

Plant succession on five naturally revegetated strip-mined deposits at Colstrip, Montana
by Chester Lee Skilbred

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Range Science
Montana State University
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Abstract:
In contrast to many studies concerning artificial restoration of strip mined deposits, this two-year study dealt with the development of vegetation through natural succession on strip mined overburden deposits within the Colstrip, Montana area.

Plant communities on five, fifty-year-old strip mined overburden deposits were examined and their similarity to native range vegetation was determined. The communities were analyzed in terms of species cover, biomass, and frequency. In addition, standard soil analyses were obtained.

Intrinsic and extrinsic factors affecting secondary succession for each community were derived from the data compiled. Natural revegetation of the strip mined areas was determined from the nature of the adjacent vegetation, the nature of the spoil deposits, and ecological requirements of the vegetation.

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Date May 30, 1979

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A thesis submitted in partial fulfillment
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ABSTRACT

In contrast to many studies concerning artificial restoration of strip mined deposits, this two-year study dealt with the development of vegetation through natural succession on strip mined overburden deposits within the Colstrip, Montana area.

Plant communities on five, fifty-year-old strip mined overburden deposits were examined and their similarity to native range vegetation was determined. The communities were analyzed in terms of species cover, biomass, and frequency. In addition, standard soil analyses were obtained.

Intrinsic and extrinsic factors affecting secondary succession for each community were derived from the data compiled. Natural revegetation of the strip mined areas was determined from the nature of the adjacent vegetation, the nature of the spoil deposits, and ecological requirements of the vegetation.

INTRODUCTION

Montana's Strip Mining and Reclamation Act of 1973 stipulated that surface mined areas must be returned to a condition similar to that of the area prior to mining. Packer (1974) estimated the time for surface mine rehabilitation in eastern Montana to be from five to ten years. Conversely, Curry (1973) estimated that in the West, unless sites were watered for 200 to 2,000 years, reclamation to the point of self-sustenance was not possible.

A thorough understanding of succession is of vital importance because of the contrast between nature's strategy of succession and priorities adopted by man in making decisions affecting landscapes and vegetation. A two-year study was initiated in 1976 to examine succession on five naturally revegetated spoil deposits at Colstrip, MT. This research project was in conjunction with Sindelar's (1977) study on the establishment, succession, and stability of vegetation on surface-mined lands in eastern Montana.

Initial investigation revealed five sites composed of excess mining overburden deposited during mining operations in 1927 and 1928. Since each of the five spoil deposits was composed of excess overburden from the same mined area, the parent material of each spoil deposit should have been similar. Directional orientation, elevation, and macroclimate of the five spoil deposits corresponded;

therefore, conditions promoting the establishment of similar plant communities should have been present.

Further investigation at each of the five study sites showed that the established plant communities were ecologically dissimilar. Dominant species varied from shrubs to halfshrubs to perennial grasses to annual grasses or to a combination of these.

Due to the complex vegetational composition on these sites, two major problems needed to be analyzed: (1) causal factors which affected the origin of the present vegetational composition, and (2) factors which are maintaining the present species composition. The questions of origin and maintenance of vegetational composition are clearly separate because factors influencing each may not be the same.

In view of this, specific objectives of this research project were:

(1) the description and identification of plant communities on five, selected 1928 spoil deposits in the vicinity of Colstrip, Montana, and

(2) the determination of specific factors affecting successional advancement of each of the five communities.

LITERATURE REVIEW

When major disturbances of natural vegetation occur, the orderly and progressive replacement of one community by another evolves until a relatively stable community occupies the disturbed area. This orderly and progressive replacement of one community for another is defined as ecological succession (Chapman, 1973).

Succession is a developmental aspect of an ecological system. (Reiners et al., 1971). Furthermore, ecological relationships of an ecosystem's existing vegetation may be understood by studying successional patterns occurring within the ecosystem. Studies of succession are used to clarify the status and distribution of various species and communities within an ecosystem.

Because the constituents of a plant community vary in age, longevity, and ecological amplitude, a continuous turnover of individual species within a community occurs. As individual species die, others of the same stratum may expand to occupy their space; or these species may be replaced by younger, suppressed species. This concept of succession suggests that a plant community cannot remain completely stable.

