



Nonseeded species invasion of twelve revegetated surface mined sites at Colstrip, Montana
by Donna Stangohr Lovell

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation

Montana State University

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Abstract:

In 1977 the Surface Mining Control and Reclamation Act (SMCRA) was passed requiring surface mining companies to "establish ...a diverse, effective, and permanent vegetative cover of the same seasonal variety. .. capable of self regeneration and plant succession at least equal in extent of cover to the natural vegetation of the native area." Nonseeded species play an important role in revegetation by increasing community diversity. Their voluntary encroachment onto revegetated minesoils is desirable to the mining industry since final bond release depends upon reclamation success.

The primary objective of this study was to identify factors that significantly affect nonseeded species invasion. Some factors known to affect encroachment of nonseeded species have already been established: direct hauling topsoil provides a live seed bank, excluding aggressive species from seed mixes limits competition, and properly utilizing management tools, such as grazing, reduces litter accumulation.

Analyses indicated that significant variables affecting nonseeded species invasion were the age of the reclaimed sites and the ratio of edge to interior of a field. Seeding mixtures and seeding rates also appeared to influence the number of invading species on these sites. Other variables analyzed were: topsoil depth, total soil depth, size of the field, season of planting, and distance from undisturbed, windward seed sources.

Subsampling was used in analyses instead of true replication. Statistical inferences should be limited to this project site. Nevertheless, the factors which revealed an influence on the invasion of reclaimed lands at Western Energy's Rosebud Mine warrant further investigation.

1

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by
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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency and is ready for submission to the College of Graduate Studies.

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ABSTRACT

In 1977 the Surface Mining Control and Reclamation Act (SMCRA) was passed requiring surface mining companies to "establish ...a diverse, effective, and permanent vegetative cover of the same seasonal variety...capable of self regeneration and plant succession at least equal in extent of cover to the natural vegetation of the native area." Nonseeded species play an important role in revegetation by increasing community diversity. Their voluntary encroachment onto revegetated minesoils is desirable to the mining industry since final bond release depends upon reclamation success.

The primary objective of this study was to identify factors that significantly affect nonseeded species invasion. Some factors known to affect encroachment of nonseeded species have already been established: direct hauling topsoil provides a live seed bank, excluding aggressive species from seed mixes limits competition, and properly utilizing management tools, such as grazing, reduces litter accumulation.

Analyses indicated that significant variables affecting nonseeded species invasion were the age of the reclaimed sites and the ratio of edge to interior of a field. Seeding mixtures and seeding rates also appeared to influence the number of invading species on these sites. Other variables analyzed were: topsoil depth, total soil depth, size of the field, season of planting, and distance from undisturbed, windward seed sources.

Subsampling was used in analyses instead of true replication. Statistical inferences should be limited to this project site. Nevertheless, the factors which revealed an influence on the invasion of reclaimed lands at Western Energy's Rosebud Mine warrant further investigation.

INTRODUCTION

In 1977 the Surface Mining Control and Reclamation Act (SMCRA) was passed. It requires that surface mined lands be returned to equal or higher land uses than those which existed prior to mining. An interest-free bond sufficient to cover the cost of reclamation must be posted before mine development; the bond is forfeited if the mine operator fails to complete reclamation. As various phases of reclamation are completed, such as recontouring of the landscape and topsoil replacement, parts of the bond can be released to the company.

Montana falls under the category of reclaimed areas receiving less than twenty-six inches of annual precipitation and is required to have a ten year bonding period after revegetation. Under SMCRA guidelines "a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area" must be established. Satisfactory revegetation, as described under this SMCRA guideline, is often the bottleneck in the bond release process.

In addition to requirements for a diverse, permanent cover, SMCRA also requires the establishment of grass species of the "same seasonal variety" (e.g. cool season or warm season) on the disturbed site. Seeding should occur during the spring and fall when moisture conditions are most favorable for seedling establishment. The seeding mixtures used at the Rosebud mine contain cool and warm season grasses;

consequently, the schedule of planting may affect seasonal dominance of grasses in the reclaimed stands.

Reclamation laws require the construction of landscapes which promote plant succession and sustain stable, productive plant communities. Secondary succession, as defined by Odum (1971) is influenced by previous plant growth and modified by environmental factors such as soil substrate. To enhance production and growth and to speed succession, the subsoil and topsoil are salvaged before mining and redistributed after regrading of the spoil material.

Redistributing direct haul topsoil to the regraded spoil area increases the total number of plant species as well as the frequency and numbers of nonseeded native species on mined land (King 1979). Nonseeded species are important in revegetation because they may establish on the reclaimed site thereby increasing community diversity and aiding in the successful reestablishment of plant communities.

Clements (1916) noted that, "From the very nature of migration, invasion is going on at all times and in all directions." This invasion, or encroachment, is affected by a number of other factors. For example, Van Zalingen (1987) found that the distance between revegetated sites and undisturbed areas is significant in the invasion of windborne, nonseeded species in alpine stands. Other physical factors affecting the encroachment of native species include soil conditions, slope stability, and aspect (Van Zalingen 1987).

Encroachment is also affected by management practices. For example, native species are inhibited when seeded in mixtures containing even a low proportion of aggressive, introduced or naturalized species (DePuit et al. 1978).

The age of a reclaimed site may also affect species diversity. Sindelar (1980) found a decline in species diversity after year three as the initial flush of weedy and nonadapted seeded species disappeared. Another study showed an increase in diversity over time as unseeded species migrate onto mined lands (Sindelar and Plantenburg 1977).

This study examines factors affecting the invasion of nonseeded species onto twelve sites seeded with native species. Six sites were seeded in the spring and six were seeded in the fall. Seeding rates, mixes, methods, ratio of edge to interior, and size of reclaimed fields are factors which may influence the invasion of species on reclaimed minelands. Some of these factors can be manipulated by the reclamation specialist to enhance diversity, thereby improving the probability of obtaining final bond release.

Objectives of this study on surface mined land were to:

- 1) determine the effects of management practices on the invasion of nonseeded species onto sites seeded with native species.
- 2) provide recommendations for promoting the invasion of desirable nonseeded species.

LITERATURE REVIEW

Succession of Plant Communities on Mined Lands

Under the guidelines of SMCRA, soil salvage is required prior to mining with soil replacement occurring after resource extraction. This promotes secondary succession which approaches a climax community more rapidly than primary succession (Odum 1971). During secondary succession, communities begin to develop with weedy pioneer species appearing first. These early pioneers are replaced by a series of more mature communities until a relatively stable community is reached. This general pattern of old field succession is well documented (Golly 1965, Bazazz 1975, Odum 1971).

Pioneer species have many adaptations that increase their initial competitive advantage. Pioneers tend to be xerophytic, frost hardy, light and heat tolerant, and to have extensive taproots to withstand droughty conditions. In addition, they produce large quantities of seed that are adapted for long range dispersal. They also have a short life cycle (Smith 1940). By the time succession has reached a stage of dense vegetative cover, as early as the second year after disturbance, conditions no longer favor the establishment of small fast-growing seedlings (Daubenmire 1968).

Pickett and Bazzaz (1978) showed that early successional annuals had broad responses to moisture gradients supporting

the utilization of broad, overlapping niches. With the presence of annual grasses such as Bromus japonicus (Japanese brome) on younger sites, Romo and Eddleman (1987) theorized that this brome could limit growth and establishment of seeded perennials which have narrower niches. They found that emergence of native bunchgrasses, Agropyron spicatum (bluebunch wheatgrass) and Koleria cristata (junegrass), was not significantly limited by Japanese brome competition. However, Sitanion hystrix (Squirreltail) emergence was significantly better in control plots without brome. Root, crown, foliage, and total biomass were reduced for all three species when grown with Japanese brome.

Since Bromus japonicus germinates in the autumn or early spring, it may have a competitive advantage over perennials seeded during these seasons. Romo and Eddleman (1987) suggested that perennial seedling mortality could be high in future years where Japanese brome is prevalent. On mined land at Colstrip, Montana, second year mortality of bluebunch averaged 46%, squirreltail 52%, and Junegrass 100% (Eddleman, unpublished data in Romo and Eddleman, 1987). But Parish and Bazazz (1982) stated that because of their broadly overlapping niches, the competition of annual species was more intense when grown together than when grown with the more specialized prairie species.

Pioneer species are replaced by perennial forbs whose dominance in the community increases annually (Costello,

1944). The perennial forb stage is followed by an increased abundance of perennial grasses with the number of species increasing as climax is approached.

One goal of reclamation is to speed up the processes of secondary succession using cultural and management practices to bypass the initial weedy stages of community development. Clements (1916) stated, "It is a universal law that all bare places give rise to new communities..." and open communities are readily invaded whereas closed communities are rarely invaded. Initial stages of succession provide managers with the opportunity to implement strategies that leave the community open for invasion. Once established, the community closes and there is little chance of invasion unless another disturbance occurs which would create new openings.

Effects of Age on Succession

Plant community succession is governed by complex, interrelated environmental and biotic factors as they interact over time (Golley 1965). This interaction makes it difficult to ascribe an observed effect to any particular factor. No single factor was of overall importance in the revegetation of unreclaimed Oklahoma coal strip mines ranging in age from 10 to 70 years (Gibson et al. 1985). Site age was relatively unimportant as an environmental variable in determining species composition whereas site latitude and substrate factors were closely related to the mine-site communities.

Sindelar (1981) found the rate of succession on mined

soils in eastern Montana to be "less than that required to assure stability of composition within a 10-year bonding period." His conclusions were based on plantings established between 1969-1977 that included aggressive introduced species. He suggested that newer seedings, post SMCRA, should prove more successful when introduced aggressive species were excluded from the seed mixes.

Productivity, Cover and Age

Productivity on mined land is not generally a concern since yields can double those of native range (1000 kg/ha on unmined rangeland), (Munshower and Neuman 1983). This enhanced productivity was attributed to introduced grasses and legumes selected for forage production. However, a decline in productivity was noted after age four probably as a result of litter buildup. Schafer et al. (1980) showed litter accumulation to be common on minesoils under pioneer vegetation resulting in wide C:N ratios, reduced available N, successional stagnation, and eventual reduced plant community production. An early peak in cover on mined lands was attributed to the growth of annual and biennial species. Cover of perennial species on mined lands was substantial but Sindelar (1981) reported that it did not reach levels equal to native range within ten years.

Microsites, Diversity and Age

Clements (1916) stated that community diversity may be positively influenced by simple variations in spatial heterogeneity such as a rock outcrop, a change in exposure, an ant-heap, a plow furrow or wheel tracks. Similarly, Billings and Bliss (1959) concluded that the micro-zonation of species and communities on the alpine tundra is largely a function of the depth and melt-rate of snowbanks. The slow summer melting of accumulated snow results in steep environmental gradients over a relatively small area. These gradients produce similarly steep vegetational gradients, with respect to floristics and productivity.

Wagner et al. (1978) found species diversity to be much greater on unmined sites than on all unreclaimed spoil banks of different ages in an abandoned coal mine in New Mexico. Of the species present, a relative Importance Value of 64 percent was calculated for annual species on spoils and only five percent for unmined sites. These mined sites were from one to thirteen years old but were still in a very early seral stage as shown by the low species diversity and short-lived taxa. No significant difference in species diversity was found between mined sites of different ages. However, there was a trend from many annuals and few perennials on newly mined sites toward fewer annuals and more perennials on older sites.

Sindelar (1981) reported that after ten years, diversity on revegetated sites was lower than that of native range sites

in SE Montana. The number of perennial grass species on mined land was similar to the number on unmined areas. Annual and biennial forb composition on mined land was comparable to native range at Colstrip, MT, whereas shrub and halfshrub composition was somewhat less than that of native range. The greatest difference between native range and revegetated areas was in the number of perennial forb species present. Compared with native range, the number of perennial forbs was very low on mined areas. This lower number of perennial forbs was attributed to the limited number of habitats available and homogenization of soils following mining and recontouring of the terrain.

Post mining soil has been depleted of micro-habitats necessary to encourage community diversity and lacks structure (Schafer et al. 1980). Post mining landscapes and soils are homogenized into a single 'habitat'. Habitat and population act and react upon each other alternating as cause and effect. "The factors of the habitat are the causes of the responses... of the community, and these are the causes of growth and development, and hence of (plant community) structure." (Clements 1916). A limited number of factors in the habitat restricts the number of community responses thereby limiting growth and development of the plant community.

Season of Planting

Reclamation laws require vegetation to be of the same seasonal variety (e.g. cool season or warm season) as that found on the area before mining. For successful seedling establishment, seeding should be initiated under the most favorable moisture conditions. DePuit et al. (1978) reported the superiority of spring versus fall seeding but this was due to higher rates of establishment of introduced species. Fall germination was poor for those same introduced species thus enabling native plants to establish a more diverse plant community.

Rennick and Munshower (1985) studied the effects of seeding date on the structure of plant community reestablishment. Perennial warm season grasses did the poorest of all life forms for all seeding dates. Warm season grasses were found only on the spring seeded plots where their composition was less than one percent. By comparison, the composition of this lifeform on native range is from 2.5 to 5.1 percent. An important point raised was the difficulty of attributing an impact on community structure to any one factor, such as time of seeding, when so many other variables may be influencing species composition as well (soil handling practices, precipitation, edaphic conditions, etc.).

Amount of Field Edge

Landscapes, as ecological units with structure and function, are composed of patches which differ in origin and dynamics. Size, shape, and spatial configuration of patches are important (Forman and Godron 1981). In 1964 Simpson formulated the hypothesis that penninsular species diversity decreases with distance from the mainland as a consequence of colonization-extinction equilibrium and the shape of the land mass. Milne and Forman (1986) concurred that the shape of a patch may exert an effect on species diversity patterns within it. They found the greatest rate of decline in species richness on penninsulas was within the first 2000 m from the mainland. This led to the conclusion that landscape configuration and patch geometry are factors which have major ecological consequences.

Patch area alone has been found to be an important determinant of species diversity, and species groups such as trees, seed-eating birds and insectivorous birds respond differently to patch area (Elfstrom 1976, Forman et al. 1976). Landscape patches affect productivity, nutrient and water flux, and species dynamics (Forman and Godron 1981).

Mining related disturbances are introduced patches under Forman's classification system (1979b). These patches are dominated by individuals (species) introduced into a matrix, or series of landscapes, by human manipulation. Even though the species used today in seeding mixtures are primarily, if

not entirely, native species, the patch and resulting community have been introduced into the surrounding matrix. Succession will proceed until the matrix converges with the patch in species similarity with the patch disappearing with time (Forman 1979b). On mined lands, however, such widespread disturbance leaves little natural matrix with which the introduced patches can converge.

These remnant patches of mined land are terrestrial islands in a matrix of native and reclaimed rangeland. Much work on island biogeography (MacArthur and Wilson 1967, Carlquist 1974, Pickett and Thompson 1978) has shown the number of species on an island is related directly to three factors, in order: the island area, its isolation, and its age. The greatest diversity is found on smaller islands which have a greater edge to interior ratio. The micro-environment in the center of an island, or a field, will be different than the microenvironment at the edge largely due to the effects of wind and the surrounding matrix (Forman and Godron 1981). Several factors affect the width of the patch edge with the angle of the sun playing a major role. Edges facing toward the equator are typically wider than those facing toward the pole, and patches in temperate areas are generally wider than in tropical areas (Wales 1972).

The degree of species difference between the patch and matrix is also significant. The patch edge varies in width

from a few meters to a few tens of meters in patches at the landscape level (Forman and Godron 1981).

Patch shape is important as a target for dispersal. A large square patch is mostly interior with bands of edge at the outer portions of the patch. A rectangle patch of the same size has proportionally less patch interior and more patch edge. A narrow strip patch of the same size may be all edge. Since community and population characteristics differ between the interior and the edge, comparing these characteristics with the interior-to-edge ratio of patches may be useful in evaluating the importance of patch shape in a landscape. Furthermore, the spatial configuration among the patches present may be just as important as the number of patches (Forman and Godron 1981).

Distance From Undisturbed, Windward Sites

Some seeds are not adapted for migration and travel only a short distance from the parent plant before coming to rest, others are adapted for long distance dispersal. All species benefit occasionally from accidental means of dispersal (Gleason 1926). Gibson et al. (1985) reported large numbers of wind and bird dispersed species on unreclaimed strip mines suggesting that dissemination efficiency is an important factor in determining initial colonization. Gibson (1982) also observed colonization in Oklahoma coal mine spoil by plants that were adapted for long-distance, or efficient, seed dispersal. Leisman (1957) and Harrington (1982) have

emphasized the importance of the surrounding vegetation and the dissemination efficiency of propagules on spoil banks. Availability of seed from undisturbed sites is a function of wind direction, seed source quality, quantities of available seed, duration of seed dispersal, and dispersal distance (Zasada 1971).

Van Zalingen (1987) found that as the distance from the nearest windward undisturbed area increased, the percent cover of native species significantly decreased. As previously cited, the windward side provides the greatest amount of edge and microhabitats thereby potentially increasing diversity (Forman and Godron 1981).

Topsoil

Topsoil is salvaged and returned to the recontoured spoil as required under the guidelines of SMCRA. Nevertheless, surface mining affects soil chemistry, soil properties, and disrupts microbial activity. Due to human influence, minesoils differ from natural soils in their lack of structure, lower organic carbon content, and unconsolidated rock fragments (Schafer et al. 1980). Although minesoils may have been altered considerably, studies have shown that adding even a few centimeters of surface soil improves infiltration and vegetative production of minesoils (Power et al. 1974). Varying the depth of topsoil across the landscape, instead of in a uniform layer, would enhance environmental heterogeneity and thus diversity.

Soil depth requirements for reestablishing perennial cool-season grass production have been studied extensively by Barth (1984). The depth required to maximize forage production averaged 50 cm over generic spoil. McGinnies and Nicholas (1980) also found the thickness of topsoil material directly influenced plant growth up to a depth of 46 cm. However, these findings may be inconclusive compared with sites having all native species. Both studies used Agropyron desertorum (crested wheatgrass) in the seed mix. This species is an introduced, aggressive grass which can dominate a site when seeded even in small proportions (DePuit et al. 1978).

