R	no	N	cool
Artemisia dracunculus		0.1	no	N	
A. frigida	15	0.1	no	N	
Bouteloua gracilis	100	R	yes	N	warm
Brassica spp.		R	no	I	
Bromus spp.	100	75-100	no	I	cool
B. inermis	5	R	no	I	cool
Calochortus nuttallii		R	no	N	cool
Camelina microcarpa	15	<1	no	I	cool
Carex filifolia	10	0.1	no	N	cool
Centaurea maculosa		R	no	I	cool
Chenopodium spp.		R	no	I	warm
Cirsium undulatum		R	no	N	warm
Descurainia pinnata		<1	no	N	cool
Draba reptans	15	R	no	N	cool
Eriogonum annuum		R	no	N	warm
Erysimum asperum	20	<1	no	N	cool
Festuca octoflora	80	0.1	no	N	cool
Gaura coccinea		R	no	N	warm
Grindelia squarrosa	10	R	no	N	warm
Gutierrezia sarothrae		0.1	no	N	
Hedeoma hispida	20	0.1	no	N	cool
Helianthus petiolaris		R	no	N	warm
Hordeum jubatum		R	no	N	cool
Kochia scoparia	70	0.1	no	I	warm
Koeleria cristata	85	<1	no	N	cool
Lactuca serriola	20	0.1	no	I	warm

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Lepidium densiflorum		R	no	N	cool
Leucocrinum montanum		R	no	N	cool
Lithospermum incisum	5	R	no	N	cool
Medicago sativa	90	<1	yes	I	cool
Microsteris gracilis	5	R	no	N	cool
Onobrychis viciaefolia	5	R	no	I	cool
Plantago patagonica	30	0.1	no	N	cool
Poa pratensis	5	0.1	no	I	cool
P. sandbergii	90	0.1	no	N	cool
Polygonum spp.	35	0.1	no	N	cool
Ratibida columnifera	5	R	no	N	warm
Salsola kali	65	1-5	no	I	warm
Sisymbrium spp.		R	no	I	cool
Stipa comata	20	<1	no	N	cool
S. viridula	5	R	yes	N	cool
Taraxacum officinale	15	0.1	no	I	cool
Tradescantia bracteata		R	no	N	cool
Tragopogon dubius		<1	no	I	cool
Triticum aestivum	90	1-5	yes	I	cool
SITE I-F					
Agropyron cristatum	5	R	yes	I	cool
A. dasystachyum	25	0.1	yes	N	cool
A. elongatum		0.1	yes	I	cool
A. smithii	70	1-5	yes	N	cool
A. trachycaulum		R	yes	N	cool
Allium textile		R	no	N	cool
Ambrosia psilostachya	75	<1	no	N	warm
Andropogon gerardi		1-5	yes	N	warm
A. hallii	5	1-5	yes	N	warm
Artemisia dracunculus		0.1	no	N	
Astragalus cicer		R	no	I	warm
A. lotiflorus		R	no	N	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
A. missouriensis		0.1	no	N	cool
Atriplex canescens		0.1	no	N	
Bouteloua curtipendula	10	1-5	yes	N	warm
B. gracilis		0.1	yes	N	warm
Bromus spp.	30	<1	no	I	cool
Bromus inermis		1-5	yes	I	cool
Buchloe dactyloides	25	5-10	yes	N	warm
Calamovilfa longifolia		0.1	yes	N	warm
Chenopodium spp.	5	R	no	I	warm
Cirsium arvense	5	R	no	I	cool
C. undulatum		0.1	no	N	warm
Conyza canadensis		R	no	N	warm
Dactylis glomerata		R	yes	I	cool
Descurainia pinnata		0.1	no	N	cool
Elymus cinereus		0.1	yes	N	cool
E. junceus		0.1	yes	I	cool
E. triticoides		R	yes	N	cool
Eriogonum annuum		0.1	no	N	warm
Festuca ovina		0.1	yes	I	cool
F. pratensis		R	yes	I	cool
Gutierrezia sarothrae		0.1	no	N	
Helianthus petiolaris		R	no	N	warm
Hordeum jubatum		R	no	N	cool
Koeleria cristata		R	no	N	cool
Lactuca pulchella	25	1-5	no	N	warm
L. seriolla	100	< 1	no	I	warm
Liatris punctata		R	no	N	warm
Linum perenne		0.1	yes	N	cool
Lygodesmia juncea		0.1	no	N	warm
Medicago sativa			no	I	cool
Melilotus officinalis	5		no	I	cool
Oenothera nuttallii	35		no	N	warm
Oryzopsis hymenoides	10		yes	N	cool
Panicum virgatum		0.1	yes	N	warm
Penstemon albidus		R	no	N	cool
Petalosteman purpureum	5	0.1	no	N	warm