Changes that occur within plant communities are not haphazard. Similar habitats support similar communities; and these habitats may have a sequence of vegetational dominants that tend to succeed

each other in the same progression. Trends in a community within a given habitat in a climatic area are predictable. Successional changes in a plant community are normally gradual, continuous, often reliable, and in part, controlled by the community itself.

Causes of Succession

Cowles (1911) recognized three broad categories of succession and outlined some causal factors. The categories were: (1) regional successions -- those attributed to widespread climatic changes; (2) topographic successions -- those associated with changes in topography which resulted from erosion and deposition, and (3) biotic successions -- those due to plant and animal agents (McCormick, 1968).

The specific cause of a successional change within a community may not be obvious due to the complex interrelationship of intrinsic and extrinsic community properties. Kershaw (1964) stressed that successional changes were induced by environmental changes or by intrinsic properties of the plants; Smith (1974) postulated that successional changes were brought about by the organisms themselves. Smith (1974) showed that as organisms exploited the environment, their own life activities made the habitat unfavorable for their survival but suitable for survival by another group of organisms.

Oosting (1958) concluded that two general types of directional or habital changes could result in the modification of a community's structure or composition. He noted that the development of a community caused parallel developmental changes to the environment which could modify the environment materially.

Conclusively, a community's composition is determined by the total environment of the ecosystem rather than by an individual aspect of the environment. Since the characteristics and the edaphic and biotic interrelationships of each species are involved, succession represents an ecocline in time (Smith, 1974; Whittaker, 1975).

Concepts of Climax

Pioneer stages of primary succession are slow because their progression occurs only with soil development. In contrast, the early stages of secondary succession may be remarkably rapid; dominant species may change every year. Unfortunately, a model of succession is not applicable to all instances, but certain trends appear in most cases (McCormick, 1968; Odum, 1969).

Examples of succession show that vegetation develops to a certain degree of equilibrium (Cowles, 1899; Dansereau and SeGadas-Vianna, 1952; Knight, 1965; Krebs, 1972). The final equilibrium

stage of succession is termed climax (Whittaker, 1975). Smith (1974) defines climax as the terminal community characterized by species diversification, well-developed spatial structures, complex food chains, and an equilibrium between production and respiration. Braun-Blanquet (1932) defined climax as the development of vegetation and the formation of soil toward a definite end-point determined and limited by climate. Mueller-Dombois and Ellenberg (1974) viewed a climax community as being in equilibrium with the prevailing environmental factors of the habitat whereby the member species were in dynamic balance with one another.

The nature of climax has been the subject of considerable debate. Over the years, three theoretical approaches have evolved (monoclimax, polyclimax, and pattern-climax).

The monoclimax concept states that if an area is given sufficient time, all ecosystems will pass through successional sequences to a single climax type controlled by the regional climate (Mueller-Dombois and Ellenberg, 1974). This concept of climate-climax as the normal end-point of succession is due largely to the work of Clements (1916).

Another approach is the polyclimax theory (Tansley, 1935). This theory postulates that the climax vegetation of a region consists of a number of climax communities controlled by soil

moisture, soil nutrients, topography, slope exposure, fire, and animal activity.

The third theory, pattern-climax, postulates that undisturbed communities generally intergrade with one another along environmental gradients. Pattern-climax is a theoretical concept in which a steady-state community's characteristics are determined by the characteristics of its own habitat (Whittaker, 1975).

Influences on Succession

The final stage of succession, climax, is self-maintaining and long-lived provided it is free from disturbance. However, extensive areas of original climax vegetation no longer exist throughout most of the settled parts of North America and other continents (Smith, 1974). Therefore, internal and external disturbances (drought, competition, grazing, and strip-mining) as well as soil characteristics are influential factors in successional development.

Drought

As a result of drought conditions in true and mixed prairie grasslands, high percentages of herbaceous vegetation may disappear. Mortality is usually greatest among species with relatively short root systems; i.e., little bluestem (*Andropogon scoparius*), prairie junegrass (*Koeleria cristata*), and needleandthread (*Stipa comata*).

Species with deeper root systems are injured to a lesser degree; i.e., big bluestem (*Andropogon gerardii*) (Weaver, 1968).