Topsoil that has not been stockpiled is an effective supplier of nonseeded species (King 1980). King found an increase in the total number of species, nonseeded species, and nonseeded native species on a direct haul site versus stockpiled sites. His data indicated that properly handled topsoil can increase the number of total species and the frequency of nonseeded native species on revegetated mined land. However, canopy cover of nonseeded native species were not significantly increased by topsoiling.

Cultural Practices and Diversity

The requirement to reestablish diversity within the ten year bonding period is the most challenging aspect of revegetation on western mined lands today. Reclamation managers must make decisions which can positively influence the outcome of revegetation efforts and which are cost

effective. Some cultural aspects of reclamation such as seeding mixtures, seeding rates, methods, and mulching practices can influence revegetation costs and success.

A study conducted from 1977 to 1979 evaluated the establishment of diverse native plant communities as influenced by seeding methods, mixtures, and rates (Depuit et al. 1980). They reported diversity had attained a level within the range of native plant communities of the Colstrip, Montana area within two years. However, by the third growing season diversity declined substantially with the loss of pioneer species. This is evidence that initial diversity levels are not necessarily indicative of diversity levels in later stages of plant community development.

Broadcast seeding at twice the drill seed rate initially promoted higher diversity, however, this relationship between diversity and seeding method disappeared by the third growing season. This initial increase in diversity with broadcast seeding may have been a result of the greater number of favorable microsites created. A rough seedbed is used when broadcast seeding and provides variable depth seeding necessary with different seed sizes and creates a greater number of favorable microsites for seedlings (Call and Roundy 1991). Seedling recruitment is a result of the number of seeds in favorable microsites in the seedbed rather than the total number of available seeds (Young 1988). These favorable microsites have been termed "safesites" by Harper (1977) and

may occur naturally in gravel or as cracks and depressions in the soil.

Depuit et al. (1980) found that heavier seeding rates for broadcast and drill seeding exerted a negative effect on plant community diversity. This was attributed to reduced evenness of cover among seeded species with a few rate-responsive species dominating.

Increasing the number of species seeded is a way of trying to compensate for a lack of understanding of plant-site relationships (Vallentine 1989). An increase in the number of species seeded did, however, result in increased plant community diversity during the first three years of their study (Depuit et al. 1980).

When two competing individual plants are of the same species, each may be affected equally by the presence of the other because of the similarity in their genetic identity and capabilities of utilizing a given resource. Species sown in mixtures should be chosen on the basis of ecological evidence that they can coexist (Pyke and Archer 1991). When the number of species seeded is increased, niche overlap should be reduced.

Research by Parish and Bazazz (1982) supported the theory that niche reduction and separation can effectively reduce competition within a community, and that selection to reduce competition was more important in the evolution of late-successional species than for early successional species.

Their competition study showed that prairie species have a higher relative yield in mixed stands versus homogenous stands. These findings were consistent with their prediction that late-successional species should use relatively more of the total resources available in mixed stands. If resources are sufficiently heterogeneous, would be competitors in a more homogeneous environment may coexist via small scale spatial segregation (Tillman 1982)..

Using a nurse crop as a temporary stabilizer is not recommended for areas receiving less than 30 cm of annual precipitation due to competition for moisture between the grass seedlings and the nurse crop (Munshower 1991). Instead, a crimped straw mulch is recommended for these regions.

However, root penetration creates microsites that add diversity to the post-mining soil profile. Schuman et al. (1991) found the use of a stubble mulch (Hordeum vulgare) in south central Wyoming resulted in greater seeded grass production and had significantly greater water infiltration than the crimped straw mulch treatment. The small grain crop may have improved the physical condition of the revegetated soil through root penetration leading to greater water infiltration.

METHODS AND MATERIALS

Data Collection

Twelve revegetated surface mined sites at Western Energy's Rosebud mine in southeast Montana were chosen for this study on the basis of age and available historical data. These data included seed mixes, methods, rates, soil depths, and time of planting. These twelve sites were divided into six pairs of spring and fall seeding dates and were either directly adjacent to one another or within the same mine area (Figure 1). Ages of the fields ranged from two to eleven years. Samples were collected twice in 1991, in late May, to estimate the cover of early forbs and again in late July to measure standing biomass by lifeform as well as percent cover of the dominant species.

Acreages ranged from 1.6 ha (4 a) to 11.3 ha (28 a). To limit bias, each field was visually divided into fourths and a stake was set at a central point for each quarter. Each sample location was placed at a randomly selected distance and direction from the central stake.

Percent canopy cover was measured using Daubenmire (1959) coverage classes. Cover data were collected by placing twenty frames (20 x 50 cm) in each field, five within each quarter, and recording areal cover in each frame by species. The number of sample frames was based on species area curves. To be consistent and to provide 'replication', the number of frames per field was held constant at twenty.

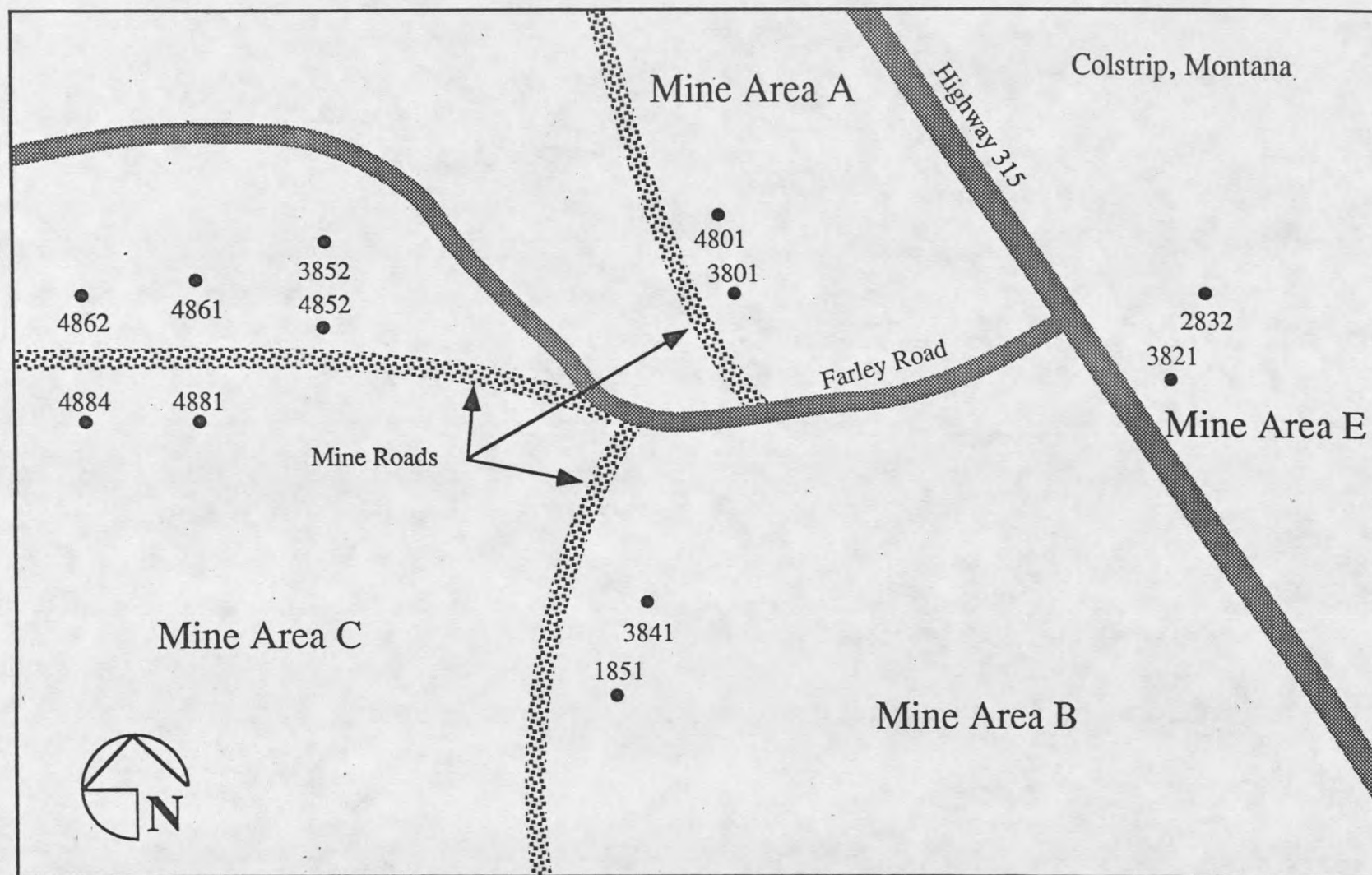


Figure 1. Diagram of the Rosebud Mine areas and study site locations.

In late July canopy cover as well as standing biomass were measured. For species encountered both times, the record with the greatest amount of cover was entered into the data base.

Vegetation was clipped to approximately 1 cm from the ground to estimate standing biomass by lifeform. Vegetative litter was also collected. After estimating cover, a 50 X 50 cm frame was laid on top of the left edge of the cover frame. The plants were clipped by lifeform, put into appropriately marked paper sacks, and oven dried for forty-eight hours at 56°C and then weighed.

Seeding mixtures were known for each field. Each species encountered in a frame was entered into the data base as either seeded or nonseeded to determine invading species.

Distances from undisturbed sites were taken from maps provided by Western Energy Company. Two directions were measured for the prevailing wind. The dominant wind usually rises from the northwest but as summer approaches it becomes more southeasterly (Mitchell and Super 1972).

The ratio of edge to interior of a field was calculated from Western Energy maps. The field's circumference, or edge, was measured and divided by the area within each field giving a ratio of the edge to interior (m/ha).

Topsoil and subsoil samples were collected for each site by Dana Nile of WECO and shipped to Montana State University. Samples were analyzed at the Reclamation Research laboratory

for pH, EC, and for textural class using methods described in Methods of Soil Analysis (Gee and Bauder 1986)

Seeding Histories

Each field was assigned a seeding 'code' to simplify analysis of the seeding variables. Western Energy Company's reclamation mixes fall into one of four categories:

- 1) Upland mix: composed of cool and warm season native grasses.
- 2) Cover: a nurse crop of either wheat or wintergraze.
- 3) Supplemental mix: primarily perennial forbs.
- 4) Warm season mix: warm season grass species.

Table 1 provides a summary of the seeding history for all fields used in this study. Seeding variables are listed in the order referred to above.

Statistical Analysis

Data used in statistical analyses included information provided by Western Energy Company's reclamation records as well as cover and production data collected during 1991. Analyses consisted primarily of covariance analysis using the General Linear Model (GLM) procedure in SAS (Version 6.03, SAS Institute, Cary, NC, 1983). Variables were considered significant when P-values were 0.10 or lower. Analyses were done at the frame level to provide replication. I acknowledge that this is not true replication and therefore the data will be interpreted to establish trends on these sites rather than to infer absolute conclusions of reclaimed sites in general.

Dependent variables were percent areal cover, productivity of standing biomass, and percent invading species. Independent variables were age of fields, season of planting, ratio of edge to interior of fields, soil depths, and distance from undisturbed windward sites from the northwest and southeast.

Seeding methods, mixes, and rates were not included in models for analysis of variance; each field was uniquely defined by a combination of these variables. These variables are discussed in the text.

Table 1. Seeding history of fields.

Field	Seed rate (kg/ha PLS)	Seed mix*	Seed method**	Age of field- season
3801	8-1-0-0***	18-37-0-0	2-2-0-0	10-F****
4801	30-4-0-0	18-37-0-0	2-2-0-0	10-S
1851	44-0-13-0	22-0-24-0	1-0-2-0	6-S
3841	25-2-16-0	22-37-25-0	1-1-2-0	7-F
3852	23-0-10-0	22-0-25-0	1-0-2-0	6-F
4852	12-0-8-0	28-0-27-0	1-0-2-0	5-S
4861	16-0-11-30	28-0-27-26	1-0-2-2	5-F
4862	22-0-6-30	29-0-30-26	1-0-2-2	4-S
4884	13-0-8-0	33-0-30-0	1-0-2-0	2-S
4881	22-0-5-0	33-0-30-0	1-0-2-0	3-F
2832	33-7-21-0	19-36-20-0	1-2-2-0	8-S
3821	67-10-0-0	19-36-0-0	1-1-0-0	9-F

* See table 59, Appendix C; numbers refer to mixes.

** 1=drill

2=broadcast.

*** Refers to the type of mix, i.e. upland, cover, supplemental, and warm season.

****F=fall seeding

S=spring seeding.

SITE DESCRIPTION

The study area is located in southeastern Montana near the town of Colstrip at Western Energy Company's Rosebud Mine. Twelve topsoiled sites ranging in age from two to ten years were chosen on the basis of age and available historical data. Six of these sites were in Area C of the Rosebud Mine, two in Area A, two in Area B, and two in Area E (Figure 1).

Colstrip is located along the east fork of Armell's Creek at approximately 980 m above sea level. This area has a semiarid, continental climate, with annual precipitation averaging 40 cm most of which occurs from April to June. Streams generally flow intermittently and major channels drain northerly into the Yellowstone River. The landscape is dominated by rolling prairie with sandstone bluffs, broad valleys, footslopes, and stream terraces. The vegetation is characterized by mixed prairie and pine savanna typical of southeastern Montana.

Native soils are usually sandy or loamy, and poorly developed with a general absence of a B horizon. They are classified as Ustic Toriorthents, Borollic camborthids, Aridic haploborolls, and Ustic torrifluvents.

Results and Discussion

Results

Each of the twelve fields in this study has a unique set of characteristics that define its history and therefore influence its present state. Such variability among sites makes it difficult to directly imply cause and effect to the observed results. Nevertheless, these data should be used to support further research for improving diversity on mined lands.

Significance tests were run to determine effects on percent areal cover, standing biomass, and percent invading species. Independent variables analyzed were: age, season of planting, ratio of edge to interior of fields, field size, top soil depth, total soil depth and distance from northwest and southeast undisturbed sites.

A descriptive summary of each field is presented in the text, management practices are noted when applied. Statistical results are presented and should be limited to the scope of this study.

Field 3801

This field is one of the two sites in area A of the Rosebud mine (Figure 1). It was fall seeded in October of 1981 with an uplands mix at 8.5 kg/ha (7 lb/a) pure live seed (PLS), and a cover crop of wheat at 1.5 kg/ha (1.3 lb/a). Both mixes were broadcast seeded (Table 1). Four species were in the uplands mix and only Agropyron trachycaulum (slender wheatgrass), was not found on the site. This was not surprising since this species usually disappears by the third or fourth growing season (S.C.S. 1988). Agropyron smithii (western wheatgrass) and A. dasystachyum (thickspike wheatgrass) were not differentiated in the field and were considered collectively as Agropyron smithii for this study. The total number of species within frames for this field was thirty-five; of this total thirty-two were invaders. Table 2 summarizes variables for this field.

Table 2. Summary of field 3801.

Age	10 years
Time of planting	October 1981
Ratio of edge to interior	377 m/ha
Size of field	1.6 ha
Topsoil depth	30 cm
Total soil depth	102 cm
NW distance from undisturbed area	810 m
SE distance from undisturbed area	268 m
Total species seeded	4 + cover
Total species within frames	35
Invading species within frames	32
Floristic richness*	14

*Based on species having >1% cover.

Field 3801 had the greatest number of invading species for all fields in this study. It was one of three fields to be seeded with an uplands mixture containing only four species plus a cover crop. A cover crop is generally an annual grain crop such as Triticum aestivum (wheat) which provides rapid soil stabilization but which dies out within a few growing seasons. The seeding rate for this field was the lowest reported for this study (Table 1).

Table 3 lists the species seeded, their percentage of the mix, and their percent composition, by cover, at the time of this study. Species are noted by four character abbreviations throughout this report and are defined in Table 50. Table 4 summarizes canopy coverage data by species for field 3801. Table 5 lists all species observed throughout the field, their origin (native or introduced), and whether or not they were an invading species.

Table 3. Species seeded in field 3801 with percent composition recorded at the time of study.

Species and variety	Percent of mix	Percent composition*
Mix 18: Uplands mixture		
AGTRA**	5	0
AGSM Rosanna/AGDA	40/25	8
STVI	30	16
Mix 37: Cover crop		
TRAE	100	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 5).

**See Table 50.

Table 4. Summary of data by species for field 3801.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
ACMI**	Y	5	0.13	0.56	0
AGCR	Y	5	0.13	0.56	0
AGSM	N	95	10.25	11.12	8
AGTRA	N	5	0.13	0.56	0
AMPS	Y	10	0.88	3.37	0
ARDR	Y	15	0.38	0.92	0
ARDU	Y	5	0.75	3.35	1
ARLU	Y	10	2.63	8.87	2
ASCI	Y	5	1.88	8.39	1
BOGR	Y	5	0.13	0.56	0
BRIN	Y	5	0.75	3.35	1
BRJA	Y	100	31.50	15.88	24
BRTE	Y	100	5.63	5.55	4
CAFI	Y	5	0.13	0.56	0
DRRE	Y	5	0.13	0.56	0
ERAS	Y	10	0.88	3.37	1
ERST	Y	20	3.50	9.23	3
GUCO	Y	10	0.25	0.77	0
KOPY	Y	5	0.13	0.56	0
LASE	Y	60	1.50	1.26	1
MEOF	Y	40	28.25	42.59	22
MESA	Y	5	3.13	13.98	2
MOSS	Y	30	1.38	3.39	1
ONVI	Y	15	0.38	0.92	0
OXSE	Y	5	0.13	0.56	0
PEPU	Y	5	0.75	3.35	1
PLPA	Y	15	4.63	14.38	4
POCO	Y	10	0.25	0.77	0
PSES	Y	15	4.63	14.38	4
STCO	Y	20	1.75	4.60	1
STVI	N	60	21.13	29.71	16
TAOF	Y	5	0.13	0.56	0
TRDU	Y	35	2.13	4.54	2
VUOC	Y	5	0.13	0.56	0
YUGL	Y	5	0.13	0.56	0
BARE	X	100	4.38	4.58	X
LITR	X	100	95.00	5.13	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the total cover for the site.