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Phleum pratense		0.1	yes	I	cool
Poa pratensis		R	no	I	cool
Psoralea argophylla		10-25	no	N	warm
Ratibida columnifera		R	no	N	warm
Rosa woodsii		R	no	N	
Salsola kali	95	R	no	I	warm
Schizachyrium scoparium		1-5	yes	N	warm
Sisymbrium altissimum	85	0.1	no	I	cool
Stip comata	30	0.1	no	N	cool
S. viridula	10	0.1	yes	N	cool
Taraxacum officinale	15	0.1	no	I	cool
Tradescantia bracteata		R	no	N	cool
Tragopogon dubius	20	0.1	no	I	cool
Yucca glauca	10	R	no	N	

SITE II-A

Agropyron cristatum	100	5-10	yes	I	cool
A. dasystachyum	10	<1	no	N	cool
A. smithii	50	1-5	yes	N	cool
A. trachycaulum	5	0.1	no	N	cool
A. trichophorum	85	<1	no	I	cool
Ambrosia psilostachya	5	<1	no	N	warm
Artemisia dracunculus		0.1	no	N	
Artemisia frigida		<1	no	N	
Aster falcatus		R	no	N	warm

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Astragalus cicer		0.1	no	I	warm
A. lotiflorus		R	no	N	cool
Bromus spp.	95	0.1	no	I	cool
Bromus inermis	85	5-10	yes	I	cool
Calamovilfa longifolia		0.1	no	N	warm
Camelina microcarpa	30	0.1	no	I	cool
Cirsium undulatum	5	0.1	no	N	warm
Echinacea pallida		R	no	N	warm
Gaura coccinea		0.1	no	N	warm
Gutierrezia sarothrae	15	<1	no	N	
Kochia scoparia	15	0.1	no	I	warm
Lactuca serriola		0.1	no	I	warm
Medicago sativa	95	33-50	yes	I	cool
Melilotus officinalis		<1	yes	I	cool
Opuntia fragilis		R	no	N	cool
Penstemon albidus		R	no	N	cool
Poa pratensis	15	0.1	no	I	cool
Polygala alba		0.1	no	N	cool
Psoralea argophylla		0.1	no	N	warm
Salsola kali	5	0.1	no	I	warm
Sisymbrium spp.		R	no	I	cool
Sphaeralcea coccinea		0.1	no	N	cool
Stipa comata	10	0.1	no	N	cool
Stipa viridula	15	<1	yes	N	cool
Taraxacum officinale	15	0.1	no	I	cool
SITE II-B					
Atriplex canescens	15		yes	N	
Bromus inermis	100		yes	I	cool
Cirsium undulatum		R	no	N	warm
Conyza canadensis	5	R	no	N	warm
Erysimum asperum	5	R	no	N	cool
Lactuca serriola	15	R	no	I	warm
Psoralea argophylla		0.1	no	N	warm

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
SITE II-C[2]					
Agropyron cristatum	100	1-5	yes	I	cool
Artemisia frigida		R	no	N	
Bromus spp.	10	R	no	I	cool
Bromus inermis	100	5-10	yes	I	cool
Descurainia pinnata	5	R	no	N	cool
Kochia scoparia	5	R	no	I	warm
Lactuca pulchella		R	no	N	warm
Lactuca serriola	10	R	no	I	warm
Medicago sativa	90	1-5	yes	I	cool
Melilotus officinalis		0.1	yes	I	cool
Misc. annual forb		R	no		
Salsola kali		R	no	I	warm
Sisymbrium spp.	5	R	no	I	cool
Sitanion hystrix	5	R	no	N	cool
Taraxacum officinale	5	R	no	I	cool
Tragopogon dubius		0.1	no	I	cool
SITE II-D					
Agropyron cristatum	85	10-25	yes	I	cool
Androsace occidentalis	5	R	no	N	cool
Astragalus cicer	10	<1	yes	I	warm
Bromus spp.	5	R	no	I	cool
B. inermis	100	10-25	yes	I	cool
Descurainia pinnata	10	R	no	N	cool
Kochia scoparia	15	0.1	no	I	warm
Lactuca serriola	10	0.1	no	I	warm