Since severe drought may damage or kill many plants, an immediate adjustment in species relationships results. Various species resprout and recolonize a drought affected area. Annuals and/or deep-rooted rhizomatous grasses were the primary drought-resistant species to appear following the great drought of the 1930's (Weaver, 1954). So abundant were these invading weed species that many depleted grasslands resembled abandoned fields rather than the true prairie.

Following drought, secondary succession on badly depleted ranges occurred in four stages (Albertson and Weaver, 1944). In the first two stages, annual forbs and grasses were dominant species. Russian thistle (*Salsola kali*), lambsquarters goosefoot (*Chenopodium album*), narrowleaf goosefoot (*Chenopodium leptophyllum*), common sunflower (*Helinathus annuus*), and sixweeks fescue (*Festuca octoflora*) were the dominant annual species of the first and second stages. In the final two stages, annual forbs and grasses were suppressed by perennial grasses. Sand dropseed (*Sporobolus crytandrus*), western wheatgrass (*Agropyron smithii*), sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis*), and buffalograss (*Buchloe dactyloides*) were the dominant perennial grasses of the third and fourth stages.

Drought is capable of retarding succession, influencing species composition, and reshaping the characteristics of a community (Weaver, 1968). Therefore, the composition of pre-drought and post-drought communities may be different. In this way, drought has changed the species composition of many existing ecosystems.

Grazing

Grazing by domestic and wild animals alters successional patterns (Smith, 1974). The effect of grazing on certain species in a community may handicap those species and encourage others. Ellison (1960) reported that heavy grazing caused a reduction of palatable grasses and forbs and a subsequent increase in shrubby species.

When grazing causes substantial herbage reduction, the microclimate is altered. This alteration is responsible for increased evaporational losses which usually create a warmer and drier microenvironment. The resulting drought condition may enhance invasion of the grazed lands by weedy species (Ellison, 1960).

Piemeisel (1938, 1951) studied the relationship between invasion of weedy species and overgrazing in Idaho. During the first two years of his study, the area was dominated by Russian thistle. Annual mustards (*Descurainia* spp.; *Sisymbrium* spp.)

dominated the next two years; and from the fifth year onward, cheatgrass (*Bromus tectorum*) was the dominant species.

Successional trends are roughly proportional to grazing intensity; i.e., they are pronounced under severe intensity and difficult to distinguish at light or moderate grazing levels (Ellison, 1960). Therefore, sequences of annual succession can be interrupted and retarded by continued excessive livestock grazing (Ellison, 1960).

Strip Mining

Established ecosystems are disrupted drastically by strip mining. These operations bring undisturbed, unweathered rock strata to the surface. Nutrients in these disturbed strata would normally have been leached and recycled slowly; but when strip mining operations move them to the surface, they are subjected to rapid weathering and chemical actions. Nutrients and other elements are then released in greater amounts than plants can utilize and/or tolerate.

Pioneer vegetation that invades strip mined areas is usually determined by the nature of the spoil, the nature of adjacent vegetation, and the habitat requirements of the vegetation (Hall, 1956; Leisman, 1957).

The microrelief of spoil banks plays a major role during the first years of plant invasion. Small depressions and ridges in the surface of spoil banks provide areas for disseminule retention and reservoirs for precipitation collection.

Parent material of the spoils was also responsible for the texture and chemistry of the resulting substrate.

From a chemical and physical standpoint, a very important characteristic of spoil material is clay content (Leisman, 1957). With increases in clay content, water holding capacity and base exchange capacity of the soil increase. These characteristics are of major importance to plant growth and plant nutrition.

Competition

Harper (1977) defined competition as changes in the environment brought about by the proximity of individual plants. Research has shown that the presence of a plant changed the environment of its neighbors. Accordingly, each plant tends to alter its neighbor's growth rate and form.

Daubenmire (1968) noted that competition is more intense when the needs of two organisms are similar; intraspecific competition is more keen than interspecific competition. Weaver and Clements (1938) stated that competition occurs between plants when the supply of a single, necessary factor falls below the combined demands of

the plants. Risser (1969) stressed that competition among organisms is evident when simultaneous demands for identical resources exceed the immediate supply.