**Table 50.

Table 5. Complete species list of field 3801.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X		X	
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>Ambrosia psilostachya</u>	X		X	
<u>Artemisia cana</u>	X		X	
<u>A. dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>A. ludoviciana</u>	X		X	
<u>A. tridentata</u>	X		X	
<u>Astragalus crassicaupus</u>	X		X	
<u>A. cicer</u>		X	X	
<u>Bouteloua gracilis</u>	X		X	
<u>Bromus inermis</u>		X	X	
<u>B. japonicus</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Carex fillifolia</u>	X		X	
<u>Cirsium undulatum</u>	X		X	
<u>Draba reptans</u>	X		X	
<u>Echinacea pallida</u>	X		X	
<u>Erysimum asperum</u>	X		X	
<u>Gaura coccinea</u>	X		X	
<u>Gutierrezia sarothrae</u>	X		X	
<u>Heterotheca villosa</u>	X		X	
<u>Koeleria pyramidata</u>	X		X	
<u>Lactuca serriola</u>		X	X	
<u>Leucocrinum montanum</u>	X		X	
<u>Liatris punctata</u>	X		X	
<u>Lithospermum incisum</u>	X		X	
<u>Melilotus officinalis</u>		X	X	
<u>Onobrychis viciaefolia</u>		X	X	
<u>Oxytropis sericea</u>	X		X	
<u>Petalostemon purpureum</u>	X		X	
<u>Poa compressa</u>		X	X	
<u>Polygala alba</u>	X		X	
<u>Psoralea argophylla</u>	X		X	
<u>P. esculenta</u>	X		X	
<u>Rosa woodsii</u>	X		X	
<u>Solidago spp.</u>	X		X	
<u>Stipa comata</u>	X		X	
<u>S. viridula</u>	X		X	
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Yucca glauca</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

Management practices on this site include the application of fertilizer one month after seeding, and grazing during summers since 1985.

Field 4801

This site is adjacent to 3801 (Figure 1) and was seeded in February, 1981 with an uplands mix and a wheat cover crop at 30.3 kg/ha PLS (25 lb/a) and 3.9 kg/ha PLS (3.2 lb/a), respectively. Both mixes were broadcast seeded (Table 1). Of the four species seeded, again, only Agropyron trachycaulum was not observed in the field.

The number of species within frames totaled nineteen, seventeen of these were invader species. Table 6 summarizes variables for this field.

Table 6. Summary of field 4801.

Age	10 years
Time of planting	February 1981
Ratio of edge to interior	238 m/ha
Size of field	2.8 ha
Topsoil depth	36 cm
Total soil depth	89 cm
NW distance from undisturbed area	933 m
SE distance from undisturbed area	350 m
Total species seeded	4 + cover
Total species within frames	19
Invading species within frames	17
Floristic richness*	9

*Based on species having >1% cover.

This field is the same age as 3801 and both should be at the same successional stage, yet the total number of species is almost half of that of field 3801. One was seeded in the

fall and one in the spring. Both were seeded with the same seed mix, using the same method, broadcast, but at different rates. The fewer number of species in this field may be a function of the time of seeding, or of a heavier seeding application which was more than three times that for field 3801 (Table 1). The smaller ratio of edge to interior of field 4801 may also be a factor in influencing the number of invading species.

Table 7 lists seeded species, their proportion in the mix, and their remaining percent composition. Table 8 summarizes canopy coverage data by species for the field. Table 9 lists all species observed throughout the field, their origin (native or introduced), and whether or not they were an invading species.

Table 7. Species seeded in field 4801 with percent composition recorded at the time of study.

Species and variety	Percent of mix	Percent composition*
Mix 18: Uplands mixture		
AGTRA**	5	0
AGSM Rosanna/AGDA Critana**	40/25	13
STVI	30	13
Mix 37: Cover crop		
TRAE	100	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 9).

**See Table 50.

Table 8. Summary of data by species for field 4801.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
AGCR**	Y	5	0.13	0.56	0
AGSM	N	100	11.13	8.75	13
AGSP	Y	55	8.00	15.80	9
AMPS	Y	5	0.13	0.56	0
ASCI	Y	5	0.75	3.35	1
BRJA	Y	100	10.38	11.01	12
BRTE	Y	95	4.13	7.88	5
COAR	Y	65	16.50	23.87	19
GRSQ	Y	5	0.13	0.56	0
LASE	Y	30	0.38	0.90	0
LIPE	Y	10	0.88	3.37	1
MEOF	Y	60	15.13	24.34	18
MOSS	Y	5	0.75	3.35	1
ONVI	Y	5	0.75	3.35	1
POCO	Y	10	0.88	3.37	1
RACO	Y	10	0.88	3.37	1
STVI	N	80	11.00	12.96	13
TRDU	Y	15	2.13	8.36	3
VIAM	Y	15	1.00	3.38	1
BARE	X	100	6.75	13.67	X
LITR	X	100	91.00	12.86	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the cover for the site.

**Table 50.

Table 9. Complete species list of field 4801.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X		X	
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. dasystachyum</u>	X			X
<u>A. frigida</u>	X		X	
<u>A. ludoviciana</u>	X		X	
<u>A. tridentata</u>	X		X	
<u>Astragalus crassicaupus</u>	X		X	
<u>A. cicer</u>		X	X	
<u>Bromus inermis</u>		X	X	
<u>B. japonicus</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Convolvulus arvensis</u>		X	X	
<u>Draba reptans</u>	X		X	
<u>Erigeron strigosus</u>	X		X	
<u>Erysimum asperum</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Lactuca serriola</u>		X	X	
<u>Linum perenne</u>	X		X	
<u>Melilotus officinalis</u>		X	X	
<u>Onobrychis viciaefolia</u>		X	X	
<u>Phleum pratense</u>		X	X	
<u>Poa compressa</u>		X	X	
<u>P. sanbergii</u>	X		X	
<u>Rosa woodsii</u>	X		X	
<u>Stipa viridula</u>	X			X
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Vicia americana</u>	X		X	
<u>Xanthium strumarium</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

In the spring of 1983 this field was burned, it has been grazed during the summers since 1985.

Field 1851

This site was spring seeded in May, 1985 with an uplands mix at 43.6 kg/ha PLS (36 lb/a) and a supplemental mix at 13.3 kg/ha PLS (11 lb/a) (Table 1). The uplands mix was drill

seeded and the supplemental mix was broadcast seeded. Two of the fifteen species seeded were not seen. Neither Agropyron trachycaulum nor Atriplex canescens (fourwing saltbush) were found on the site. Two varieties of saltbush were seeded, Nuttals and Wytana. The absence of fourwing saltbush may be explained by the small proportion of this species in the seed mix, only one percent, or the seed may not have been dewinged which gives greater control of planting depth (S.C.S. 1988). The number of species within frames totaled twenty eight with fifteen of these being invaders. Table 10 summarizes the variables for this field.

Table 10. Summary of field 1851.

Age	6 years
Time of planting	May 1985
Ratio of edge to interior	245 m/ha
Size of field	1.6 ha
Topsoil depth	30 cm
Total soil depth	232 cm
NW distance from undisturbed area	213 m
SE distance from undisturbed area	321 m
Total species seeded	15
Total species within frames	28
Invading species within frames	15
Floristic richness*	9

*Based on species having >1% cover.

Table 11 lists species seeded, their proportion in the mix, and remaining composition. Table 12 summarizes canopy coverage data by species for this field.

Table 11. Species seeded in field 1851 with percent composition recorded at the time of study.

Species and variety	Percent of mix	Percent composition*
Mix 22: Uplands mixture		
AGSP**Secar	24	30
AGSM Rosanna/AGDA Critana	20/11	22
AGTRA Revenue	10	0
STVI Lodorm	34	15
POCO Reubens	1	2
Mix 24: Supplemental Mixture		
CALO Goshen	7	0
ORHY Nezpar	7	0
BOGR	14	6
BOCU Bueree	8	1
BOCU Pierre	8	0
ANHA Gardner	12	0
PEPU Kaneb	11	1
RACO	6	0
LIPE	3	0
ACMI	1	0
ASCI	7	2
ONVI Eski	11	0
ATCA Wytana	1	0
ATCA Nuttals	3	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 13).

**Table 50.

Table 12. Summary of data by species for field 1851.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
AGSM**	N	100	18.00	17.56	22
AGSP	N	85	24.63	25.27	30
AGTRI	Y	5	0.13	0.56	0
AMPS	Y	5	0.13	0.56	0
ASCI	N	5	1.88	8.39	2
BOCU	N	10	0.88	3.37	1
BOGR	N	20	4.63	11.73	6
BRIN	Y	5	0.13	0.56	0
BRJA	Y	90	9.50	15.36	11
BRTE	Y	60	2.13	3.27	3
CAFI	Y	5	0.13	0.56	0
CALO	N	5	0.13	0.56	0
CHVI	Y	100	3.13	2.80	4
ECAN	Y	5	0.13	0.56	0
HEAN	Y	10	0.88	3.37	1
KOPY	Y	5	0.13	0.56	0
LASE	Y	5	0.13	0.56	0
MESA	Y	5	0.75	3.35	1
MOSS	Y	5	0.13	0.56	0
ONVI	N	15	0.38	0.92	0
PEPU	N	5	0.75	3.35	1
POCO	N	20	1.75	4.60	2
RACO	N	10	0.25	0.77	0
STVI	N	55	12.13	17.92	15
TAOF	Y	10	0.25	0.77	0
ZIVE	Y	5	0.13	0.56	0
BARE	X	100	12.75	16.04	X
LITR	X	100	81.50	23.68	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the total cover for the site.

**Table 50.

Table 13 lists all species observed throughout the field, their origin (native or introduced), and whether or not they were an invading species.

Table 13. Complete species list for Field 1851.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X			X
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>A. trichophorum</u>		X	X	
<u>Ambrosia psilostachya</u>	X		X	
<u>Andropogon hallii</u>	X			X
<u>Artemesia dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>Astragalus cicer</u>		X		X
<u>Bouteloua curtipendula</u>	X			X
<u>B. gracilis</u>	X			X
<u>Bromus inermis</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Calamovilfa longifolia</u>	X			X
<u>Cirsium undulatum</u>	X		X	
<u>Convolvulus arvensis</u>		X	X	
<u>Echinacea pallida</u>	X		X	
<u>Erigeron strigosus</u>	X		X	
<u>Erysimum asperum</u>	X		X	
<u>Gaura coccinea</u>	X		X	
<u>Glycyrrhiza lepidota</u>	X		X	
<u>Gutierrezia sarothrae</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Koeleria pyramidata</u>	X			X
<u>Lactuca serriola</u>		X	X	
<u>Leucocrinum montanum</u>	X		X	
<u>Linum perenne</u>	X			X
<u>Lithospermum incisum</u>	X		X	
<u>Medicago sativa</u>		X	X	
<u>Onobrychis viciaefolia</u>		X		X
<u>Opuntia polyacantha</u>	X		X	
<u>Oryzopsis hymenoides</u>	X		X	
<u>Penstemon albidus</u>	X		X	
<u>Petalostemon purpureum</u>	X			X
<u>Poa canbyi</u>	X		X	
<u>P. compressa</u>		X	X	
<u>Polygala alba</u>	X		X	
<u>Psoralea esculenta</u>	X		X	
<u>Ratibida colonifera</u>	X			X
<u>Solidago spp.</u>	X		X	
<u>Sphaealcea coccinea</u>	X		X	
<u>Stipa comata</u>	X		X	
<u>S. viridula</u>	X		X	
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	

Table 13, continued.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Vulpia octoflora</u>	X		X	
<u>Xanthium strumarium</u>	X		X	
<u>Yucca glauca</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

The only management practice on this site has been summer grazing since 1988.

Field 3841

This site was fall seeded in October, 1984 with an uplands mix at 15.7 kg/ha PLS (13 lb/a), a cover of winter wheat at 2.4 kg/ha bulk (2 lb/a), and a supplemental mix 25.4 kg/ha PLS (21 lb/a). The uplands mix and the cover crop were drill seeded, the supplemental mix was broadcast seeded (Table 1). Three seeded species were not recorded: Achillea millifolium (yarrow), Agropyron trachycaulum and Sphaeralcea coccinea (scarlet globemallow). The absence of scarlet globemallow may be due to the small proportion in the mix, two percent, or by the need to scarify the seed to improve germination (Bjugstad and Uresk 1981). The absence of yarrow cannot be explained since it is considered to be an aggressive species readily invading disturbed sites (S.C.S. 1988). The mix contained nine percent of this species. The number of species within frames was thirty-one, twenty-three were invaders. Table 14 summarizes variables for this field.

Table 15 lists species seeded at this site, their proportion in the mix, and remaining percent composition.

Table 14. Summary of field 3841.

Age	7 years
Time of planting	October 1984
Ratio of edge to interior	222 m/ha
Size of field	3.8 ha
Topsoil depth	35 cm
Total soil depth	88 cm
NW distance from undisturbed area	285 m
SE distance from undisturbed area	371 m
Total species seeded	15 + cover
Total species within frames	31
Invading species within frames	23
Floristic richness*	12

*Based on species with >1% cover.

Table 15. Species seeded for field 3841 with percent composition recorded at the time of study.

Species and variety	Percent of mix	Percent composition*
Mix 22: Uplands mixture		
AGSP**Secar	24	41
AGSM Rosanna/AGDA Critana	20/11	12
AGTRA Revenue	10	0
STVI Lodorm	34	5
POCO Reubens	1	1
Mix 25: Supplemental mixture		
BOGR	26	0
KOPY	4	0
POCA	18	0
ACMI	9	0
PEPU	26	0
RACO	4	0
SPCO	2	0
LIPE	9	0
ARCA	2	1
Mix 37: Cover crop		
TRAE	100	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 17).

**Table 50.

Table 16 summarizes canopy coverage data by species. Table 17 lists all species observed throughout the field, their origin, and whether or not they were invader species.

Table 16. Summary of data by species for field 3841.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
AGCR**	Y	10	3.25	13.96	4
AGSM	N	80	10.50	11.34	2
AGSP	N	90	36.13	30.56	41
AMPS	Y	5	1.88	8.39	2
ARCA	N	5	0.75	3.35	1
ARLU	Y	5	0.13	0.56	0
ASCI	Y	25	4.75	11.70	5
ATCA	Y	5	0.75	3.35	1
BOCU	Y	5	0.13	0.56	0
BOGR	N	5	0.13	0.56	0
BRJA	Y	25	0.63	1.11	1
BRTE	Y	65	5.25	9.14	6
CAFI	Y	5	0.13	0.56	0
CALO	Y	10	0.88	3.37	1
CHVI	Y	5	0.13	0.56	0
GUCO	Y	5	0.75	3.35	1
HEAN	Y	5	0.13	0.56	0
KOPY	Y	5	0.13	0.56	0
LASE	Y	10	0.25	0.77	0
LEMO	Y	5	0.13	0.56	0
LIPE	N	5	0.13	0.56	0
ONVI	Y	50	1.25	1.28	1
ORHY	Y	5	3.13	13.98	4
PEPU	N	5	0.13	0.56	0
POCO	N	10	0.88	3.37	1
STCO	Y	40	5.88	9.88	7
STVI	N	40	4.13	6.50	5
TAOF	Y	10	0.88	3.37	1
TRDU	Y	25	1.25	3.39	1
VUOC	Y	50	3.13	5.25	4
BARE	X	100	15.25	18.39	X
LITR	X	100	70.25	27.08	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% for the total cover for the site.

**Table 50.

Table 17. Complete species list of field 3841.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>Ambrosia psilostachya</u>	X		X	
<u>Andropogon hallii</u>	X		X	
<u>Artemisia dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>A. ludoviciana</u>	X		X	
<u>Astralus cicer</u>		X	X	
<u>Atriplex canescens</u>	X		X	
<u>Bouteloua curtipendula</u>	X		X	
<u>B. gracilis</u>	X			X
<u>Bromus tectorum</u>		X	X	
<u>Carex fillifolia</u>	X		X	
<u>Cirsium undulatum</u>	X		X	
<u>Echinacea pallida</u>	X		X	
<u>Erysimum asperum</u>	X		X	
<u>Gaillardia aristata</u>	X		X	
<u>Heterotheca villosa</u>	X		X	
<u>Koeleria pyramidata</u>	X		X	
<u>Lactuca serriola</u>		X	X	
<u>Leucocrinum montanum</u>	X		X	
<u>Linum perenne</u>	X			X
<u>Lithospermum incisum</u>	X		X	
<u>Onobrychis viciaefolia</u>		X	X	
<u>Oryzopsis hymenoides</u>	X		X	
<u>Penstemon albidus</u>	X		X	
<u>Poa canbyi</u>	X			X
<u>Psoralea esculenta</u>	X		X	
<u>Ratibida colonifera</u>	X			X
<u>Stipa viridula</u>	X			X
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Vulpia octoflora</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

Management practices implemented on this site include: fertilization during seeding in 1984, mowing in July of 1985, and summer grazing since 1988.

Field 3852

Six fields were chosen in area C of the Rosebud mine, three were seeded in the spring and three in the fall (Figure 1). This field was fall seeded in October, 1985, with an uplands mix at 23 kg/ha PLS (19 lb/a) and a supplemental mix at 9.7 kg/ha PLS (8 lb/a). The uplands mix was drill seeded and the supplemental mix was broadcast seeded (Table 1). Out of fifteen species seeded, all but four were seen in the field. These were Poa compressa (Canada bluegrass), Bouteloua gracilis (Blue gramma), Koeleria pyramidata (Prairie junegrass), and Petalostemon purpureum (Purple prairie clover). Establishment of blue gramma was poor on all fields in this study. It is moderately difficult to establish and should be drill seeded for best results (S.C.S. 1988). This species was broadcast in this field. Prairie junegrass performs better if seeded in the spring rather than in the fall (O.S.M. 1988).

The number of species within frames totaled nineteen. Of that total fourteen were invaders. Table 18 summarizes variables for this field. Table 19 lists seeded species with their proportion in the mix and remaining composition. Table 20 summarizes canopy coverage data by species for field 3852.

Table 18. Summary of field 3852.

Age	6 years
Time of planting	October 1985
Ratio of edge to interior	299 m/ha
Size of field	3.2 ha
Topsoil depth	30 cm
Total soil depth	60 cm
NW distance from undisturbed area	126 m
SE distance from undisturbed area	959 m
Total species seeded	15
Total species within frames	19
Invading species within frames	14
Floristic richness*	12

*Based on species having >1% cover.

Table 19. Species seeded in field 3852 with percent composition recorded at the time of study.