	% Frequency / % Cover	Seeded	Native vs Introduced	Seasonality
Lithospermum incisum	5 R	no	N	cool
Medicago sativa	100 75-100	yes	I	cool
Melilotus officinalis	5-10	yes	I	cool
Misc. annual forb	5 R	no		
Onobrychis viciaefolia	R	no	I	cool
Salsola kali	10 0.1	no	I	warm
Taraxacum officinale	20 0.1	no	I	cool
Tragopogon dubius	5 0.1	no	I	cool
Trifolium repens	5 R	no	I	cool

SITE II-E

Agropyron cristatum	100 10-25	yes	I	cool
Bromus spp.	5 R	no	I	cool
Bromus inermis	100 10-25	yes	I	cool
Camelina microcarpa	5 0.1	no	I	cool
Festuca ovina	5 <1	no	I	cool
Lactuca serriola	15 0.1	no	I	warm
Medicago sativa	100 50-75	yes	I	cool
Melilotus officinalis	<1	yes	I	cool
Onobrychis viciaefolia	0.1	no	I	cool
Psoralea argophylla	<1	no	N	warm
Salsola kali	20 R	no	I	warm
Taraxacum officinale	10 0.1	no	I	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
SITE II-F					
Agropyron cristatum	100	1-5	yes	I	cool
A. dasytachyum	65	<1	yes	N	cool
A. elongatum	10	<1	yes	I	cool
A. smithii	35	0.1	yes	N	cool
A. trachycaulum		R	yes	N	cool
Ambrosia psilostachya	5	R	no	N	warm
Aster falcatus		R	no	N	warm
Astragalus cicer	5	1-5	yes	I	warm
Bromus spp.	90	R	no	I	cool
B. inermis	100	5-10	yes	I	cool
Dactylis glomerata	30	<1	yes	I	cool
Erysimum asperum		R	no	N	cool
Festuca octoflora		R	no	N	cool
F. ovina		R	yes	I	cool
F. pratensis	5	R	yes	I	cool
Gutierrezia sarothrae	15	R	no	N	
Hordeum jubatum		R	no	N	cool
Kochia scoparia		R	no	I	warm
Lactuca serriola	15	R	no	I	warm
Lithospermum incisum	5	R	no	N	cool
Medicago sativa	65	5-10	yes	I	cool
Melilotus officinalis		1-5	no	I	cool
Misc. annual forb		R	no		
Onobrychis viciaefolia	5	R	yes	I	cool
Poa sandbergii	5	R	no	N	cool
Psoralea argophylla		R	no	N	warm
Salsola kali	25	R	no	I	warm
Sisymbrium spp.		R	no	I	cool
S. loeselii		R	no	I	cool
Stipa comata	10	0.1	no	N	cool
S. viridula		R	yes	N	cool
Taraxacum officinale	20	R	no	I	cool
Tragopogon dubius	5	R	no	I	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
SITE II-G					
Agropyron cristatum	100	5-10	yes	I	cool
A. dasystachyum	40	<1	no	N	cool
A. smithii	25	<1	yes	N	cool
A. trachycaulum	35	<1	yes	N	cool
A. trichophorum	100	1-5	yes	I	cool
Ambrosia psilostachya		0.1	no	N	warm
Androsace occidentalis	15	R	no	N	cool
Artemisia cana		<1	no	N	
A. dracunculus		0.1	no	N	
A. frigida	5	<1	no	N	
Astragalus cicer		<1	yes	I	warm
Atriplex canescens	20	<1	yes	N	
Bouteloua gracilis		R	yes	N	warm
Bromus spp.	100	<1	no	I	cool
B. inermis	100	10-25	yes	I	cool
Camelina microcarpa	5	0.1	no	I	cool
Cirsium undulatum		R	no	N	warm
Descurainia pinnata		0.1	no	N	cool
Gaura coccinea		0.1	no	N	warm
Grindelia squarrosa	5	0.1	no	N	warm
Gutierrezia sarothrae	20	0.1	no	N	
Hedeoma hispida	10	0.1	no	N	cool
Kochia scoparia	25	0.1	no	I	warm
Lactuca serriola	10	0.1	no	I	warm
Medicago sativa		<1	no	I	cool
Melilotus officinalis	35	0.1	no	I	cool
Onobrychis viciaefolia	95	1-5	yes	I	cool
Oryzopsis hymenoides		R	yes	N	cool
Plantago patagonica	10	0.1	no	N	cool
Salsola kali		0.1	no	I	warm
Sisymbrium loeselii	50	0.1	no	I	cool
Taraxacum officinale	70	0.1	no	I	cool
Tragopogon dubius	20	0.1	no	I	cool
Yucca glauca		0.1	no	N	