Harper (1977) stated that plants are in competition for many factors: (1) space -- above ground and below ground, (2) light -- above ground, (3) carbon dioxide -- above ground, (4) nutrients -- below ground, and (5) water -- below ground. Other studies have shown that the severity of species competition varies with the season and the habitat (Daubenmire, 1968).

The following plant characteristics are also significant in competition: morphological structure, the ability to obtain nutrients, seed production, seed dissemination, depth of root systems, rate of growth, time of initial growth, longevity, time of root penetration, reproductive potential, and endurance in drought (Daubenmire, 1968). Any of these characteristics may affect the competitive ability of a species.

Competition among life forms and species is a fundamental process in succession (Mueller-Dombois and Ellenberg, 1974); any adaption that helps the plant cope with or modify its environment enables the species to achieve a higher competitive advantage. Therefore, the outcome of competition is dependent upon the inherent qualities of the competing species, modified by the

abiotic and biotic environments, and controlled by available habitatal resources.

Soil Characteristics

Soil characteristics important in plant community distributions include soil texture, soil depth, soil pore size, kinds and quantities of clay minerals, permeability, available nutrients, organic matter content, soil moisture characteristics, slope, topography, and exposure (Branson et al., 1965). Coupland's (1950) studies of mixed prairies revealed that as soil textural classes varied, vegetative types also varied. Within a given area, vegetation may follow a pattern of distribution determined by the physical and chemical properties of the soil (Taylor and Valum, 1974).

Study Methods

Several methods are available to study vegetational changes within an area. Side-by-side comparison of contemporary communities and studies on the same area are two of the most common (Mueller-Dombois and Ellenberg, 1974).

Side-by-Side Comparison

Because few researchers have followed successional/vegetational changes that occurred within a community for any length of time,

most research on secondary plant succession has relied upon information from comparisons of spatially disjunct side-by-side communities (McCormick, 1968; Drury and NisBet, 1973; Horn, 1974). Such studies assume that all factors relating to the study sites, except age, were effected under a sufficiently similar set of environmental conditions. The similarities in environmental conditions allowed the reconstruction of vegetational change which has occurred through time.

A recent study tested the hypothesis that understory or herbaceous vegetation was similar in areas where dominant overstory vegetation was structurally and functionally similar (Keeley and Johnson, 1977). Results indicated a close similarity in shrub growth but a significant dissimilarity in herbaceous growth.

Successional information can also be inferred from side-by-side studies of communities where the dates of disturbance or starting time of succession are known. Studies of plant diversity in chronosequences examined and evaluated the changes in plant diversity during primary succession (Lawrence, 1958; Reiners et al., 1971). Also, long-term studies of plant reinvasion have been conducted on bare areas (Cooper, 1923, 1931, 1939). Results showed that the evenness of distribution of foliar cover among species was erratic but tended to increase with age.

Similarly, Squires and Wistendahl (1977) examined stages of early secondary succession on plant species diversity in an experimental old-field system. From their study, it was evident that a general trend of increased species richness occurred through time (Odum, 1960; Golley, 1965).

Studies on the Same Area

Although a general pattern of plant succession can be established by side-by-side comparison research, the dynamics of secondary succession require intensive research on the same area. This method of study uses the following techniques for analysis of vegetational changes: (a) permanent quadrats or transects, (b) photos taken at different times, (c) studies within exclosures, and (d) comparision of existing vegetation with earlier vegetational records.

Vegetational changes are best studied by a means of permanent quadrats or transects. Daubenmire (1968) stated that herbaceous vegetation can be periodically re-evaluated by taking quantitative measurements along a relocatable line transect. Watt's (1957, 1960, 1962) studies of long-term changes on grasslands, Thomas's (1960) work on changes in vegetation since the advent of myxomatosis, and Cooper's (1923, 1931, 1939) research on plant reinvasion on bare

areas documented and verified the importance of permanent quadrats as a valid method of study.

Photographs of the same area taken at different times are useful in successional studies. If the exact point is relocated and if a camera of the same focal length is used, comparison of past vegetational photographs with more recent ones clearly shows changes in vegetation (Daubenmire, 1968; Chapman, 1976).

Aerial photographs are also used in studies of succession. Although the detail obtainable from aerial photography is limited by scale, general vegetative structural changes can be evaluated by this technique (Wilken, 1967).