Species and variety	Percent of mix	Percent composition*
Mix 22: Uplands mixture		
AGSP**Secar	24	16
AGSM Rosanna/AGDA Critana	20/11	15
AGTRA Revenue	10	1
STVI Lodorm	34	5
POCO Reubens	1	0
Mix 25: Supplemental mixture		
BOGR	26	0
KOPY	4	0
POCA	18	0
ACMI	9	0
PEPU	26	0
RACO	4	0
SPCO	2	0
LIPE	9	2
ARCA	2	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 21).

**Table 50.

Table 20. Summary of data by species for field 3852.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
AGCR**	Y	10	2.63	8.87	2
AGSM	N	100	17.76	18.47	15
AGSP	N	80	18.63	18.58	16
AGTRA	N	10	0.88	3.37	1
ATDR	Y	20	0.50	1.03	0
BOCU	Y	5	0.75	3.35	1
BRIN	Y	45	17.25	29.91	15
BRJA	Y	100	29.75	24.92	26
BRTE	Y	75	7.88	11.54	7
CAMI	Y	30	0.75	1.18	1
COAR	Y	5	1.88	8.39	2
ERAS	Y	10	0.25	0.77	0
HEAN	Y	5	1.88	8.39	2
LASE	Y	15	0.38	0.92	0
LIPE	N	20	2.38	5.47	2
MESA	Y	5	1.88	8.39	2
PEAL	Y	5	0.79	3.44	1
STVI	N	65	5.38	6.55	5
TRDU	Y	15	2.25	5.50	2
BARE	X	45	9.50	20.09	X
LITR	X	100	86.13	22.47	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the cover for the site.

**Table 50.

Table 21 lists all species observed throughout the field, their origin (native or introduced), and whether or not they are an invading species. This field has been grazed during summers since 1988.

Table 21. Complete species list of field 3852.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X			X
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>Allium textile</u>	X		X	
<u>Artemisia cana</u>	X		X	
<u>A. dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>Bromus inermis</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Chenopodium spp.</u>	X	X	X	
<u>Convolvulus arvensis</u>		X	X	
<u>Delphinium bicolor</u>	X		X	
<u>Draba reptans</u>	X		X	
<u>Echinacea pallida</u>	X		X	
<u>Erysimum asperum</u>	X		X	
<u>Gutierrezia sarothrae</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Juniperus scopulorum</u>	X			X
<u>Lactuca serriola</u>		X	X	
<u>Leucocrinum montanum</u>	X		X	
<u>Linum perenne</u>	X			X
<u>Lithospermum incisum</u>	X		X	
<u>Medicago sativa</u>		X	X	
<u>Melilotus officinalis</u>		X	X	
<u>Oryzopsis hymenoides</u>	X		X	
<u>Penstemon albidus</u>	X		X	
<u>Plantago patagonica</u>	X		X	
<u>Poa canbyi</u>	X			X
<u>Ratibida colonifera</u>	X			X
<u>Rosa woodsii</u>	X		X	
<u>Sphaeralcea coccinea</u>	X			X
<u>Stipa comata</u>	X		X	
<u>S. viridula</u>	X			X
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Yucca glauca</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

Field 4852

This field is adjacent to 4852 and was spring seeded in May of 1986 with an uplands mix at 12.1 kg/ha PLS (10 lb/a) and a supplemental mix at 8.5 kg/ha PLS (7 lb/a). The uplands mixture was drill seeded and the supplemental mixture was broadcast seeded (Table 1). Sixteen species were seeded and of these, all but two were observed, which were Poa canbyi, and Petalostemon candida (white prairie clover). This clover is very drought tolerant with high emergence on mine spoils (Bjugstad and Whitman 1989). White prairie clover comprised four percent of the seed mix whereas purple prairie clover comprised twenty-seven percent. Only purple prairie clover was observed on this field with one percent canopy cover (Table 23).

The number of species within frames was twenty-five, of that total seventeen were invaders. Table 22 summarizes variables for this field.

Table 22. Summary of field 4852.

Age	5 years
Time of planting	May 1986
Ratio of edge to interior	259 m/ha
Size of field	8.9 ha
Topsoil depth	21 cm
Total soil depth	62 cm
NW distance from undisturbed area	236 m
SE distance from undisturbed area	1144 m
Total species seeded	16
Total species within frames	25
Invading species within frames	17
Floristic richness*	12

*Based on species having >1% cover.

Table 23 lists seeded species with their proportion in the mix and remaining composition. Table 24 summarizes canopy coverage data by species for field 4852.

Table 23. Species seeded in field 4852 with percent composition recorded at the time of study.

Species and variety	Percent of mix	Percent composition*
Mix 28: Uplands mixture		
AGSP**Secar	18	21
AGTRA Revenue	18	0
AGSM Rosanna/AGDA Critana	12/4	3
STVI Lodorm	18	17
STCO	3	0
ORHY Nezpar	18	0
BOCU	11	0
Mix 27: Supplemental mixture		
BOGR	27	1
POCA	21	0
PEPU	27	1
ACMI	9	0
LIPE	9	20
PECA	4	0
SPCO	2	0
ARCA	1	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 25).

**Table 50.

Table 24. Summary of data by species for field 4852.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
AGCR**	Y	20	10.00	26.06	13
AGSM	N	60	2.75	4.36	3
AGSP	N	70	16.75	20.25	21
AGTRA	N	15	0.38	0.92	0
AMPS	Y	5	0.13	0.56	0
BOCU	N	5	0.13	0.56	0
BOGR	N	15	1.00	3.38	1
BRIN	Y	40	5.88	9.88	7
BRJA	Y	40	1.63	3.37	2
BRTE	Y	30	0.75	1.18	1
CAMI	Y	05	0.13	0.56	0
COAR	Y	20	0.50	1.03	1
GACO	Y	15	0.38	0.92	0
GRSQ	Y	20	0.50	1.03	1
GUSA	Y	5	0.13	0.56	0
LESPP	Y	5	0.13	0.56	0
LIPE	N	65	16.00	20.59	20
MEOF	Y	30	1.38	3.39	2
MESA	Y	20	1.13	3.39	1
PEPU	N	15	1.00	3.38	1
RACO	Y	25	4.25	9.53	5
SAKA	Y	10	0.25	0.77	0
STVI	N	55	13.88	21.34	17
TAOF	Y	10	0.25	0.77	0
TRDU	Y	10	0.25	0.77	0
BARE	X	100	37.50	29.90	X
LITR	X	100	53.63	31.41	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the cover for the site.

**Table 50.

Table 25 lists all species observed throughout the field, their origin (native or introduced), and whether or not they were an invading species.

Table 25. Complete species list of field 4852.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X			X
<u>Agropyron smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>A. trachycaulum</u>	X			X
<u>Ambrosia psilostachya</u>	X		X	
<u>Artemisia cana</u>	X			X
<u>A. dracunculus</u>	X		X	
<u>A. tridentata</u>	X		X	
<u>Astragalus cicer</u>		X	X	
<u>Bouteloua curtipendula</u>	X		X	
<u>B. gracilis</u>	X			X
<u>Bromus inermis</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Convolvulus arvensis</u>		X	X	
<u>Echinacea pallida</u>	X		X	
<u>Erysimum asperum</u>	X		X	
<u>Gaura coccinea</u>	X		X	
<u>Grindelia squarrosa</u>	X		X	
<u>Gutierrezia sarothrae</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Heterotheca villosa</u>	X		X	
<u>Lactuca serriola</u>		X	X	
<u>Liatris punctata</u>	X		X	
<u>Linum perenne</u>	X			X
<u>Lithospermum incisum</u>	X		X	
<u>Medicago sativa</u>		X	X	
<u>Melilotus officinalis</u>		X	X	
<u>Poa compressa</u>		X	X	
<u>Polygonum aviculare</u>	X		X	
<u>Psoralea argophylla</u>	X		X	
<u>Ratibida colonifera</u>	X			X
<u>Rosa woodsii</u>	X		X	
<u>Salsola kali</u>	X		X	
<u>Solidago spp.</u>	X		X	
<u>Sphaeralcea coccinea</u>	X			X
<u>Stipa viridula</u>	X		X	
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	

Management practices for this site include summer grazing since 1988 and the planting of one hundred Juniperus scopulorum (Rocky mountain juniper) trees in 1987.

Field 4861

This site was fall seeded in October, 1986 with an uplands mix at 15.7 kg/ha PLS (13 lb/a), a supplemental mix at 10.9 kg/ha PLS (9 lb/a), and a warm season grass mix at 30.3 kg/ha PLS (25 lb/). It was one of two fields, 4862, to be seeded with a warm season mixture which contained primarily warm season grass species. This fall seeded field had no warm season grass production versus 56 kg/ha for the spring seeded field (Table 54).

The uplands mix was drill seeded, the warm season and supplemental mixes were broadcast seeded (Table 1). Twenty-one species were seeded and of these, six were not seen on the field. These were Poa canbyi, Calamovilfa longifolia, Schizachyrium scoparium, Artemisia cana, and Petalostemon candidum. Species within frames totaled twenty-three, thirteen were invader species. Table 26 summarizes variables for this field.

Table 26. Summary of field 4861.

Age	5 years
Time of planting	October 1986
Ratio of edge to interior	196 m/ha
Size of field	9.3 ha
Topsoil depth	28 cm
Total soil depth	61 cm
NW distance from undisturbed area	230 m
SE distance from undisturbed area	1414 m
Total species seeded	21
Total species within frames	23
Invading species within frames	13
Floristic richness*	11

*Based on species with >1% cover.

Table 27 lists seeded species, their proportion in the mix and percent composition at the time of this study. Table 28 summarizes data by species recorded within frames for field 4861.

Table 27. Species seeded in field 4861 with persisting composition.

Species and variety	Percent of mix	Percent composition*
Mix 28: Uplands mixture		
AGTRA**Revenue	18	18
AGSP Secar	18	9
AGSM Rosanna/AGDA Critana	12/4	9
STVI Lodorm	18	5
STCO	3	5
ORHY Nezpar	18	0
BOCU	11	0
Mix 27: Supplemental mixture		
BOGR	27	0
POCA	21	0
PEPU	27	0
ACMI	9	9
LIPE	9	35
PECA	4	0
SPCO	2	0
ARCA	1	0
Mix 26: Warm season mixture		
AGSP Whitmar	10	0
AGSM Rosanna	5	0
CALO Goshen	20	0
BOGR	25	0
SCSC Camper	20	0
ANHA Garden Co.	20	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 29).

**Table 50.

Table 28. Summary of data by species for field 4861.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
ACMI**	N	25	9.00	20.30	9
AGSM	N	70	10.63	11.65	9
AGSP	N	50	8.50	11.99	9
AGTRA	N	55	17.50	21.07	18
AGTRI	Y	5	0.13	0.56	0
ARLU	Y	5	3.13	13.98	3
BOGR	N	5	0.13	0.56	0
BRIN	Y	15	1.63	4.61	2
BRJA	Y	10	0.88	3.37	1
BRTE	Y	55	2.00	3.30	2
COAR	Y	15	1.00	3.38	1
GRSQ	Y	10	0.88	3.37	1
HEAN	Y	10	0.25	0.77	0
LASE	Y	5	0.13	0.56	0
LIPE	N	100	34.63	25.36	35
MEOF	Y	20	1.13	3.39	1
ORHY	N	5	0.13	0.56	0
PEPU	N	5	0.13	0.56	0
SAKA	Y	10	0.25	0.77	0
SPCO	N	5	0.13	0.56	0
STVI	N	30	5.00	9.77	5
TAOF	Y	30	0.75	1.18	1
TRDU	Y	10	0.88	3.37	1
BARE	X	100	34.63	27.41	X
LITR	X	100	60.75	24.52	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the cover for the site.

**Table 50.

Table 29 lists all species observed throughout the field, their origin (native or introduced), and whether or not they were an invading species.

Table 29. Complete species list of field 4861.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X		X	
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>A. trichophorum</u>		X	X	
<u>Ambrosia psilostachya</u>	X		X	
<u>Artemesia ludoviciana</u>	X		X	
<u>Astragalus cicer</u>		X	X	
<u>Avena sativa</u>		X	X	
<u>Bouteloua curtipendula</u>	X			X
<u>B. gracilis</u>	X			X
<u>Bromus inermis</u>		X	X	
<u>B. japonicus</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Convolvulus arvensis</u>		X	X	
<u>Echinacea pallida</u>	X		X	
<u>Grindelia squarrosa</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Lactuca serriola</u>		X	X	
<u>Linum perenne</u>	X		X	
<u>Lithospermum incisum</u>	X		X	
<u>Melilotus officinalis</u>		X	X	
<u>Medicago sativa</u>		X	X	
<u>Oryzopsis hymenoides</u>	X			X
<u>Petalostemon purpureum</u>	X		X	
<u>Ratibida colonifera</u>	X			X
<u>Rumex crispus</u>		X	X	
<u>Salsola kali</u>	X		X	
<u>Sphaeralcea coccinea</u>	X			X
<u>Stipa comata</u>	X			X
<u>S. viridula</u>	X		X	
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	

Field 4862

This field was the second of two, 4861, to have the warm season grass mixture seeded. At 56 kg/ha, the production of warm season grass here was greatest for all fields (Table 54). In April of 1987 it was seeded with an uplands mix at 21.8 kg/ha PLS (18 lb/a), a supplemental mix at 6.1 kg/ha PLS

(5 lb/a), and a warm season grass mix at 30.1 kg/ha PLS (25 lb/a). The uplands mix was drill seeded, the supplemental and warm season mixes were broadcast seeded (Table 1).

Of the nineteen species seeded, only Ceratoides lanata (winter fat) was not found on the field. The absence of this half shrub is surprising since it establishes easily from seed and is widely used to restore mine land plant communities (S.C.S. 1988). The number of species within frames was twenty-five, of that total thirteen were invader species. Table 30 summarizes variables for this field.

Table 30. Summary of field 4862..

Age	4 years
Time of planting	April 1987
Ratio of edge to interior	307 m/ha
Size of field	3.6 ha
Topsoil depth	25 cm
Total soil depth	53 cm
NW distance from undisturbed area	188 m
SE distance from undisturbed area	1989 m
Total species seeded	19
Total species within frames	25
Invading species within frames	13
*Floristic richness	13

*Based on species with >1% cover.

Table 31 lists species seeded with their proportion in the mix and percent composition, by cover, at the time of this study. Table 32 summarizes data for species recorded within frames.

Table 31. Species seeded in field 4862 with percent composition recorded at the time of study.

Species and variety		Percent of mix	Percent composition*
Mix 29: Uplands mixture			
AGTRA**	Revenue	17	17
AGSP	Secar	13	0
AGSM	Rosanna/AGDA Critana	17/5	9
STVI	Lodorm	11	19
STCO		9	6
BOCU		17	3
CELA		11	0
Mix 30: Supplemental mixture			
PEPU		27	6
LIPE	Apar	9	0
ACMI		9	0
RACO		4	1
SPCO		2	0
BOGR		27	4
POCA	Canbar	18	0
KOPY		4	0
Mix 26: Warm season mixture			
AGSP	Whitmar	10	0
AGSM	Rosanna	5	0
CALO	Goshen	20	0
BOGR		25	0
SCSC	Camper	20	1
ANHA	Garden Co.	20	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 33).

**Table 50.

Table 32. Summary of data by species for field 4862.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
AGSM**	N	70	9.13	9.71	9
AGSP	N	5	0.13	0.56	0
AGTRA	N	50	17.88	21.92	17
AMPS	Y	15	1.63	4.61	2
BOCU	N	20	3.50	9.23	3
BOGR	N	40	4.63	9.40	4
BRIN	Y	20	9.38	28.08	9
BRJA	Y	35	4.50	14.06	4
BRTE	Y	55	7.25	13.45	7
COAR	Y	10	0.25	0.77	0
HEAN	Y	10	0.25	0.77	0
LASE	Y	5	0.13	0.56	0
LIPE	N	5	0.13	0.56	0
MEOF	Y	50	7.88	11.96	7
MESA	Y	30	4.38	14.09	4
PEPU	N	25	6.50	13.77	6
POPR	Y	5	0.13	0.56	0
RACO	N	5	0.75	3.35	1
SAKA	Y	15	0.38	0.92	0
SCSC	N	5	0.75	3.35	1
SPCO	N	10	0.25	0.77	0
STCO	N	50	6.13	9.75	6
STVI	N	65	20.00	24.06	19
TAOF	Y	5	0.13	0.56	0
TRDU	Y	5	0.13	0.56	0
BARE	X	100	34.63	27.41	X
LITR	X	100	54.88	27.54	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the cover for the site.

**Table 50.

Table 33 lists all species observed throughout the field, their origin (native or introduced), and whether or not they were an invading species.

Table 33. Complete species list of field 4862.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X			X
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>Andropogon hallii</u>	X			X
<u>Ambrosia psilostachya</u>	X		X	
<u>Avena sativa</u>		X	X	
<u>Bouteloua curtipendula</u>	X			X
<u>B. gracilis</u>	X			X
<u>Bromus inermis</u>		X	X	
<u>B. japonicus</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Calamovilfa longifolia</u>	X			X
<u>Ceratoides lanata</u>	X			X
<u>Convolvulus arvensis</u>		X	X	
<u>Grindelia squarrosa</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Koeleria pyramidata</u>	X			X
<u>Lactuca serriola</u>		X	X	
<u>Linum perenne</u>	X			X
<u>Melilotus officinalis</u>		X	X	
<u>Medicago sativa</u>		X	X	
<u>Oryzopsis hymenoides</u>	X		X	
<u>Petalostemon purpureum</u>	X			X
<u>Poa canbyi</u>	X			X
<u>Ratibida colonifera</u>	X			X
<u>Salsola kali</u>	X		X	
<u>Schizachyrium scoparium</u>	X			X
<u>Sphaeralcea coccinea</u>	X			X
<u>Stipa comata</u>	X			X
<u>S. viridula</u>	X			X
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	

Field 4884

This site was spring seeded in April, 1989 with an uplands mix at 13.3 kg/ha PLS (11 lb/a) and a supplemental mix at 8.5 kg/ha PLS (7 lb/a). The uplands mix was drill seeded, and the supplemental mix was broadcast seeded (Table 1). Of fifteen species seeded, four were not seen on the field, they were Ceratoides lanata, Petalostemon purpureum, Sphaeralcea coccinea, and Bouteloua gracilis. The number of species within frames totaled twenty-eight, of that total twenty were invader species. Table 34 summarizes variables for this field.