	% Frequency / % Cover		Seeded	Native vs Introduced	Seasonality
SITE II-H					
Agropyron cristatum	90	10-25	yes	I	cool
A. dasystachyum	85	1-5	yes	N	cool
A. smithii	65	1-5	yes	N	cool
A. trachycaulum	35	<1	yes	N	cool
A. trichophorum	100	10-25	yes	I	cool
Amaranthus spp.		R	no		
Artemisia frigida	5	0.1	no	N	
Atriplex canescens	5	0.1	yes	N	
Bromus spp.	40	<1	no	I	cool
B. inermis	80	1-5	yes	I	cool
Camelina microcarpa	20	0.1	no	I	cool
Chorispora tenella		0.1	no	I	cool
Descurainia pinnata	10	0.1	no	N	cool
Eriogonum annuum		0.1	no	N	warm
Erysimum asperum		R	no	N	cool
Hordeum vulgare	80	<1	yes	I	cool
Kochia scoparia	85	0.1	no	I	warm
Lactuca serriola	15	<1	no	I	warm
Melilotus officinalis	45	10-15	no	I	cool
Onobrychis viciaefolia	95	5-10	yes	I	cool
Oryzopsis hymenoides		R	yes	N	cool
Plantago patagonica	5	0.1	no	N	cool
Ratibida columnifera	5	R	no	N	warm
Salsola kali	80	0.1	no	I	warm
Sisymbrium spp.	15	0.1	no	I	cool
S. loeselii	10	0.1	no	I	cool
Stipa viridula	15	0.1	yes	N	cool
Taraxacum officinale	35	<1	no	I	cool
Thlaspi arvense	5	R	no	I	cool
Tragopogon dubius	15	<1	no	I	cool
Triticum aestivum		0.1	yes	I	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Season-ality
SITE II-I					
Achillea millefolium	20	0.1	no	N	cool
Agropyron cristatum	65	1-5	yes	I	cool
A. dasystachyum	60	1-5	yes	N	cool
A. smithii	90	<1	yes	N	cool
A. trachycaulum	75	1-5	yes	N	cool
A. trichophorum	85	5-10	yes	I	cool
Alyssum alyssoides		R	no	I	cool
Androsace occidentalis	20	R	no	N	cool
Atriplex canescens	5	0.1	yes	N	
Avena fatua		R	no	I	cool
Bouteloua curtipendula		R	yes	N	warn
Bromus spp.	100	1-5	no	I	cool
B. inermis	75	1-5	yes	I	cool
Camelina microcarpa	80	0.1	no	I	cool
Chenopodium album		0.1	no	I	warm
Descurainia pinnata	60	0.1	no	N	cool
Kochia scoparia	35	0.1	no	I	warm
Lactuca serriola	65	0.1	no	I	warm
Linum perenne	65	0.1	no	N	cool
Melilotus officinalis	60	0.1	yes	I	cool
Misc. annual forb I		R	no		
Misc. annual forb II	20	0.1	no		
Misc. annual forb III	5	R	no		
Onobrychis viciaefolia	35	1-5	yes	I	cool
Plantago patagonica	5	0.1	no	N	cool
Polygonum douglasii	45	0.1	no	N	cool
Ratibida columnifera	15	R	no	N	warm
Salsola kali	45	0.1	no	I	warm
Sisymbrium spp.		R	no	I	cool
Stipa viridula	5	<1	yes	N	cool
Taraxacum officinale	20	0.1	yes	I	cool
Thlaspi arvense	30	0.1	no	I	cool
Tragopogon dubius	5	R	no	I	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
SITE III-A					
Agropyron cristatum	25	0.1	no	I	cool
A. dasystachyum	100	10-25	yes	N	cool
A. smithii	100	25-33	yes	N	cool
A. trachycaulum	40	1-5	yes	N	cool
Artemisia frigida		R	no	N	
Aster falcatus		R	no	N	warm
Astragalus gilviflorus		R	no	N	cool
Bromus spp.	15	0.1	no	I	cool
Camelina microcarpa	5	R	no	I	cool
Conyza canadensis		0.1	no	N	warm
Grindelia squarrosa		R	no	N	warm
Hordeum jubatum		0.1	no	N	cool
Kochia scoparia		0.1	no	I	warm
Lactuca serriola	45	0.1	no	I	warm
Medicago sativa		0.1	yes	I	cool
Melilotus officinalis	5	<1	yes	I	cool
Oryzopsis hymenoides	10	R	no	N	cool
Poa pratensis	5	R	no	I	cool
Ratibida columnifera		R	no	N	warm
Salsola kali	90	R	no	I	warm
Sisymbrium spp.	75	0.1	no	I	cool
Solidago missouriensis		R	no	N	warm
Taraxacum officinale	40	R	no	I	cool
Tragopogon dubius		R	no	I	cool
SITE III-B					
Agropyron cristatum	35	<1	no	I	cool
A. dasystachyum	90	10-25	yes	N	cool
A. elongatum		<1	no	I	cool
A. smithii	100	10-25	yes	N	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Agropyron trachycaulum	50	<1	yes	N	cool
Ambrosia psilostachya		<1	no	N	warm
Artemisia cana		<1	no	N	
Bromus spp.	70	1-5	no	I	cool
B. inermis	10	0.1	no	I	cool
Camelina microcarpa	15	0.1	no	I	cool
Chrysopsis villosa		0.1	no	N	warm
Chrysothamnus nauseosus var. *glabratus*		0.1	no	N	
Cirsium arvense		R	no	I	cool
C. undulatum		0.1	no	N	warm
Gaura coccinea		R	no	N	warm
Grindelia squarrosa	5	0.1	no	N	warm
Hedeoma hispida	5	0.1	no	N	cool
Helianthus petiolaris	5	R	no	N	warm
Hordeum jubatum		0.1	no	N	cool
Lactuca serriola	25	<1	no	I	warm
Lappula spp.	5	R	no	I	cool
Medicago sativa	25	<1	yes	I	cool
Melilotus officinalis	100	50-75	yes	I	cool
Mentzelia decapetala		0.1	no	N	cool
Oryzopsis hymenoides	5	0.1	no	N	cool
Pinus ponderosa		0.1	no	N	
Poa pratensis		0.1	no	I	cool
Populus deltoides		5-10	no	N	
Rumex crispus		R	no	I	cool
Salsola kali	5	0.1	no	I	warm
Sisymbrium altissimum	5	0.1	no	I	cool
S. loeselii	5	0.1	no	I	cool
Taraxacum officinale	25	0.1	no	I	cool
Tragopogon dubius	20	<1	no	I	cool
Yucca glauca		0.1	no	N	