Exclosure studies with permanent quadrats allow investigation of the cause of community development when most grazing animals are excluded (Mueller-Dombois and Ellenberg, 1974). Exclosures are often designed primarily to demonstrate the type and amount of vegetation that land supported when it was free from biotic factors (Brown, 1954). Brown (1954) also stated that exclosures provided an environment for study of undisturbed succession.

Written descriptions of vegetation of an area at earlier dates tend to reveal useful information about succession. The most common source of early written descriptions of vegetation is land survey records (Eric, 1956); old survey records are available for

most of the continental United States. The advantage of these records is that they were written "on-the-spot" according to a previously determined plan. They constitute a definite sample of the vegetation; thus they may be usable for quantitative as well as qualitative analysis (Eric, 1956).

The usefulness of early vegetational records depends entirely upon the objectives of the study. Although historical records may be useful in determining or reflecting vegetational changes over time, they may not show the potential vegetative climax of a region.

STUDY AREA

Study Site Location

Intensive research in the Colstrip, Montana area (Figure 1) is significant because mining activity has disturbed approximately 1,416 ha of native vegetation in this region since 1924. Presently an estimated 7,770 ha of reserve coal is mineable near Colstrip, Montana (Montana Department of Natural Resources, 1974).

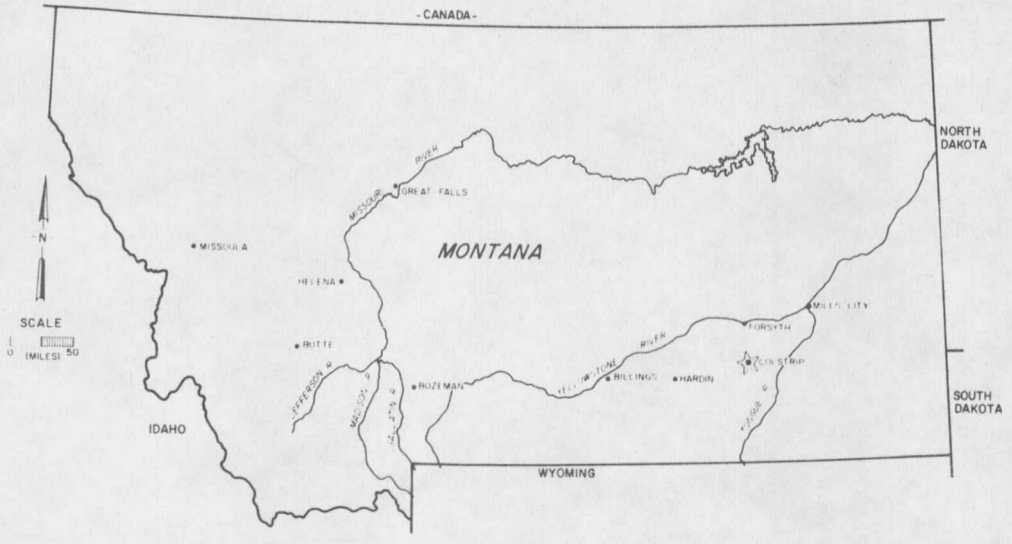


Figure 1. Location of Colstrip, Montana.

Six study sites were located approximately 1.5 km southeast of Colstrip, Montana, in Rosebud County (Section 3, T1N, R42E, and

Section 35, T2N, R42E of the Montana Principal Meridian). Five study sites were located on flattened mounds of excessive overburden and one study site was located on unmined, native rangeland (Figure 2). The five flattened mounds were approximately 0.6 ha in size while the native range study site was approximately 0.03 ha in size.

Early draglines were capable of manipulating approximately 15 m of overburden materials (Schafer et al., 1976). Any material that exceeded 15 m was considered excess overburden and was removed by shovel and truck operations prior to the removal of overburden above the coal vein (Figures 3 and 4).

Material that formed the five study site waste mounds was removed from Pit 1 during mining operations dating from October, 1927 through November, 1928 (Figure 5). The maximum depth of overburden in Pit 1 was approximately 20 m; therefore, the material forming the waste mounds of the five study sites was excessive overburden and was composed of the upper five m of the total overburden profile of Pit 1 (Figure 6).

Topography

The topography of the Colstrip area is largely determined by resistence of geologic strata to erosion (Bennett et al., 1976). Rolling prairies with alternating ridges, drainages, and sandstone



Figure 2. Study sites located near Colstrip, Montana.