Table 34. Summary of field 4884.

Age	4 years
Time of planting	April 1987
Ratio of edge to interior	307 m/ha
Size of field	3.6 ha
Topsoil depth	25 cm
Total soil depth	53 cm
NW distance from undisturbed area	188 m
SE distance from undisturbed area	1989 m
Total species seeded	15
Total species within frames	28
Invading species within frames	20
*Floristic richness	10

*Based on species with >1% cover.

Table 35 lists the species seeded at this site, their proportion in the mix and remaining percent composition.

Table 35. Species seeded in field 4884 with percent composition recorded at the time of study.

Species and variety	Percent of mix	Percent composition*
Mix 33: Uplands mixture		
AGSP** Secar	20	37
STVI	20	7
AGSM/AGDA Critana	20/10	5
AGTRA	15	9
CELA	10	0
BOCU	5	0
Mix 30: Supplemental mixture		
PEPU	27	0
LIPE Apar	9	9
ACMI	9	16
RACO	4	0
SPCO	2	0
BOGR	27	0
POCA Canby	18	0
KOPY	4	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 37).

**Table 50.

Table 36 summarizes data for species recorded within frames. Table 37 lists all species observed throughout the field by their scientific name, origin (native or introduced), and whether or not they were an invading species.

Table 36. Summary of data by species for field 4884.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
ACMI**	N	65	15.50	19.75	16
AGCR	Y	5	0.13	0.56	0
AGSM	N	70	4.88	6.10	5
AGSP	N	100	36.13	28.28	37
AGTRA	Y	100	9.31	16.91	9
AGTRI	Y	5	0.13	0.56	0
ARDR	Y	5	0.13	0.56	0
ARLU	Y	5	0.13	0.56	0
ARTR	Y	20	1.19	4.00	1
BOCU	N	10	0.25	0.77	0
BRIN	Y	10	0.88	3.37	1
BRJA	Y	65	4.75	6.17	5
BRTE	Y	35	1.50	3.38	2
CAMI	Y	10	0.25	0.77	0
COAR	Y	10	0.25	0.77	0
ERST	Y	5	0.75	3.35	1
KOPY	Y	5	0.13	0.56	0
LASE	Y	5	0.13	0.56	0
LIPE	N	85	9.25	13.08	9
MEOF	Y	30	0.75	1.18	1
POCO	Y	60	3.88	8.56	4
PSES	Y	5	0.13	0.56	0
RACO	N	5	0.13	0.56	0
SAKA	Y	10	0.25	0.77	0
STVI	N	60	7.00	9.75	7
SYOC	Y	5	0.13	0.56	0
TAOF	Y	15	0.38	0.92	0
BARE	X	100	17.88	21.56	X
LITR	X	100	79.00	22.43	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the cover for the site.

**Table 50.

Table 37. Complete species list of field 4884.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X			X
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>A. trichophorum</u>		X	X	
<u>Allium textile</u>	X		X	
<u>Ambrosia psilostachya</u>	X		X	
<u>Artemisia cana</u>	X		X	
<u>A. dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>A. ludoviciana</u>	X		X	
<u>A. tridentata</u>	X		X	
<u>Bromus inermis</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Chrysothamnus nauseosus</u>	X		X	
<u>Cirsium undulatum</u>	X		X	
<u>Convolvulus arvensis</u>		X	X	
<u>Erigeron strigosus</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Hordeum jubatum</u>	X		X	
<u>Koeleria pyramidata</u>	X			X
<u>Lactuca serriola</u>		X	X	
<u>Linum perenne</u>	X			X
<u>Medicago sativa</u>		X	X	
<u>Melilotus officinalis</u>		X	X	
<u>Oxytropis sericea</u>	X		X	
<u>Plantago patagonica</u>	X		X	
<u>Poa canbyi</u>	X		X	
<u>P. compressa</u>		X	X	
<u>Psoralea esculenta</u>	X		X	
<u>Ratibida colonifera</u>	X			X
<u>Rosa woodsii</u>	X		X	
<u>Salsola kali</u>	X		X	
<u>Solidago spp.</u>	X		X	
<u>Stipa viridula</u>	X			X
<u>Symphoricarpos occidentalis</u>	X		X	
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Vicia americana</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

Field 4881

This site is east of 4884 (Figure 1) and was fall seeded in November, 1988. The same mixes were planted on both fields using the same methods, but at different rates (Table 1). The uplands mix was seeded at 21.8 kg/ha PLS (18 lb/a) and the supplemental mix at 4.8 kg/ha (4 lb/a). Fifteen species were seeded and out of these only two were not seen in the field. They were Ceratoides lanata, and Bouteloua gracilis. The number of species within frames totaled thirty-three, of that total twenty-two were invading species. Table 38 summarizes variables for this field. Table 39 lists the species seeded at this site, their proportion in the mix and percent composition at the time of this study. Table 40 summarizes data for species recorded within frames. Table 41 lists all species observed throughout the field by their scientific name, origin (native or introduced), and whether or not they were an invading species.

Table 38. Summary of field 4881.

Age	3 years
Time of planting	November 1988
Ratio of edge to interior	211 m/ha
Size of field	7.3 ha
Topsoil depth	30 cm
Total soil depth	63 cm
NW distance from undisturbed area	392 m
SE distance from undisturbed area	1381 m
Total species seeded	15
Total species within frames	33
Invading species within frames	22
Floristic richness*	11

*Based on species with >1% cover.

Table 39. Species seeded in field 4881 with persisting composition.

Species and variety	Percent of mix	Percent composition*
Mix 33: Uplands mixture		
AGSP** Secar	20	26
STVI	20	3
AGSM/AGDA Critana	20/5	6
AGTRA	15	13
CELA	10	0
BOCU	5	0
Mix 30: Supplemental mixture		
PEPU	27	0
LIPE Apar	9	15
ACMI	9	12
RACO	4	0
SPCO	2	0
BOGR	27	0
POCA Canby	18	1
KOPY	4	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 41).

**Table 50.

Table 40. Summary of data by species for field 4881.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
ACMI**	N	50	11.50	19.86	12
AGSM	N	80	5.75	6.29	6
AGSP	N	75	24.50	32.30	26
AGTRA	Y	75	11.94	23.59	13
ARCA	Y	5	0.13	0.56	0
ARDR	Y	5	0.13	0.56	0
ARFR	Y	5	0.13	0.56	0
ARTR	Y	5	0.13	0.56	0
BOGR	N	5	0.13	0.56	0
BRJA	Y	50	6.00	11.65	6
BRTE	Y	55	5.63	14.09	6
CAMI	Y	30	0.75	1.18	1
GUSA	Y	5	0.75	3.35	1
LASE	Y	5	0.13	0.56	0
LESPP	Y	10	0.25	0.77	0
LIPE	N	90	14.25	16.96	15
MEOF	Y	25	1.88	4.58	2
MESA	Y	5	3.13	13.98	3
PEPU	N	15	0.38	0.92	0
PLPA	Y	5	0.13	0.56	0
POCA	N	10	0.88	3.37	1
POCO	Y	15	0.38	0.92	0
PSES	Y	10	0.25	0.77	0
RACO	N	10	0.25	0.77	0
SAKA	Y	25	1.25	3.39	1
SCSC	Y	5	0.13	0.56	0
SPCO	N	10	0.25	0.77	0
STVI	N	25	2.38	8.33	3
SYOC	Y	5	0.13	0.56	0
TAOF	Y	5	0.13	0.56	0
TRDU	Y	5	0.13	0.56	0
VIAM	Y	5	0.13	0.56	0
BARE	X	95	31.13	24.12	X
LITR	X	100	68.13	25.62	X

*Percent composition of 0 indicates the species was recorded in a frame but was less than 1% of the cover for the field.

**Table 50.

Table 41. Complete species list of field 4881.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Achillea millefolium</u>	X			X
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X			X
<u>Allium textile</u>	X		X	
<u>Ambrosia psilostachya</u>	X		X	
<u>Artemisia cana</u>	X		X	
<u>A. dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>A. ludoviciana</u>	X		X	
<u>A. tridentata</u>	X		X	
<u>Astragalus crassicaupus</u>	X		X	
<u>Avena fatua</u>		X	X	
<u>Bouteloua gracilis</u>	X			X
<u>Bromus inermis</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Cirsium undulatum</u>	X		X	
<u>Echinacea pallida</u>	X		X	
<u>Grindelia squarrosa</u>	X		X	
<u>Gutierrezia sarothrae</u>	X		X	
<u>Heterotheca villosa</u>	X		X	
<u>Koeleria pyramidata</u>	X			X
<u>Lactuca serriola</u>		X	X	
<u>Leucocrinum montanum</u>	X		X	
<u>Linum perenne</u>	X			X
<u>Lomatium foeniculaceum</u>	X		X	
<u>Medicago sativa</u>		X	X	
<u>Melilotus officinalis</u>		X	X	
<u>Petalostemon purpureum</u>	X			X
<u>Poa canbyi</u>	X			X
<u>Psoralea argophylla</u>	X		X	
<u>Ratibida colonifera</u>	X			X
<u>Rosa woodsii</u>	X		X	
<u>Salsola kali</u>	X		X	
<u>Schizachyrium scoparium</u>	X		X	
<u>Solidago spp.</u>	X		X	
<u>Sphaeralcea coccinea</u>	X			X
<u>Stipa comata</u>	X		X	
<u>S. viridula</u>	X			X
<u>Symphoricarpos occidentalis</u>		X	X	
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Vicia americana</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

Field 2832

Both fields in area E were seeded using a two-phase seeding strategy. These fields were initially seeded with a supplemental mixture and one year later were interseeded with an uplands grass mixture. This was to provide the initially seeded species, such as forbs and warm season grasses, a competitive advantage over the later, more competitive cool season grasses.

In March, 1983 it was first seeded in with a supplemental mix at 20.6 kg/ha PLS (17 lb/a) and a cover crop of wintergraze at 7.3 kg/ha (6 lb/a). In May, 1984 it was interseeded with an uplands mix at 32.7 kg/ha PLS (27 lb/a) and Ceratoides lanata (winter fat) at 2.4 kg/ha bulk (2 lb/a). The supplemental mixture and cover crop were broadcast seeded. The uplands mixture and winter fat were interseeded using a drill seeder (Table 1). Of eighteen species seeded, eight of these were not seen in the field. These were Ceratoides lanata, Bouteloua gracilis, Agropyron trachycaulum, Amorpha canescens, Aster falcatus, Gaillardia aristata, Achillea millefolium, and Echinacea pallida (purple prairie coneflower). Coneflower seed totaled six percent of the mix and generally has good emergence and growth on minesoils (Bjugstad and Whitman 1989). The number of species recorded within frames was twenty- six, of that total twenty were invaders. Table 42 summarizes the variables analyzed for this field. Table 43 lists seeded species, their proportion in the

mix and remaining percent composition. Table 44 summarizes data for species recorded within frames. Table 45 lists all species observed throughout the field by their scientific name, origin (native or introduced), and whether or not they were an invading species.

Management practices for this site included a two-phase seeding program, fertilizing in the spring of 1983, mowing in the fall of 1983, planting of three species of tublings: rose, silver sage, and currant in 1983, and grazing in 1989.

Table 42. Summary of field 2832.

Age	8 years
Time of planting-phase 1	March 1983
Time of planting-phase 2	May 1984
Ratio of edge to interior	183 m/ha
Size of field	11.7 ha
Topsoil depth	30 cm
Total soil depth	83 cm
NW distance from undisturbed area	4645 m
SE distance from undisturbed area	1602 m
Total species seeded	18 + cover
Total species within frames	26
Invading species within frames	20
Floristic richness*	14

*Based on species with >1% cover.

Table 43. Species seeded in field 4881 with percent composition recorded at time of study.

Species and variety	Percent of mix	Percent composition*
Mix 19: Uplands mixture		
AGTRA**	5	0
AGSM Rosanna/AGDA Critana	40/25	35
STVI	30	2
Mix 20: Supplemental mixture		
ORHY Nezpar	12	0
BOGR	2	0
BOCU	33	0
RACO	3	0
ECAN	3	0
LIPE	2	0
AMCA	2	0
ASFA	1	0
GAAR	5	0
ACMI	3	0
ONVI Esci	9	0
ASCI Lutana	6	0
ATCA	15	4
CELA	11	0
Additional seeding		
CELA	100	0
Mix 36: Cover crop		
Wintergraze	100	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list (Table 41).

**Table 50.

Table 44. Summary of data by species for field 2832.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
ACMI**	N	50	11.50	19.86	12
AGCR	Y	5	0.75	3.35	1
AGSM	N	95	33.38	25.88	35
AGSP	Y	85	17.13	19.94	18
AMPS	Y	35	4.50	9.45	5
ARDR	Y	20	0.50	1.03	1
ARFR	Y	10	0.25	0.77	0
ATCA	N	5	4.25	19.01	4
BOCU	N	10	0.25	0.77	0
BRIN	Y	15	0.38	0.92	0
BRJA	Y	5	1.88	8.39	2
BRTE	Y	65	5.88	9.36	6
KOPY	Y	10	0.25	0.77	0
LIPE	N	15	0.38	0.92	0
MEOF	Y	30	4.38	9.49	5
MESA	Y	10	2.00	8.37	2
ONVI	Y	5	0.13	0.56	0
ORHY	N	5	0.13	0.56	0
POCO	Y	15	3.38	13.94	4
POPR	Y	5	0.13	0.56	0
SAKA	Y	5	4.88	21.80	5
STCO	Y	15	3.88	11.51	4
STVI	N	30	2.00	4.56	2
TAOF	Y	15	0.38	0.92	0
TRDU	Y	20	1.75	4.60	2
VUOC	Y	5	0.13	0.56	0
YUGL	Y	20	3.00	6.16	3
BARE	X	100	15.63	14.09	X
LITR	X	100	84.38	14.09	X
ROCK	X	5	0.13	0.56	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1% for the cover for the field.

**Table 50.

Table 45. Complete species list of field 2832.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>A. spicatum</u>	X		X	
<u>A. trichophorum</u>		X	X	
<u>Ambrosia psilostachya</u>	X		X	
<u>Andropogon gerardii</u>	X		X	
<u>Artemisia cana</u>	X		X	
<u>A. dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>A. ludoviciana</u>	X		X	
<u>Astragalus cicer</u>		X		X
<u>Atriplex canescens</u>	X			X
<u>Bouteloua curtipendula</u>	X			X
<u>Bromus inermis</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Echinacea pallida</u>	X			X
<u>Erysimum asperum</u>	X		X	
<u>Koeleria pyramidata</u>	X			X
<u>Linum perenne</u>	X			X
<u>Medicago sativa</u>		X	X	
<u>Melilotus officinalis</u>		X	X	
<u>Onobrychis viciaefolia</u>		X		X
<u>Oryzopsis hymenoides</u>	X			X
<u>Penstemon albidus</u>	X		X	
<u>Petalostemon purpureum</u>	X		X	
<u>Poa compressa</u>		X	X	
<u>P. pratensis</u>		X	X	
<u>P. sanbergii</u>	X		X	
<u>Psoralea esculenta</u>	X		X	
<u>Ratibida colonifera</u>	X			X
<u>Salsola kali</u>	X		X	
<u>Stipa comata</u>	X		X	
<u>S. viridula</u>	X			X
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Vicia americana</u>	X		X	
<u>Vulpia octoflora</u>	X		X	
<u>Yucca glauca</u>	X		X	

Field 3821

This field was also seeded in two-phases. In October, 1982 an uplands mix was seeded at 33.9 kg/ha PLS (28 lb/a), and a cover crop of wintergraze at 9.7 kg/ha (8 lb/a). It was again seeded with the uplands mix at 32.7 kg/ha PLS (27 lb/a) and winter fat at 2.4 kg/ha bulk (2 lb/a) in May of 1984. All mixes and the cover crop were drill seeded (Table 1). Of the five species seeded, two were not seen on the field, these were Agropyron trachycaulum and Ceratoides lanata. This field, with twenty-five invading species, was second only to field 3801 where thirty-two invaders were recorded. Both of these fields were seeded with only five species and a cover crop.

Table 46 summarizes variables for this field. Table 47 lists species seeded, percent in the mix, and remaining composition. Table 48 summarizes species data within frames. Table 49 lists all species observed throughout the field, their origin (native or introduced), and whether or not they were an invading species.

Table 46. Summary of field 3821.

Age	9 years
Time of planting-phase 1	October 1982
Time of planting-phase 2	May 1984
Ratio of edge to interior	353 m/ha
Size of field	2.0 ha
Topsoil depth	46 cm
Total soil depth	112 cm
NW distance from undisturbed area	4645 m
SE distance from undisturbed area	1494 m
Total species seeded	4 + cover
Total species within frames	27
Invading species within frames	25
*Floristic richness	12

*Based on species with >1% cover.

Table 47. Species seeded in field 4881 with percent composition recorded at time of study.

Species and variety	Percent of mix	Percent composition*
Mix 19: Uplands mixture		
AGTRA**	5	0
AGSM Rosanna/AGDA Critana	40/25	38
STVI	30	2
Additional seeding		
CELA	100	0
Mix 36: Cover crop		
Wintergraze	100	0

* Species with 0% composition may not have been recorded in a frame but may have been noted on the complete species list.

**Table 50.

Table 48. Summary of data by species for field 3821.
(N=20)

Species	Invader	Percent frequency	Mean % Cover	SD	Percent composition*
AGCR**	Y	5	3.13	13.98	3
AGSM	N	95	38.00	27.44	38
AGSP	Y	40	8.75	17.25	9
AMPS	Y	60	11.75	16.74	12
ANGE	Y	5	1.88	8.39	2
ARDR	Y	30	3.75	9.16	4
ARFR	Y	5	0.13	0.56	0
ARLU	Y	10	2.63	8.87	3
BOCU	Y	10	0.25	0.77	0
BRTE	Y	50	4.88	9.30	5
ECAN	Y	5	0.13	0.56	0
ERAS	Y	5	0.13	0.56	0
GUCO	Y	30	3.13	8.77	3
MEOF	Y	40	1.00	1.26	1
ORHY	Y	5	0.13	0.56	0
POCO	Y	5	0.75	3.35	1
POPR	Y	15	3.38	9.26	3
PSES	Y	5	0.13	0.56	0
SAKA	Y	30	0.75	1.18	1
SOMI	Y	10	2.00	8.37	2
SPCO	Y	5	0.13	0.56	0
STCO	Y	30	2.63	5.41	3
STVI	N	20	1.75	4.60	2
TAOF	Y	10	0.25	0.77	0
TRDU	Y	25	3.13	6.12	3
VUOC	Y	20	1.13	3.39	1
YUGL	Y	15	5.13	19.10	5
BARE	X	0	23.00	20.04	X
LITR	X	0	78.88	18.59	X

* Percent composition of 0 indicates the species was recorded in a frame but was less than 1%.