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
SITE III-C					
Agropyron cristatum	55	1-5	yes	I	cool
A. dasystachyum	5	<1	no	N	cool
A. elongatum	45	1-5	yes	I	cool
A. smithii	20	<1	yes	N	cool
A. trachycaulum		0.1	no	N	cool
Bromus spp.	5	0.1	no	I	cool
B. inermis	45	<1	yes	I	cool
Camelina microcarpa		0.1	no	I	cool
Dactylis glomerata	25	<1	no	I	cool
Grindelia squarrosa		R	no	N	warm
Gutierrezia sarothrae		<1	no	N	
Kochia scoparia	5	0.1	no	I	warm
Lactuca serriola	15	0.1	no	I	warm
Medicago sativa	30	1-5	yes	I	cool
Melilotus officinalis	20	1-5	yes	I	cool
Poa pratensis	5	R	no	I	cool
Salsola kali	80	<1	no	I	warm
Stipa comata		0.1	no	N	cool
S. viridula	5	0.1	yes	N	cool
Taraxacum officinale	15	0.1	no	I	cool
Tragopogon dubius	20	<1	no	I	cool
SITE III-D					
Amaranthus spp.	25	R	no		warm
Artemisia frigida		R	no	N	
Astragalus lotiflorus		R	no	N	cool
Bromus spp.		R	no	I	cool
Grindelia squarrosa		R	no	N	warm
Lactuca serriola	20	R	no	I	warm
Melilotus officinalis		R	no	I	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Mentzelia decapetala		R	no	N	cool
Misc. perennial forb		R	no		
Poa pratensis		R	no	I	cool
Salsola kali	100	5-10	no	I	warm
Sphaeralcea coccinea		R	no	N	cool
Stipa viridula		R	no	N	cool
Taraxacum officinale		R	no	I	cool
Tragopogon dubius		R	no	I	cool
SITE III-E					
Agropyron cristatum	90	<1	yes	I	cool
A. dasystachyum	100	1-5	yes	N	cool
A. elongatum	10	<1	yes	I	cool
A. smithii	40	0.1	yes	N	cool
Ambrosia psilostachya		R	no	N	warm
Aster falcatus	20	<1	no	N	warm
Bromus spp.	80	<1	no	I	cool
B. inermis	60	1-5	yes	I	cool
Camelina microcarpa	5	R	no	I	cool
Chrysopsis villosa		0.1	no	N	warm
Chrysothamnus nauseosus	5	1-5	no	N	warm
C. nauseosus var. *glabratus*	100	10-25	no	N	warm
Cirsium undulatum		R	no	N	warm
Dactylis glomerata		R	yes	I	cool
Descurainia pinnata		R	no	N	cool
Festuca octoflora		R	no	N	cool
F. ovina	15	.1	no	I	cool
Gutierrizia sarothrae	5	.1	no	N	
Lactuca serriola	10	R	no	I	warm
Lepidium densiflorum		R	no	N	cool
Lithospermum incisum	5	R	no	N	cool