Figure 3. A Bycyrus-Erie shovel is shown loading excessive overburden on side-dump trucks in 1929 (Dean Collection).



Figure 4. Side-dump trucks unloading excessive overburden on spoil deposits in 1929 (Dean Collection).

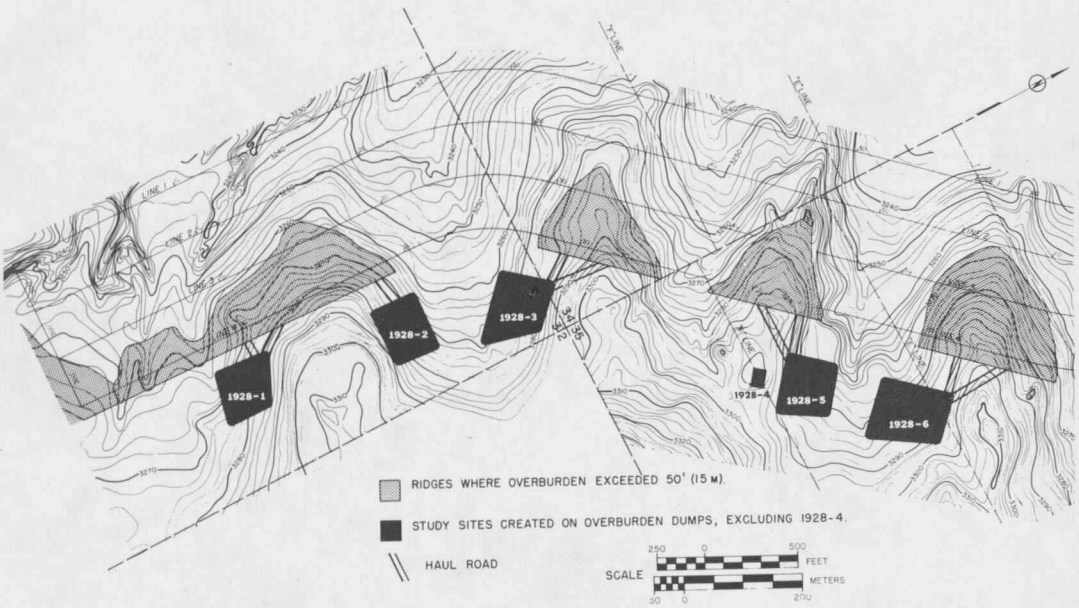


Figure 5. Topographic map of Study Sites near Pit 1.

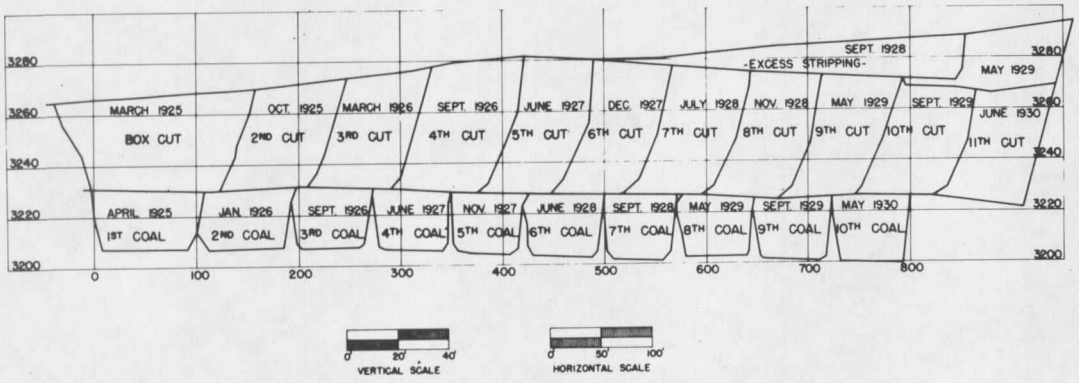


Figure 6. Cross-sectional profile of Pit 1 which indicates coal cuts, overburden cuts, and areas of excess stripping (Western Energy Company).

bluffs characterized the landscape patterns. Drainages of the area are mainly oriented in a northerly direction; stream water ultimately flows into the Yellowstone River.