**Table 50.

Table 49. Complete species list of Field 3821.

Scientific binomial	Native		Invader	
	Yes	No	Yes	No
<u>Agropyron cristatum</u>		X	X	
<u>A. smithii</u>	X			X
<u>Andropogon gerardii</u>	X		X	
<u>Ambrosia psilostachya</u>	X		X	
<u>Artemisia dracunculus</u>	X		X	
<u>A. frigida</u>	X		X	
<u>A. ludoviciana</u>	X		X	
<u>Astragalus cicer</u>		X	X	
<u>Bromus inermis</u>		X	X	
<u>B. tectorum</u>		X	X	
<u>Bouteloua curtipendula</u>	X			X
<u>Calamovilfa longifolia</u>	X			X
<u>Calochortus nuttallii</u>	X		X	
<u>Carex filifolia</u>	X		X	
<u>Cirsium undulatum</u>	X		X	
<u>Echinacea pallida</u>	X		X	
<u>Erysimum asperum</u>	X		X	
<u>Gaura coccinea</u>	X		X	
<u>Helianthus annuus</u>	X		X	
<u>Koeleria pyramidata</u>	X			X
<u>Lactuca serriola</u>		X	X	
<u>Liatris punctata</u>	X		X	
<u>Lithospermum incisum</u>	X		X	
<u>Melilotus officinalis</u>		X	X	
<u>Onobrychis viciaefolia</u>		X	X	
<u>Oryzopsis hymenoides</u>	X			X
<u>Opuntia polyacantha</u>	X		X	
<u>Petalostemon purpureum</u>	X		X	
<u>Poa compressa</u>		X	X	
<u>P. pratensis</u>		X	X	
<u>P. sanbergii</u>	X		X	
<u>Polygala alba</u>	X		X	
<u>Psoralea esculenta</u>	X		X	
<u>Rosa woodsii</u>	X		X	
<u>Rumex spp.</u>		X	X	
<u>Salsola kali</u>	X		X	
<u>Schizachyrium scoparium</u>	X		X	
<u>Solidago spp.</u>	X		X	
<u>Sphaeralcea coccinea</u>	X		X	
<u>Stipa comata</u>	X		X	
<u>S. viridula</u>	X			X
<u>Taraxacum officinale</u>		X	X	
<u>Tragopogon dubius</u>		X	X	
<u>Yucca glauca</u>	X		X	
<u>Zigadenus venosus</u>	X		X	

Management practices for this site included a two-phase seeding program, fertilizing in the fall of 1982, the planting of silver sage tubelings in 1983, and grazing in 1989.

Biomass Productivity

All data analyses tables are printed in Appendix B. Production of standing biomass was not significantly affected by any of the independent variables (Table 55). The fall seeded fields had slightly greater productivity with the average production of fall seeding being 2250 kg/ha versus 2164 kg/ha for the spring seeded fields.

Percent Cover

There was a significant interaction between topsoil depth and season of planting ($P=.007$) on the dependent variable percent cover. As the amount of topsoil increased, the amount of canopy cover decreased significantly for the spring, but not for the fall (Table 56).

Number of Invading Species

Two of the independent variables analyzed, age ($P=.0001$) and the ratio of edge to interior of a field ($P=.0001$), influenced the percentage of invading species (Table 57). As the age of a field increased, the number of invading species increased. As the amount of edge in the field increased, the number of invading species also increased.

Season of Planting

Spring seedings averaged 109 kg/ha of cool season, introduced, annual grasses (Table 54) which was less than that of native range at 200 kg/ha (Munshower and Neuman 1983). In contrast, fall seedings were higher than native range in annual grass production with a mean of 220 kg/ha.

Spring seedings appeared to produce more perennial, warm season grasses; production was more than twice that of fall seeded fields. Warm season grass production for spring seedings averaged 19 kg/ha whereas fall seedings averaged only 3 kg/ha.

Seeding Variables

Seeding variables are listed in Table 1, page 25. A summary of invasion for all fields is printed in Table 58. Seeding rate appears to influence standing biomass but these findings are inconclusive. Field 3841 had the greatest productivity at a fairly heavy seeding rate, it was also seeded with three of the four classes of mixes (Table 1). However, the least productive field, 4861, had a similar seeding history and (Table 58).

Production means of seed mixes and seed rates were ranked in the same order using Waller-Duncan T tests (SAS Institute, Cary, NC, Ver. 6.03 1983). These two variables were then considered collectively.

The number of invading species appeared to be influenced by the seeding mixes. Three fields with a high number of

invaders: 3801, 4801, 3821, were seeded with only four species plus a cover crop (Table 58).

Soil Factors

Soil texture, pH, and EC results are printed in Table 60. All fields had a loamy-sand texture except for field 4801 which was sandy-loam in texture. Soil pH ranged from mildly alkaline to moderately alkaline. Electrical conductivity was non-saline for all fields. These soil variables were omitted from analysis due to lack of variability.

Age and Productivity

The relationship between age and biomass productivity was not significant, however, productivity tended to decrease with age. The reverse of this trend was apparent for litter build-up, as the age of the field increased, so did the amount of vegetative litter (Figure 2).

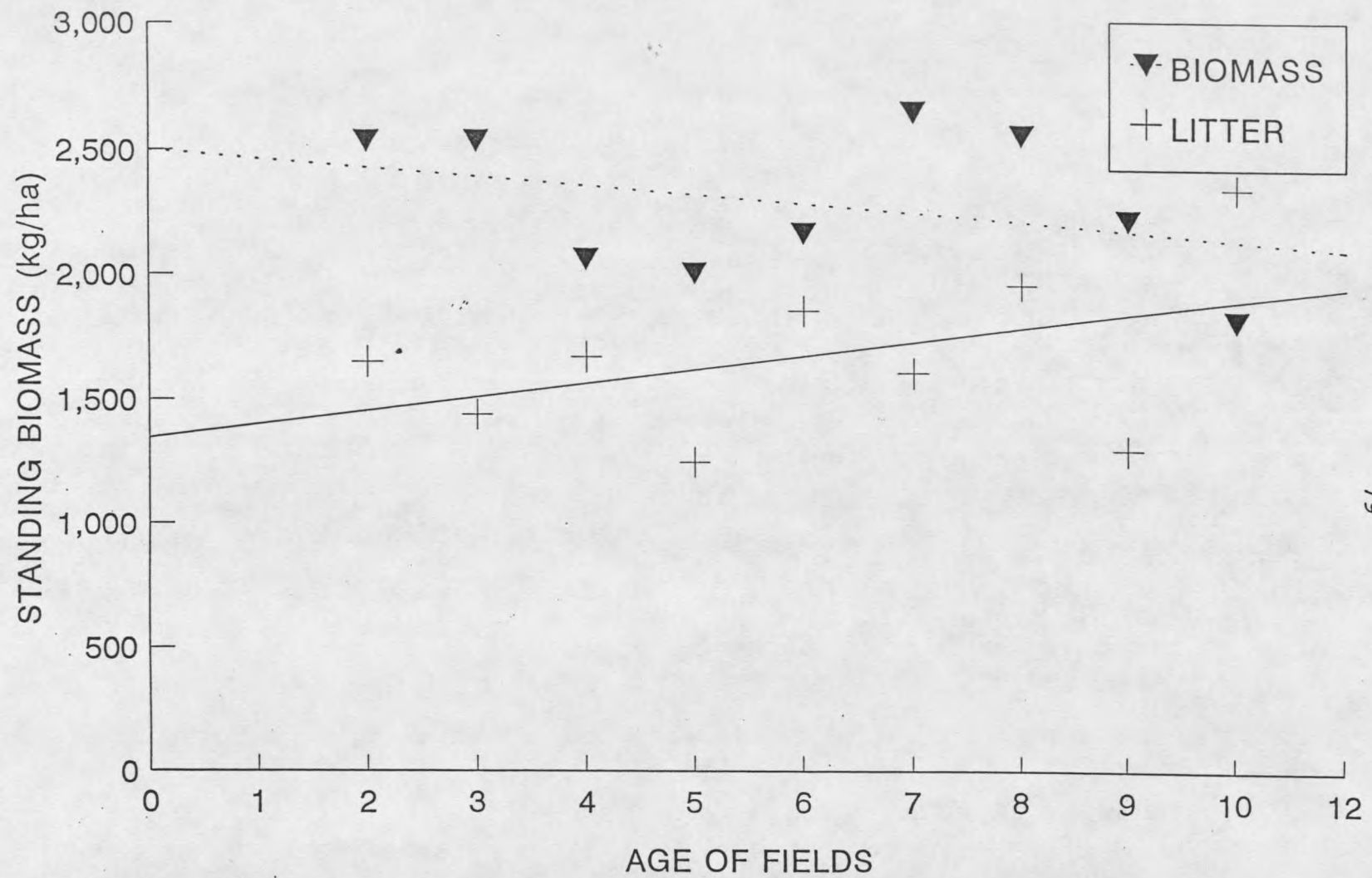


FIGURE 2: TRENDS WITH AGE

Discussion

Biomass Productivity

Production on unmined native range land in Colstrip, Montana averaged 1000 kg/ha (Munshower and Neuman 1983). Productivity of reclaimed surface mined lands was double that of native range land in the Colstrip area after two years (Sindelar 1981). This rate of productivity was attributed to introduced grasses and legumes selected for forage production. Results from the present study also showed productivity to be nearly double the rate of productivity for native range even though they were seeded primarily with native species (Table 54). These results concur with DePuit et al. (1980) who indicated that exclusive seeding of native species is not at the expense of productivity.

Even though age was not significant in relation to productivity, production trends do concur with Sindelar's results (1981) which showed standing biomass to decrease with age as litter increased. Data from this study are shown in Figure 2. This production trend may also be attributed to stabilization within the community as later successional stages become established and the more productive annuals die off. This dying off of early successional species opens up new niches within the community eventually giving rise to a more stable community.

Percent Cover

Results for this variable were surprising since analyses showed a significant interaction between topsoil depth and season of planting. Percent canopy cover decreased as topsoil depth increased. This relationship was more significant for the spring seeded sites than for the fall seeded sites (Table 56). Barth (1984) had shown that a coversoil depth of up to 46 cm directly influenced plant growth. All sites in this study exceeded this recommendation and there was little variation in soil depths among sites. However, since native species were seeded here instead of the introduced species used in Barth's study, this trend may indicate that native species utilize a smaller portion of the soil resource.

Number of Invading Species

The ratio of edge to interior of fields significantly affected the number of invading species ($P=.06$). This supports the importance of patch shape in landscapes found by Forman and Godron (1981). The greater the amount of edge, the more diverse are the microhabitats created by the association of patch shape and environmental factors such as wind and sun. Increasing the amount of edge around a field increases the number of microhabitats thereby creating additional niches for species invasion.

Age also significantly affected the percentage of invading species ($P=.007$). This may be due to the mortality of the initially seeded species, such as Agropyron

trachycaulum, which opens up the community for the invasion of other species, or it may be a function of community stabilization.

Season of Planting

Time of planting did not significantly contribute to standing biomass, however, spring seeded production averaged 1864 kg/ha whereas fall seeded fields averaged 2250 kg/ha. These results conflict with DePuit et al. (1978) who reported greater productivity for spring versus fall seedings, they attributed this trend to the higher rates of establishment of introduced species. In the current study, most of the species seeded were native.

Perennial, warm season grass production was more than twice as great for fields planted in the spring than for those planted in the fall. However, to attribute this effect only to the time of seeding would not be justifiable. The seed mixes also played an important role. Some fields were seeded with an exclusive 'warm season' mix. Other fields were seeded with the 'supplemental' mixes which also contained warm season grass species.

Support for the argument that spring seeding increases warm season grass production can be seen in the only pair of fields in this study to be seeded with the exclusive 'warm season' mix. The fall seeding had no warm season grass production while the spring seeding produced 56 kg/ha of warm

season grasses. This was the greatest amount recorded for any field in the study.

Seeding Variables

Field 3801 had the greatest number of invading species for all fields in this study. It was one of three fields (4801 and 3821) to be seeded with an uplands mixture which included only four species and a cover crop. All fields with a cover crop had higher numbers of invaders than fields with no cover crop (Table 58). This supports the idea that leaving a community open provides space for invader species to become established. When the annual cover crop dies back it leaves open niches in the community for the invasion of nonseeded species. In contrast, the field with the lowest number of invading species, 4861, had the highest number of seeded species and no cover crop.

The seeding rate for field 3801 was also the lowest for any field and it was broadcast seeded (Table 1). DePuit et al. (1980) found that broadcast seeding at low rates promoted community diversity. However, they noted the advantage of broadcast seeding over drill seeding had disappeared by the third growing season. These fields were nine (3821) and ten years old (3801 and 4801) at the time of this study and were drill and broadcast seeded, respectively. No advantage of broadcast over drill seeding was apparent in these three fields. Without replication of the seeding methods at the same rates, these findings are inconclusive. Nevertheless,

they suggest that when seeding only a few species at low rates the number of invading species increases. The temporary cover crop helps alleviate the problem of invasion by weedy species.

CONCLUSIONS

Reclamation practices used today employ traditional agriculture methods developed for the growth of economic crops, not for the recreation of ecosystems. Learning to construct these systems using the tools at hand and within the set guidelines, is a challenge for reclamation specialists.

Managers of the restoration process must comply with regulations designed to protect the environment but which also create homogenized soils and landscapes. Therefore, the goals of recreating the diversity of the natural landscape are met with limited success. Based on results from this study, certain factors under the control of the reclamation manager encourage the invasion of nonseeded species and thereby increase diversity.

Seeding mixtures are the most conspicuous and easily controlled factor. Care should be taken not to overcompensate for a lack of understanding of plant community relationships by seeding too many species. Seeding only a few species along with a cover crop encourages invasion. This is due to the open niches created when the annual cover crop dies back. Using a cover crop improves the soil structure and creates water infiltration routes via the root system (Schuman et al. 1991). Seeding at lower rates also appears to increase nonseeded species invasion. This is most likely due to reduced interspecific competition among plants.

The season of planting appears to influence warm season grass production; the spring seedings are more productive for this lifeform. Including the exclusive 'warm season' mix and seeding in the spring appears to increase production of this lifeform on minesoils, however, replication is needed to state this conclusively.

Rehabilitated minesites lack the diverse natural microhabitats which were destroyed during the mining process. Increasing the ratio of edge to interior of reclaimed sites may help to increase the number of microhabitats available without adversely affecting reclamation costs. Undulating the edges of fields during final grading of the spoil and topsoil could increase the ratio of edge to interior of fields and thereby increase the number of microsites. This would also be more appealing visually since straight lines are seldom seen in nature.

Some efforts have been made by reclamation specialists to mitigate the problem of landscape homogeneity. Placing boulder piles and tree snags on the revegetated sites creates caches of moisture, provides shade, and creates habitat for fauna and flora which may not otherwise be found there.

Freedom of experimentation, in cooperation with regulators, would allow the creation of a more diverse landscape. Allowances, such as varying topsoil depths, and leaving areas without any topsoil, could provide variations across the landscape resulting in different plant communities.

The ten year bonding period imposed under SMCRA may not be a sufficient amount of time for the reclaimed plant community to become as diverse as a reference area in the semi-arid West. Reclamation success should be based on utility, not on whether or not identical ecosystem composition has been reached. Using the reference area approach to evaluate revegetation success on mined lands, is "like comparing a newborn to a 70-year old man" (G.E. Schuman in Gillis 1991). Both are in completely different successional stages.

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APPENDICES

APPENDIX A

ABBREVIATIONS OF SPECIES AND LIFEFORMS

Table 50. Species abbreviations and lifeforms.

Abbreviation - Scientific binomial		Lifeform
ACMI	<u>Achillea millefolium</u> L.*	FORB**
AGCR	<u>Agropyron cristatum</u> (L.) Gaertn.	CIP
AGDA	<u>A. dasystachyum</u> (Hook.) Scribn.	CNP
AGSM	<u>A. smithii</u> Rydb.	CNP
AGSP	<u>A. spicatum</u> (Pursh) Scribn. and Smith	CNP
AGTRA	<u>A. trachycaulum</u> (Link) Malte	CNP
AGTRI	<u>A. trichophorum</u> (Link) Richt.	CIP
ALTE	<u>Allium textile</u> (Nels.) Macbr.	FORB
AMCA	<u>Amorpha canescens</u> Pursh	SHRB
AMPS	<u>Ambrosia psilostachya</u> DC.	FORB
ANGE	<u>Andropogon gerardii</u> Vitman	WNP
ARCA	<u>Artemisia cana</u> Pursh	SHRB
ARDR	<u>A. dracunculus</u> L.	FORB
ARFR	<u>A. frigida</u> Willd.	FORB
ARLU	<u>A. ludoviciana</u> Nutt.	FORB
ARTR	<u>A. tridentata</u> Nutt.	SHRB
ASCR	<u>Astragalus crassicaupus</u> Nutt.	LEGU
ASCI	<u>A. cicer</u> L.	LEGU
ASFA	<u>Aster falcatus</u> Lindl.	FORB
ATCA	<u>Atriplex canescens</u> (Pursh) Nutt.	SHRB
AVSA	<u>Avena sativa</u> L.	CIA
BOCU	<u>Bouteloua curtipendula</u> (Michx.) Torr.	WNP
BOGR	<u>B. gracilis</u> (H.B.K.) Lag. ex Griffiths	WNP
BRIN	<u>Bromus inermis</u> Leyss.	CIP
BRJA	<u>B. japonicus</u> Thunb.	CIA
BRTE	<u>B. tectorum</u> L.	CIA
CAFI	<u>Carex fillifolia</u> Nutt.	SDGE
CALO	<u>Calamovilfa longifolia</u> (Hook.) Scribn.	WNP
CAMI	<u>Camelina microcarpa</u> Andrz. ex DC.	FORB
CELA	<u>Ceratoides lanata</u> (Pursh) Howell	SHRB
CIUN	<u>Cirsium undulatum</u> (Nutt.) Spreng.	FORB
CHSPP	<u>Chenopodium spp.</u> L.	FORB
CHVI	<u>Chrysopsis villosa</u> (Pursh) Shinnars	FORB
COAR	<u>Convolvulus arvensis</u> L.	FORB
DEBI	<u>Delphinium bicolor</u> Nutt.	FORB
DRRE	<u>Draba reptans</u> (Lam.) Fern.	FORB
ECPA	<u>Echinacea pallida</u> Nutt.	FORB
ERAS	<u>Erysimum asperum</u> (Nutt.) DC.	FORB
ERST	<u>Erigeron strigosus</u> Muhl. ex. Willd.	FORB
GAAR	<u>Gaillardia aristata</u> Pursh	FORB
GACO	<u>Gaura coccinea</u> (Nutt.) Pursh	FORB
GLLE	<u>Glycyrrhiza lepidota</u> Pursh	FORB
GRSQ	<u>Grindelia squarrosa</u> (Pursh) Dunal	FORB
GUSA	<u>Gutierrezia sarothrae</u> (Pursh) Britt.	FORB
HEAN	<u>Helianthus annuus</u> L.	FORB
HEVI	<u>Heterotheca villosa</u> Pursh	FORB
JUSC	<u>Juniperus scopulorum</u> Sarg.	TREE

Table 50, continued.