	% Frequency / % Cover	Seeded	Native vs Introduced	Seasonality
Medicago lupulina	R	no	I	cool
Melilotus officinalis	70 25-33	yes	I	cool
Misc. annual forb	R	no		
Salsola kali	5 R	no	I	warm
Sisymbrium spp.	5 R	no	I	cool
Solidago missouriensis	R	no	N	warm
Taraxacum officinale	25 0.1	no	I	cool
Tragopogon dubius	R	no	I	cool

SITE IV-A

Agropyron cristatum	85 1-5	yes	I	cool
A. dasystachyum	45 <1	yes	N	cool
A. elongatum	85 5-10	yes	I	cool
A. smithii	<1	yes	N	cool
A. trachycaulum	R	yes	N	cool
Ambrosia psilostachya	25 <1	no	N	warm
Astragalus cicer	40 10-25	yes	I	warm
Atriplex canescens	20 1-5	yes	N	
Bromus spp.	65 0.1	no	I	cool
B. inermis	100 5-10	yes	I	cool
Camelina microcarpa	5 R	no	I	cool
Chenopodium spp.	R	no		warm
Chrysopsis villosa	10 0.1	no	N	warm
Dactylis glomerata	<1	yes	I	cool
Descurainia pinnata	R	no	N	cool
Festuca ovina	65 5-10	yes	I	cool
Lactuca serriola	5 R	no	I	warm
Lepidium campestre	0.1	no	I	cool
Medicago sativa	50 1-5	yes	I	cool
Melilotus officinalis	<1	no	I	cool
Misc. annual forb	0.1	no		
Misc. perennial forb	R	no		
Oryzopsis hymenoides	R	no	N	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Penstemon albidus		R	no	N	cool
Petalostemon candidum		<1	yes	N	warm
Salsola kali		R	no	I	warm
Sisymbrium spp.		R	no	I	cool
S. altissimum		R	no	I	cool
Taraxacum officinale	45	0.1	no	I	cool
Tragopogon dubius	10	0.1	no	I	cool
SITE IV-B					
Agropyron cristatum	90	1-5	yes	I	cool
A. dasystachyum	20	0.1	yes	N	cool
A. elongatum	30	1-5	yes	I	cool
A. smithii		0.1	yes	N	cool
Astragalus cicer	25	25-33	yes	I	warm
Atriplex canescens	20	5-10	yes	N	
Bromus spp.	5	R	no	I	cool
B. inermis	100	10-25	yes	I	cool
Dactylis glomerata		<1	yes	I	cool
Festuca ovina	20	<1	yes	I	cool
Gutierrezia sarothrae		<1	no	N	
Lactuca serriola	25	0.1	no	I	warm
Medicago sativa		1-5	yes	I	cool
Onobrychis viciaefolia		R	yes	I	cool
Salsola kali	25	0.1	no	I	warm
Taraxacum officinale	20	0.1	no	I	cool
Tragopogon dubius	5	0.1	no	I	cool

	% Frequency / % Cover	Seeded	Native vs Introduced	Seasonality
SITE IV-C				
Agropyron cristatum	85	no	I	cool
A. dasystachyum	15	yes	N	cool
A. elongatum	85	no	I	cool
A. smithii	5	yes	N	cool
A. trachycaulum	10	yes	N	cool
Bromus spp.	15	no	I	cool
B. inermis	100	no	I	cool
Medicago sativa	100	yes	I	cool
Melilotus officinalis	5	yes	I	cool
Taraxacum officinale	5	no	I	cool
SITE IV-D				
Achillea millefolium	0.1	no	N	cool
Agropyron cristatum	80	no	I	cool
A. dasystachyum	40	yes	N	cool
A. intermedium	60	no	I	cool
A. smithii	70	yes	N	cool
A. trachycaulum	15	yes	N	cool
Artemisia cana	10	no	N	
A. dracunculus	0.1	no	N	
A. tridentata	R	no	N	
Aster spp.	0.1	no		
A. falcatus	20	no	N	warm
Bromus spp.	95	no	I	cool
B. inermis	100	no	I	cool
Camelina microcarpa	15	no	I	cool
Chrysopsis villosa	0.1	no	N	warm
Chrysothamnus nauseosus var. *glabratus*	<1	no	N	
Cirsium undulatum	0.1	no	N	warm
Grindelia squarrosa	5	0.1	no	N	warm

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Gutierrezia sarothrae		<1	no	N	
Kochia scoparia	25	0.1	no	I	warm
Koeleria cristata	5	R	no	N	cool
Lactuca serriola	20	0.1	no	I	warm
Medicago sativa		<1	yes	I	cool
Melilotus officinalis	10	R	yes	I	cool
Mentzelia decapetala		R	no	N	cool
Oryzopsis hymenoides	10	0.1	no	N	cool
Polygonum douglasii		R	no	N	warm
Ratibida columnifera	5	R	no	N	warm
Sisymbrium spp.	25	0.1	no	I	cool
Taraxacum officinale	30	0.1	no	I	cool

SITE IV-E

Agropyron cristatum		10-25	yes	I	cool
A. dasystachyum		<1	yes	N	cool
A. elongatum		1-5	yes	I	cool
A. smithii		<1	yes	N	cool
Bromus inermis		10-25	yes	I	cool
Dactylis glomerata		0.1	yes	I	cool
Gutierrezia sarothrae		0.1	no	N	
Medicago sativa		33-50	yes	I	cool
Melilotus officinalis		10-25	yes	I	cool
Onobrychis viciaefolia		<1	yes	I	cool
Taraxacum officinale		0.1	no	I	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
SITE IV-F					
Agropyron cristatum		5-10	yes	I	cool
A. dasystachyum		<1	yes	N	cool
A. elongatum		<1	yes	I	cool
A. smithii		0.1	yes	N	cool
Astragalus cicer		1-5	yes	I	warm
Bromus spp.		R	no	I	cool
B. inermis		25-33	yes	I	cool
Dactylis glomerata		<1	yes	I	cool
Gutierrezia sarothrae		<1	no	N	
Medicago sativa		50-75	yes	I	cool
Melilotus officinalis		R	yes	I	cool
Onobrychis viciaefolia		1-5	yes	I	cool
Salsola kali		0.1	no	I	warm
Taraxacum officinale		0.1	no	I	cool
SITE IV-G					
Agropyron cristatum	85	5-10	yes	I	cool
A. dasystachyum	50	1-5	yes	N	cool
A. elongatum	45	5-10	yes	I	cool
A. smithii	45	1-5	yes	N	cool
A. trachycaulum	5	<1	yes	N	cool
Ambrosia psilostachya	15	1-5	no	N	warm
Artemisia dracunculus		<1	no	N	
Astragalus cicer	65	25-33	yes	I	warm
A. missouriensis		R	no	N	cool
Atriplex canescens		1-5	yes	N	
Bromus spp.	90	5-10	no	I	cool
B. inermis	80	5-10	yes	I	cool
Calamovilfa longifolia		<1	yes	N	warm
Camelina microcarpa	20	0.1	no	I	cool

	% Frequency / % Cover		Seeded	Native vs Introduced	Season-ality
Chenopodium leptophyllum	5	0.1	no	N	warm
Chrysopsis villosa	10	<1	no	N	warm
Chrysothamnus nauseosus var. *glabratus*		<1	no	N	
Dactylis glomerata	25	<1	no	I	cool
Erysimum asperum		<1	no	N	cool
Festuca ovina	5	<1	no	I	cool
Gaura coccinea		R	no	N	cool
Gutierrizia sarothrae		<1	no	N	
Koeleria cristata		R	no	N	cool
Lactuca pulchella	45	1-5	no	N	warm
L. serriola	25	<1	no	I	warm
Linum rigidum	5	R	no	N	cool
Lithospermum incisum		0.1	no	N	cool
Medicago sativa	60	10-25	no	I	cool
Melilotus officinalis		1-5	yes	I	cool
Onobrychis viciaefolia		0.1	no	I	cool
Penstemon albidus		R	no	N	cool
Poa sandbergii		0.1	no	N	cool
Polygala alba		R	yes	N	cool
Psoralea argophylla		1-5	no	N	warm
Salsola kali	20	0.1	no	I	warm
Sisymbrium spp.	10	0.1	no	I	cool
S. altissimum		0.1	no	I	cool
Solidago missouriensis		0.1	no	N	warm
Stipa comata	5	0.1	no	N	cool
Taraxacum officinale	10	<1	no	I	cool
Tragopogon dubius	30	<1	no	I	cool
Yucca glauca		0.1	no	N	