Abbreviation - Scientific binomial*

KOPY	<u>Koeleria pyramidata</u> (Lam.) Beauv.	CNP
LASE	<u>Lactuca serriola</u> L.	FORB
LEMO	<u>Leucocrinum montanum</u> Nutt.	FORB
LESPP	<u>Lepidium</u> spp. L.	FORB
LIIN	<u>Lithospermum incisum</u> Lehm.	FORB
LIPE	<u>Linum perenne</u> L.	FORB
LIPU	<u>Liatris punctata</u> Hook.	FORB
MEOF	<u>Melilotus officinalis</u> (L.) Lam.	LEGU
MESA	<u>Medicago sativa</u> L.	LEGU
ONVI	<u>Onobrychis viciaefolia</u> Scop.	LEGU
OPPO	<u>Opuntia polyacantha</u> Haw.	FORB
ORHY	<u>Oryzopsis hymenoides</u> Ricker	CNP
OXSE	<u>Oxytropis sericea</u> Nutt.	FORB
PEAL	<u>Penstemon albidus</u> Nutt.	FORB
PEPU	<u>Petalostemon purpureum</u> (Vent.) Rydb.	FORB
PLPA	<u>Plantago patagonica</u> Jacq.	FORB
POAL	<u>Polygala alba</u> Nutt.	FORB
POCA	<u>Poa canbyii</u> (Scribn.) Piper	CNP
POCO	<u>P. compressa</u> L.	CIP
POPR	<u>P. pratensis</u> L.	CIP
POSA	<u>P. sanbergii</u> Vasey	CNP
PSAR	<u>Psoralea argophylla</u> Pursh	LEGU
PSES	<u>P. esculenta</u> Pursh	LEGU
RACO	<u>Ratibida colonifera</u> (Nutt.) Woot. & Standl.	FORB
ROWO	<u>Rosa woodsii</u> Lindl.	SHRB
RUCR	<u>Rumex crispus</u> L.	FORB
SAKA	<u>Salsola kali</u> Sennen & Pau	FORB
SCSC	<u>Schizachyrium scoparium</u> Nash	WNP
SOMI	<u>Solidago</u> spp. L.	FORB
SPCO	<u>Sphaeralcea coccinea</u> (Pursh) Rydb.	FORB
STCO	<u>Stipa comata</u> Trin. and Rupr.	CNP
STVI	<u>Stipa viridula</u> Trin.	CNP
SYOC	<u>Symphoricarpos occidentalis</u> Hook.	SHRB
TAOF	<u>Taraxacum officinale</u> Weber	FORB
TRAE	<u>Triticum aestivum</u> L.	CIA
TRDU	<u>Tragopogon dubius</u> Scop.	FORB
VIAM	<u>Vicia americana</u> Muhl.	LEGU
VUOC	<u>Vulpia octoflora</u> (Walt.) Rydb.	CNA
YUGL	<u>Yucca glauca</u> Nutt.	SHRB
ZIVE	<u>Zigadenus venosus</u> Wats.	FORB

* Nomenclature from Dorn (1984), Hitchcock and Conquist (1973).

**Table 51.

Table 51. Lifeform abbreviations.

Abbreviation - Lifeform

CNP	Cool season-native-perennial grass
CNA	Cool season-native-annual grass
CIP	Cool season-introduced-perennial grass
CIA	Cool season-introduced-annual grass
WNP	Warm season-native-perennial grass
FORB	Herbaceous forb
LITR	Litter or dead material on ground
BARE	Bare ground
LEGU	Legume
MOSS	Moss
ROCK	Rock
SDGE	Sedge
SHRB	Shrub
TREE	Tree

APPENDIX B

DATA

Table 52. Summary of raw data by field and species.

Field	Species	%Canopy cover	SD	SE
1851	AGSM	18.00	17.56	3.93
1851	AGSP	24.63	25.27	5.65
1851	AGTRI	0.13	0.56	0.13
1851	AMPS	0.13	0.56	0.13
1851	ASCI	1.88	8.39	1.88
1851	BARE	12.75	16.04	3.59
1851	BOCU	0.88	3.37	0.75
1851	BOGR	4.63	11.73	2.62
1851	BRIN	0.13	0.56	0.13
1851	BRJA	9.50	15.36	3.43
1851	BRTE	2.13	3.27	0.73
1851	CAFI	0.13	0.56	0.13
1851	CALO	0.13	0.56	0.13
1851	CHVI	3.13	2.80	0.63
1851	ECAN	0.13	0.56	0.13
1851	HEAN	0.88	3.37	0.75
1851	KOPY	0.13	0.56	0.13
1851	LASE	0.13	0.56	0.13
1851	LITR	81.50	23.68	5.30
1851	MESA	0.75	3.35	0.75
1851	MOSS	0.13	0.56	0.13
1851	ONVI	0.38	0.92	0.20
1851	PEPU	0.75	3.35	0.75
1851	POCO	1.75	4.60	1.03
1851	RACO	0.25	0.77	0.17
1851	STVI	12.13	17.92	4.01
1851	TAOF	0.25	0.77	0.17
1851	ZIVE	0.13	0.56	0.13
2832	AGCR	0.75	3.35	0.75
2832	AGSM	33.38	25.88	5.79
2832	AGSP	17.13	19.94	4.46
2832	AMPS	4.50	9.45	2.11
2832	ARDR	0.50	1.03	0.23
2832	ARFR	0.25	0.77	0.17
2832	ATCA	4.25	19.01	4.25
2832	BARE	15.63	14.09	3.15
2832	BOCU	0.25	0.77	0.17
2832	BRIN	0.38	0.92	0.20
2832	BRJA	1.88	8.39	1.88
2832	BRTE	5.88	9.36	2.09
2832	KOPY	0.25	0.77	0.17
2832	LIPE	0.38	0.92	0.20
2832	LITR	84.38	14.09	3.15
2832	MEOF	4.38	9.49	2.12
2832	MESA	2.00	8.37	1.87
2832	ONVI	0.13	0.56	0.13
2832	ORHY	0.13	0.56	0.13

Table 52, continued.

Field	Species	%Canopy cover	SD	SE
2832	POCO	3.38	13.94	3.12
2832	POPR	0.13	0.56	0.13
2832	ROCK	0.13	0.56	0.13
2832	SAKA	4.88	21.80	4.88
2832	STCO	3.88	11.51	2.57
2832	STVI	2.00	4.56	1.02
2832	TAOF	0.38	0.92	0.20
2832	TRDU	1.75	4.60	1.03
2832	VUOC	0.13	0.56	0.13
2832	YUGL	3.00	6.16	1.38
3801	ACMI	0.13	0.56	0.13
3801	AGCR	0.13	0.56	0.13
3801	AGSM	10.25	11.12	2.49
3801	AGTRA	0.13	0.56	0.13
3801	AMPS	0.88	3.37	0.75
3801	ARDR	0.38	0.92	0.20
3801	ARDU	0.75	3.35	0.75
3801	ARLU	2.63	8.87	1.98
3801	ASCI	1.88	8.39	1.88
3801	BARE	4.38	4.58	1.02
3801	BOGR	0.13	0.56	0.13
3801	BRIN	0.75	3.35	0.75
3801	BRJA	31.50	15.88	3.55
3801	BRTE	5.63	5.55	1.24
3801	CAFI	0.13	0.56	0.13
3801	DRRE	0.13	0.56	0.13
3801	ERAS	0.88	3.37	0.75
3801	ERST	3.50	9.23	2.06
3801	GUCO	0.25	0.77	0.17
3801	KOPY	0.13	0.56	0.13
3801	LASE	1.50	1.26	0.28
3801	LITR	95.00	5.13	1.15
3801	MEOF	28.25	42.59	9.52
3801	MESA	3.13	13.98	3.13
3801	MOSS	1.38	3.39	0.76
3801	ONVI	0.38	0.92	0.20
3801	OXSE	0.13	0.56	0.13
3801	PEPU	0.75	3.35	0.75
3801	PLPA	4.63	14.38	3.22
3801	POCO	0.25	0.77	0.17
3801	PSES	4.63	14.38	3.22
3801	STCO	1.75	4.60	1.03
3801	STVI	21.13	29.71	6.64
3801	TAOF	0.13	0.56	0.13
3801	TRDU	2.13	4.54	1.01
3801	VUOC	0.13	0.56	0.13

Table 52, continued.

Field	Species	%Canopy cover	SD	SE
3801	YUGL	0.13	0.56	0.13
3821	AGCR	3.13	13.98	3.13
3821	AGSM	38.00	27.44	6.14
3821	AGSP	8.75	17.25	3.86
3821	AMPS	11.75	16.74	3.74
3821	ANGE	1.88	8.39	1.88
3821	ARDR	3.75	9.16	2.05
3821	ARFR	0.13	0.56	0.13
3821	ARLU	2.63	8.87	1.98
3821	BARE	23.00	20.04	4.48
3821	BOCU	0.25	0.77	0.17
3821	BRTE	4.88	9.30	2.08
3821	ECAN	0.13	0.56	0.13
3821	ERAS	0.13	0.56	0.13
3821	GUCO	3.13	8.77	1.96
3821	LITR	78.88	18.59	4.16
3821	MEOF	1.00	1.26	0.28
3821	ORHY	0.13	0.56	0.13
3821	POCO	0.75	3.35	0.75
3821	POPR	3.38	9.26	2.07
3821	PSES	0.13	0.56	0.13
3821	SAKA	0.75	1.18	0.26
3821	SOMI	2.00	8.37	1.87
3821	SPCO	0.13	0.56	0.13
3821	STCO	2.63	5.41	1.21
3821	STVI	1.75	4.60	1.03
3821	TAOF	0.25	0.77	0.17
3821	TRDU	3.13	6.12	1.37
3821	VUOC	1.13	3.39	0.76
3821	YUGL	5.13	19.10	4.27
3841	AGCR	3.25	13.96	3.12
3841	AGSM	10.50	11.34	2.54
3841	AGSP	36.13	30.56	6.83
3841	AMPS	1.88	8.39	1.88
3841	ARCA	0.75	3.35	0.75
3841	ARLU	0.13	0.56	0.13
3841	ASCI	4.75	11.70	2.62
3841	ATCA	0.75	3.35	0.75
3841	BARE	15.25	18.39	4.11
3841	BOCU	0.13	0.56	0.13
3841	BOGR	0.13	0.56	0.13
3841	BRJA	0.63	1.11	0.25
3841	BRTE	5.25	9.14	2.04
3841	CAFI	0.13	0.56	0.13
3841	CALO	0.88	3.37	0.75

Table 52, continued.

Field	Species	%Canopy cover	SD	SE
3841	CHVI	0.13	0.56	0.13
3841	GUCO	0.75	3.35	0.75
3841	HEAN	0.13	0.56	0.13
3841	KOPY	0.13	0.56	0.13
3841	LASE	0.25	0.77	0.17
3841	LEMO	0.13	0.56	0.13
3841	LIPE	0.13	0.56	0.13
3841	LITR	70.25	27.08	6.06
3841	ONVI	1.25	1.28	0.29
3841	ORHY	3.13	13.98	3.13
3841	PEAL	0.00	0.00	0.00
3841	PEPU	0.13	0.56	0.13
3841	POCO	0.88	3.37	0.75
3841	STCO	5.88	9.88	2.21
3841	STVI	4.13	6.50	1.45
3841	TAOF	0.88	3.37	0.75
3841	TRDU	1.25	3.39	0.76
3841	VUOC	3.13	5.25	1.17
3852	AGCR	2.63	8.87	1.98
3852	AGDA	0.13	0.56	0.13
3852	AGSM	17.63	18.47	4.13
3852	AGSP	18.63	18.58	4.15
3852	AGTRA	0.88	3.37	0.75
3852	ATDR	0.50	1.03	0.23
3852	BARE	9.50	20.09	4.49
3852	BOCU	0.75	3.35	0.75
3852	BRIN	17.25	29.91	6.69
3852	BRJA	29.75	24.92	5.57
3852	BRTE	7.88	11.54	2.58
3852	CAMI	0.75	1.18	0.26
3852	COAR	1.88	8.39	1.88
3852	ERAS	0.25	0.77	0.17
3852	HEAN	1.88	8.39	1.88
3852	LASE	0.38	0.92	0.20
3852	LIPE	2.38	5.47	1.22
3852	LITR	86.13	22.47	5.02
3852	MESA	1.88	8.39	1.88
3852	PEAL	0.75	3.35	0.75
3852	STVI	5.38	6.55	1.47
3852	TRDU	2.25	5.50	1.23
4801	AGCR	0.13	0.56	0.13
4801	AGSM	11.13	8.75	1.96
4801	AGSP	8.00	15.80	3.53
4801	AMPS	0.13	0.56	0.13
4801	ASCI	0.75	3.35	0.75

Table 52, continued.

Field	Species	%Canopy cover	SD	SE
4801	BARE	6.75	13.67	3.06
4801	BRJA	10.38	11.01	2.46
4801	BRTE	4.13	7.88	1.76
4801	COAR	16.50	23.87	5.34
4801	GRSQ	0.13	0.56	0.13
4801	LASE	0.38	0.90	0.14
4801	LIPE	0.88	3.37	0.75
4801	LITR	91.00	12.86	2.88
4801	MEOF	15.13	24.34	5.44
4801	MOSS	0.75	3.35	0.75
4801	ONVI	0.75	3.35	0.75
4801	POCO	0.88	3.37	0.75
4801	RACO	0.88	3.37	0.75
4801	STVI	11.00	12.96	2.90
4801	TRDU	2.13	8.36	1.87
4801	VIAM	1.00	3.38	0.76
4852	AGCR	10.00	26.06	5.83
4852	AGSM	2.75	4.36	0.98
4852	AGSP	16.75	20.25	4.53
4852	AGTRA	0.38	0.92	0.20
4852	AMPS	0.13	0.56	0.13
4852	BARE	37.50	29.90	6.69
4852	BOCU	0.13	0.56	0.13
4852	BOGR	1.00	3.38	0.76
4852	BRIN	5.88	9.88	2.21
4852	BRJA	1.63	3.37	0.75
4852	BRTE	0.75	1.18	0.26
4852	CAMI	0.13	0.56	0.13
4852	COAR	0.50	1.03	0.23
4852	GACO	0.38	0.92	0.20
4852	GRSQ	0.50	1.03	0.23
4852	GUSA	0.13	0.56	0.13
4852	LESPP	0.13	0.56	0.13
4852	LIPE	16.00	20.59	4.60
4852	LITR	53.63	31.41	7.02
4852	MEOF	1.38	3.39	0.76
4852	MESA	1.13	3.39	0.76
4852	PEPU	1.00	3.38	0.76
4852	RACO	4.25	9.53	2.13
4852	SAKA	0.25	0.77	0.17
4852	STVI	13.88	21.34	4.77
4852	TAOF	0.25	0.77	0.17
4852	TRDU	0.25	0.77	0.17
4861	ACMI	9.00	20.30	4.54
4861	AGDA	1.63	4.61	1.03

Table 52, continued.

Field	Species	%Canopy cover	SD	SE
4861	AGSM	9.00	11.65	2.61
4861	AGSP	8.50	11.99	2.68
4861	AGTRA	17.50	21.07	4.71
4861	AGTRI	0.13	0.56	0.13
4861	ARLU	3.13	13.98	3.13
4861	BARE	34.63	27.41	6.13
4861	BOGR	0.13	0.56	0.13
4861	BRIN	1.63	4.61	1.03
4861	BRJA	0.88	3.37	0.75
4861	BRTE	2.00	3.30	0.74
4861	COAR	1.00	3.38	0.76
4861	GRSQ	0.88	3.37	0.75
4861	HEAN	0.25	0.77	0.17
4861	LASE	0.13	0.56	0.13
4861	LIPE	34.63	25.36	5.67
4861	LITR	60.75	24.52	5.48
4861	MEOF	1.13	3.39	0.76
4861	ORHY	0.13	0.56	0.13
4861	PEPU	0.13	0.56	0.13
4861	SAKA	0.25	0.77	0.17
4861	SPCO	0.13	0.56	0.13
4861	STVI	5.00	9.77	2.18
4861	TAOF	0.75	1.18	0.26
4861	TRDU	0.88	3.37	0.75
4862	AGDA	0.88	3.37	0.75
4862	AGSM	9.13	9.71	2.17
4862	AGSP	0.13	0.56	0.13
4862	AGTRA	17.88	21.92	4.90
4862	AMPS	1.63	4.61	1.03
4862	BARE	34.63	27.41	6.13
4862	BOCU	3.50	9.23	2.06
4862	BOGR	4.63	9.40	2.10
4862	BRIN	9.38	28.08	6.28
4862	BRJA	4.50	14.06	3.14
4862	BRTE	7.25	13.45	3.01
4862	COAR	0.25	0.77	0.17
4862	HEAN	0.25	0.77	0.17
4862	LASE	0.13	0.56	0.13
4862	LIPE	0.13	0.56	0.13
4862	LITR	54.88	27.54	6.16
4862	MEOF	7.88	11.96	2.67
4862	MESA	4.38	14.09	3.15
4862	PEPU	6.50	13.77	3.08
4862	POPR	0.13	0.56	0.13
4862	RACO	0.75	3.35	0.75
4862	SAKA	0.38	0.92	0.20

Table 52, continued.

Field	Species	%Canopy cover	SD	SE
4862	SCSC	0.75	3.35	0.75
4862	SPCO	0.25	0.77	0.17
4862	STCO	6.13	9.75	2.18
4862	STVI	20.00	24.06	5.38
4862	TAOF	0.13	0.56	0.13
4862	TRDU	0.13	0.56	0.13
4881	ACMI	11.50	19.86	4.44
4881	AGSM	5.75	6.29	1.41
4881	AGSP	24.50	32.30	7.22
4881	AGTRA	11.94	23.59	3.73
4881	ARCA	0.13	0.56	0.13
4881	ARDR	0.13	0.56	0.13
4881	ARFR	0.13	0.56	0.13
4881	ARTR	0.13	0.56	0.13
4881	BARE	31.13	24.12	5.39
4881	BOGR	0.13	0.56	0.13
4881	BRJA	6.00	11.65	2.61
4881	BRTE	5.63	14.09	3.15
4881	CAMI	0.75	1.18	0.26
4881	GUSA	0.75	3.35	0.75
4881	LASE	0.13	0.56	0.13
4881	LESPP	0.25	0.77	0.17
4881	LIPE	14.25	16.96	3.79
4881	LITR	68.13	25.62	5.73
4881	MEOF	1.88	4.58	1.02
4881	MESA	3.13	13.98	3.13
4881	PEPU	0.38	0.92	0.20
4881	PLPA	0.13	0.56	0.13
4881	POCA	0.88	3.37	0.75
4881	POCO	0.38	0.92	0.20
4881	PSES	0.25	0.77	0.17
4881	RACO	0.25	0.77	0.17
4881	SAKA	1.25	3.39	0.76
4881	SCSC	0.13	0.56	0.13
4881	SPCO	0.25	0.77	0.17
4881	STVI	2.38	8.33	1.86
4881	SYOC	0.13	0.56	0.13
4881	TAOF	0.13	0.56	0.13
4881	TRDU	0.13	0.56	0.13
4881	VIAM	0.13	0.56	0.13
4884	ACMI	15.50	19.75	4.42
4884	AGCR	0.13	0.56	0.13
4884	AGSM	4.88	6.10	1.36
4884	AGSP	36.13	28.28	6.32
4884	AGTRA	9.31	16.91	2.67

Table 52, continued.

Field	Species	%Canopy cover	SD	SE
4884	AGTRI	0.13	0.56	0.13
4884	ARDR	0.13	0.56	0.13
4884	ARLU	0.13	0.56	0.13
4884	ARTR	1.19	4.00	0.63
4884	BARE	17.88	21.56	4.82
4884	BOCU	0.25	0.77	0.17
4884	BRIN	0.88	3.37	0.75
4884	BRJA	4.75	6.17	1.38
4884	BRTE	1.50	3.38	0.76
4884	CAMI	0.25	0.77	0.17
4884	COAR	0.25	0.77	0.17
4884	ERST	0.75	3.35	0.75
4884	KOPY	0.13	0.56	0.13
4884	LASE	0.13	0.56	0.13
4884	LIPE	9.25	13.08	2.93
4884	LITR	79.00	22.43	5.01
4884	MEOF	0.75	1.18	0.26
4884	POCO	3.88	8.56	1.91
4884	PSES	0.13	0.56	0.13
4884	RACO	0.13	0.56	0.13
4884	SAKA	0.25	0.77	0.17
4884	STVI	7.00	9.75	2.18
4884	SYOC	0.13	0.56	0.13
4884	TAOF	0.38	0.92	0.20

Table 53. Cover by lifeform.

Field	Life-form	%Canopy cover	SD	SE
1851	BARE	12.75	16.04	3.59
1851	CIA	5.81	11.58	1.83
1851	CIP	0.67	2.76	0.36
1851	CNP	13.72	19.68	2.20
1851	FORB	0.63	1.88	0.15
1851	LEGU	0.94	4.78	0.53
1851	LITR	81.50	23.68	5.30
1851	MOSS	0.13	0.56	0.13
1851	SDGE	0.13	0.56	0.13
1851	WNP	1.88	7.21	0.93
2832	BARE	15.63	14.09	3.15
2832	CIA	3.88	9.00	1.42
2832	CIP	0.95	6.42	0.64
2832	CNA	0.13	0.56	0.13
2832	CNP	9.46	18.56	1.69
2832	FORB	1.80	9.17	0.78
2832	LEGU	3.19	8.92	1.41
2832	LITR	84.38	14.09	3.15
2832	ROCK	0.13	0.56	0.13
2832	SHRB	3.63	13.96	2.21
2832	WNP	0.25	0.77	0.17
3801	BARE	4.38	4.58	1.02
3801	CIA	18.56	17.59	2.78
3801	CIP	0.38	2.00	0.26
3801	CNA	0.13	0.56	0.13
3801	CNP	6.68	16.26	1.63
3801	FORB	1.29	5.58	0.33
3801	LEGU	6.50	21.55	1.97
3801	LITR	95.00	5.13	1.15
3801	MOSS	1.38	3.39	0.76
3801	SDGE	0.13	0.56	0.13
3801	SHRB	0.13	0.56	0.13
3801	WNP	0.13	0.56	0.13
3821	BARE	23.00	20.04	4.48
3821	CIA	4.88	9.30	2.08
3821	CIP	2.42	9.77	1.26
3821	CNA	1.13	3.39	0.76
3821	CNP	10.25	20.36	2.04
3821	FORB	2.32	7.75	0.50
3821	LEGU	0.56	1.06	0.17
3821	LITR	78.88	18.59	4.16
3821	SHRB	5.13	19.10	4.27
3821	WNP	1.06	5.93	0.94

Table 53, continued.

Field	Life-form	%Canopy cover	SD	SE
3841	BARE	15.25	18.39	4.11
3841	CIA	2.94	6.84	1.08
3841	CIP	2.06	10.09	1.60
3841	CNA	3.13	5.25	1.17
3841	CNP	8.57	18.15	1.53
3841	FORB	0.53	3.11	0.20
3841	LEGU	2.04	6.97	0.90
3841	LITR	70.25	27.08	6.06
3841	SHRB	0.75	3.35	0.75
3841	WNP	0.38	2.00	0.26
3852	BARE	9.50	20.09	4.49
3852	CIA	18.81	22.14	3.50
3852	CIP	9.94	23.00	3.64
3852	CNP	8.53	14.41	1.44
3852	FORB	1.22	4.85	0.36
3852	LEGU	1.88	8.39	1.88
3852	LITR	86.13	22.47	5.02
3852	WNP	0.75	3.35	0.75
4801	BARE	6.75	13.67	3.06
4801	CIA	7.25	9.96	1.58
4801	CIP	0.50	2.42	0.38
4801	CNP	10.04	12.70	1.64
4801	FORB	2.67	10.36	0.82
4801	LEGU	4.41	13.76	1.54
4801	LITR	91.00	12.86	2.88
4801	MOSS	0.75	3.35	0.75
4852	BARE	37.50	29.90	6.69
4852	CIA	1.19	2.53	0.40
4852	CIP	7.94	19.56	3.09
4852	CNP	8.44	16.20	1.81
4852	FORB	1.91	7.79	0.50
4852	LEGU	1.17	3.33	0.43
4852	LITR	53.63	31.41	7.02
4852	WNP	0.56	2.43	0.38
4861	BARE	34.63	27.41	6.13
4861	CIA	1.44	3.34	0.53
4861	CIP	0.88	3.33	0.53
4861	CNP	6.96	12.93	1.18
4861	FORB	4.64	14.43	0.97
4861	LEGU	0.63	2.45	0.39
4861	LITR	60.75	24.52	5.48
4861	WNP	0.13	0.56	0.13

Table 53, continued.

Field	Life- form	%Canopy Cover	SD	SE
4862	BARE	34.63	27.41	6.13
4862	CIA	5.88	13.65	2.16
4862	CIP	4.75	20.16	3.19
4862	CNP	9.02	16.14	1.47
4862	FORB	0.40	1.92	0.14
4862	LEGU	6.25	13.16	1.70
4862	LITR	54.88	27.54	6.16
4862	WNP	2.96	7.89	1.02
4881	BARE	31.13	24.12	5.39
4881	CIA	5.81	12.76	2.02
4881	CIP	0.38	0.92	0.20
4881	CNP	9.56	20.77	1.90
4881	FORB	2.25	8.50	0.53
4881	LEGU	1.15	6.58	0.66
4881	LITR	68.13	25.62	5.73
4881	SHRB	0.28	1.73	0.19
4881	WNP	0.13	0.55	0.09
4884	BARE	17.88	21.56	4.82
4884	CIA	3.13	5.18	0.82
4884	CIP	1.25	4.79	0.54
4884	CNP	11.13	19.45	1.78
4884	FORB	2.47	8.59	0.58
4884	LEGU	0.44	0.96	0.15
4884	LITR	79.00	22.43	5.01
4884	SHRB	0.83	3.31	0.43
4884	WNP	0.25	0.77	0.17

Table 54. Production by lifeform (kg/ha).

FIELD	AGE	CNP	CIP	CIA	WNP	FORB	LITTER	TOTAL
4884	2	1898	101	85	1	432	1649	2533
4881	3	1846	17	104	0	550	1438	2532
4862	4	1116	436	84	56	366	1667	2058
4852	5	1327	296	39	15	638	1056	2325
4861	5	594	37	13	0	1036	1436	1679
1851	6	1486	28	151	34	46	1893	1745
3852	6	1330	408	593	1	247	1803	2579
3841	7	1991	43	71	17	436	1603	2645
2832	8	1853	58	60	11	570	1949	2552
3821	9	1665	58	48	0	337	1293	2212
4801	10	947	7	232	0	600	2754	1768
3801	10	468	19	493	0	865	1922	1851

*TOTAL reflects total productivity of all lifeforms without litter. Shrub data were omitted from this table (See Table 53, Appendix B).

Table 55. Analysis of variance for production of standing biomass without litter.

Dependent Variable: LITLSWT

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	7082.059117	1011.722731	1.41	0.2013
Error	231	165526.528371	716.565058		
Corrected total	238	172608.578488			
R-Square		C.V.	Root MSE	LITLSWT Mean	
0.041030		48.29082	26.76873	55.4323431	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
AGE*TOTDPTH*SEDIST					
1	1	88.6362235	88.6362235	0.12	0.7254
AGE*TOTDPTH					
1	1	1.4392071	1.4392071	0.00	0.9643
AGE*SEDIST					
1	1	43.0728701	43.0728701	0.06	0.8065
TOTDPTH*SEDIST					
1	1	553.7554624	553.7554624	0.77	0.3803
AGE					
1	1	3.0397099	3.0397099	0.00	0.9481
TOTDPTH					
1	1	343.8650436	343.8650436	0.48	0.4892
SEDIST					
1	1	758.7568468	758.7568468	1.06	0.3045

Table 56. Analysis of variance for percent cover.

Dependent Variable: COVSUM					
Source	DF	Sum of squares	Mean square	F value	Pr > F
Model	2	1134.15572	5567.07786	5.03	0.0072
Error	237	262260.74011	1106.58540		
Corrected total	237	262260.74011			
R-Square		C.V.	Root MSE		COVSUM Mean
0.040726		33.42554	33.26538		99.5208333
Source	DF	Type III SS	Mean square	F value	Pr > F
TSDPTH*PLNTD					
1	1	3402.197685	3402.197685	3.19	0.0755
Parameter		Estimate	T for HO: Parameter=0	Pr>T	Std. error of estimate
Intercept		117.5491911	9.46	.0001	12.4291729
TSDPTH*PLNTD	1	-0.8530594	-1.93	.0550	0.4424442
	2	-0.3626797	-0.97	.3324	0.3734210

*PLNTD 1=spring seeded, PLNTD 2=fall seeded.

Table 57. Analysis of variance for percentage of invading species.

Dependent Variable: PCTINVDR					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.89172749	1.44586374	84.16	0.0001
Error	237	4.07142508	0.01717901		
Corrected total	239	6.96315257			
R-Square		C.V.	Root MSE	LITLSWT	
0.415290		31.18068	0.131069	0.42035232	
Source	DF	Type III SS	Mean Square	F Value	Pr > F
Age	1	2.65888382	2.65888382	154.78	0.0001
Edge	1	0.35408274	0.35408274	20.61	0.0001
Parameter	Estimate	T for HO: Parameter=0	Pr>T	Std. error of estimate	
Intercept	0.0162007061	0.41	0.6850	0.0398945	
Age	0.0418574551	12.44	0.0001	0.0033645	
Edge	0.0005147488	4.54	0.0001	0.0001133	

Table 58. Summary of invasion for all fields.

Field	Age	Edge (m/ha)	Planted	Total seeded species	Species within frames	No. of invader species	Rich- ness
3801	10	377	fall	4 +cover	35	31	14
4801	10	238	spring	4 +cover	19	17	9
1851	6	245	spring	15	28	15	9
3841	7	222	fall	15+cover	31	23	12
3852	6	299	fall	15	20	14	12
4852	5	259	spring	16	25	17	12
4861	5	196	fall	21	24	13	11
4862	4	307	spring	19	26	13	13
4884	4	307	spring	19	26	13	10
4881	3	211	fall	15	33	22	11
2832	8	183	spring	18+cover	26	20	14
3821	9	353	fall	4 +cover	27	25	12

APPENDIX C

WESTERN ENERGY COMPANY SEED MIXES

Table 59. Western Energy Company (WECO) historical seed mixes reported in this study.

Mix 18: Uplands-cool season mixture

Species and variety		Percent of mix
AGSM	Rosanna	40
AGTRA		5
AGDA	Critana	25
STVI		30

Mix 19: Uplands-cool season mixture

Species and variety		Percent of mix
AGSM	Rosanna	40
AGTRA		5
AGDA	Critana	25
STVI		30

Mix 20: Supplemental mixture

Species and variety		Percent of mix
ORHY	Nezpar	12
BOGR		2
BOCU		33
RACO		3
ECAN		3
LIPE		2
ARCA		2
ASFA		1
GAAR		.5
ACMI		.3
ONVI	Eski	9
ASCI	Lutana	6
ATCA		15
CELA		11

Table 59, continued.

Mix 22: Uplands-cool season mixture

Species and variety		Percent of mix
AGSP	Secar	24
AGSM	Rosanna	20
AGTRA		10
AGDA	Critana	11
STVI	Lodorm	34
POCO	Ruebens	1

Mix 24: Supplemental mixture

Species and variety		Percent of mix
CALO	Goshen	7
ORHY	Nezpar	7
BOGR		14
BOCU	Bueree	8
BOCU	Pierre	8
ANHA	Gardner	12
PEPU	Kaneb	11
RACO		6
LIPE		3
ACMI		1
ASCI		7
ONVI	Eski	11
ATCA	Wytana	1
ATCA	Nuttals	3

Mix 25: Supplemental mixture

Species and variety		Percent of mix
BOGR		26
KOPY		4
POCA		18
ACMI		9
PEPU		26
RACO		4
SPCO		2
LIPE		9
ARCA		2

Table 59, continued.

 Mix 26: Warm Season Mixture

Species and variety		Percent of Mix
AGSP	Whitmar	10
AGSM	Rosanna	5
CALO	Goshen	20
BOGR		25
SCSC	Camper	20
ANHA	Garden Co.	20

 Mix 27: Supplemental mixture

Species and variety		Percent of mix
BOGR		27
POCA		21
PEPU		27
ACMI		9
LIPE		9
PECA		4
SPCO		2
ARCA		1

 Mix 28: Uplands mixture

Species and variety		Percent of mix
ADTRA	Revenue	18
AGSP	Secar	18
AGSM	Rosanna	12
AGDA	Critana	4
STVI	Lodorm	18
STCO		3
ORHY	Nezpar	18
BOCU		11

Table 59, continued.

 Mix 29: Uplands mixture

Species and variety		Percent of mix
AGTRA	Revenue	17
AGDA	Critana	5
AGSP	Secar	13
AGSM	Rosanna	17
STVI	Lodorm	11
STCO		9
BOCU		17
CELA		11

 Mix 30: Supplemental mixture

Species and variety		Percent of mix
PEPU		27
LIPE	Apar	9
ACMI		9
RACO		4
SPCO		2
BOGR		27
POCA	Canbar	18
KOPY		4

 Mix 33: Uplands mixture

Species and variety		Percent of mix
AGSP	Secar	20
STVI		20
AGSM		20
AGTRA		15
CELA		10
AGDA	Critana	10
BOCU		5

Table 59, continued.

Mix 36: Cover crop

Species and variety	Percent of mix
Wintergraze	100

Mix 37: Cover crop

Species and variety	Percent of mix
TRAE	100

APPENDIX D
SOIL ANALYSES

Table 60. Soil analyses.

Field	Texture	pH topsoil	pH subsoil	EC topsoil (mmhos/cm)	EC subsoil (mmhos/cm)
3801	Loamy sand	8.05	8.21	0.64	0.81
4801	Sandy loam	8.28	8.0	0.78	0.73
1851	Loamy sand	8.05	8.06	0.49	0.60
3841	Loamy sand	7.92	8.04	0.58	0.50
3852	Loamy sand	7.84	7.73	0.49	1.39
4852	Loamy sand	8.23	8.05	0.58	0.45
4861	Loamy sand	8.08	8.14	0.66	0.53
4862	Loamy sand	7.84	8.09	0.49	1.40
4884	Loamy sand	7.80	8.10	0.40	0.63
4881	Loamy sand	7.88	7.61	0.50	0.49
3821	Loamy sand	7.88	8.35	0.59	0.52
2832	Loamy sand	8.24	8.37	0.60	0.44



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