	% Frequency / % Cover	Seeded	Native vs Introduced	Seasonality
CAPE OLIVER				
Achillea millefolium	15 <1	no	N	cool
Agropyron smithii	55 <1	no	N	cool
A. spicatum	90 5-10	no	N	cool
Ambrosia psilostachya	<1	no	N	warm
Aristida longiseta	10 0.1	no	N	warm
Artemisia cana	5 1-5	no	N	
A. dracunculus	5 R	no	N	
A. frigida	35 <1	no	N	
Aster falcatus	40 <1	no	N	warm
Astragalus adsurgens	40 <1	no	N	cool
Bromus spp.	70 <1	no	I	cool
Camelina microcarpa	5 R	no	I	cool
Chrysopsis villosa	0.1	no	N	warm
Cirsium undulatum	R	no	N	warm
Cryptantha celosioides	R	no	N	cool
Descurainia pinnata	15 0.1	no	N	cool
Draba reptans	5 R	no	N	cool
Erysimum asperum	10 0.1	no	N	cool
Gutierrezia sarothrae	80 1-5	no	N	
Kochia scoparia	R	no	I	warm
Koeleria cristata	75 1-5	no	N	cool
Lactuca pulchella	R	no	N	warm
L. serriola	40 0.1	no	I	warm
Linum perenne	10 0.1	no	N	cool
Lithospermum incisum	5 R	no	N	cool
Melilotus officinalis	80 5-10	no	I	cool
Misc. annual forb	15 R	no		
Panicum virgatum	15 0.1	no	N	warm
Petalostemon purpureum	R	no	N	warm
Pinus ponderosa	10-25	no	N	
Poa juncifolia	5 <1	no	N	cool
P. pratensis	70 1-5	no	I	cool
P. sandbergii	25 0.1	no	N	cool

	% Frequency / % Cover	Seeded	Native vs Introduced	Seasonality
Ratibida columnifera	25 <1	no	N	warm
Rhus trilobata	1-5	no	N	
Rosa woodsii	R	no	N	
Salsola kali	R	no	I	warm
Sitanion hystrix	5 0.1	no	N	cool
Solidago missouriensis	20 <1	no	N	warm
S. rigida	<1	no	N	warm
Stipa comata	60 1-5	no	N	cool
Taraxacum officinale	60 0.1	no	I	cool
Tragopogon dubius	50 <1	no	I	cool
Yucca glauca	15 1-5	no	N	
NATIVE RANGE				
Agropyron smithii	60 5-10		N	cool
Ambrosia psilostachya	45 5-10		N	warm
Androsace occidentalis	65 0.1		N	cool
Antennaria spp.	<1		N	
Aristida fendleriana	<1		N	warm
A. longiseta	5 1-5		N	warm
Artemisia cana	1-5		N	
A. frigida	20 0.1		N	
A. ludoviciana	10-25		N	
Bouteloua gracilis	45 <1		N	warm
Bromus spp.	100 1-5		I	cool
Calamagrostis montanensis	25 R		N	cool
Carex eleocharis	85 5-10		N	cool
C. filifolia	25 1-5		N	cool
C. pensylvanica	<1		N	cool
Chrysopsis villosa	10 0.1		N	warm
Conyza canadensis	10 0.1		N	warm
Delphinium bicolor	5 R		N	cool
Eriogonum annuum	25 <1		N	warm
Ergsimum asperum	25 1-5		N	cool

	% Frequency	% Cover	Seeded	Native vs Introduced	Seasonality
Evolvulus nuttallianus		<1		N	warm
Gaura coccinea	35	1-5		N	warm
Hedeoma hispida	20	0.1		N	cool
Koeleria cristata	65	5-10		N	cool
Lactuca serriola	10	<1		I	warm
Lithospermum incisum	45	<1		N	cool
Lygodesmia juncea		1-5		N	warm
Phlox hoodii		<1		N	cool
Plantago patagonica	40	<1		N	cool
Poa pratensis	5	1-5		I	cool
P. sandbergii	15	<1		N	cool
Polygonum spp.	5	R			
Psoralea argophylla	15	1-5		N	warm
P. esculenta		R		N	warm
Solidago mollis		1-5		N	warm
Sphaeralcea coccinea		1-5		N	cool
Stipa comata	100	25-33		N	cool
Taraxacum officinale	15	0.1		I	cool
Tradescantia bracteata		<1		N	cool
Tragopogon dubius	100	1-5		I	cool
Misc. annual grass		5-10			

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1 Shrubs and half shrubs were not classified as cool or warm.

2 Species lists from frequency and Sindelar and Plantenberg cover (1979).

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