Study Site Topography

Site 1928-1. This site was a rectangular mound approximately 91 m long by 45 m wide. The long side of the mound was oriented east and west; the short side of the mound was oriented north and south. The surface was 1,008 m above sea level and covered an area of approximately 0.41 ha. The surface of the mound sloped one percent (1%) to the north and west with the northwest corner 2.6 m lower than the rest of the mound.

Site 1928-2. This site was a rectangular mound approximately 100 m long by 61 m wide. The long side of the mound was oriented east and west; the short side of the mound was oriented north and south. The surface was 1,012 m above sea level and covered an area of approximately .61 ha. The surface of the mound sloped three percent (3%) to the south and west with the southwest corner 2.5 m lower than the rest of the mound.

Site 1928-3. This site was a rectangular mound approximately 122 m long by 63 m wide. The long side of the mound was oriented east and west; the short side of the mound was oriented north and south. The surface was 1,012 m above sea level and covered an area

of approximately .65 ha. The surface of the mound sloped three percent (3%) toward the north with the north side of the mound 1.8 m lower than the rest of the mound.

Site 1928-4. This site was the native range site. It was located between sites 1928-3 and 1928-5. The site's surface was 1,016 m above sea level. It was relatively flat and typical of the native rangeland of this management unit.

Site 1928-5. This site was a rectangular mound approximately 91 m long by 61 m wide. The long side of the mound was oriented northwest by southeast; the short side of the mound was oriented northeast by southwest. The surface was 1,012 m above sea level and covered an area of approximately .55 ha. The surface of the mound sloped four percent (4%) toward the south and west with the southwest corner 1.8 m lower than the rest of the surface.

Site 1928-6. This site was a rectangular mound approximately 106 m long by 91 m wide. The long side of the mound was oriented northeast by southwest; the short side was oriented northwest by southeast. The surface was 1,012 m above sea level and covered an area of approximately .97 ha. The surface of the mound sloped two percent (2%) toward the north with the north side of the mound 1.9 m lower than the rest of the surface.

Topography of the study sites is summarized in Table 1.

Table 1. Summary of study site topography.

SITES	PHYSICAL CHARACTERISTICS					
	LENGTH (m)	WIDTH (m)	AREA (ha)	ELEVATION (m)	SLOPE (%)	ASPECT
1928-1	91	45	.41	1,008	1	Northern
1928-2	100	61	.61	1,012	3	Southern
1928-3	122	63	.65	1,012	3	Northern
1928-4	20	15	.03	1,016	level	--
1928-5	91	61	.55	1,012	4	Southern
1928-6	106	91	.97	1,012	2	Northern

Climate

Cold, dry winters with warm summers characterize the continental climate of the Colstrip area (Brown, 1971). January is the coldest month with a mean temperature of -6.7°C and July is typically the warmest month with a mean temperature of 23.9°C (Munshower and DePuit, 1975).

The annual mean precipitation of Colstrip averages approximately 50 cm (Sindelar and Plantenberg, 1978). Maximum precipitation occurs as rainfall during the months of April, May,

and June (Holechek, 1976). Lowest precipitation occurs during December, January, and March. Monthly temperature and precipitation values for the Colstrip area are presented in Figures 7 and 8.

The average frost-free season is 120-124 days in length (Sindelar et al., 1974). The last spring freeze occurs between May 15-25; and the first fall freeze is expected from September 15-22 (Hodder et al., 1972).

Study Site Microclimate

The climate of the study sites corresponded to Colstrip's climate; the annual mean temperature, precipitation, and frost-free season were similar. However, site microclimate variations resulted from differences in slope, vegetation, and soil. For example, the greatest microclimatic differences existed between the north and the south slopes. Study sites 1928-1, 1928-3, and 1928-6 had north-facing slopes while study sites 1928-2 and 1928-5 had south-facing slopes. South-facing slopes received more solar energy than north-facing slopes. This affected the moisture and heat budget of the sites. On south-facing slopes the evaporation may be fifty percent (50%) higher, average temperature may be higher, and soil moisture may be lower than on north-facing slopes (Smith, 1974).

Vegetation also affected site microclimate. Perennial forbs, grasses, shrubs, and halfshrubs altered wind movement, evaporation

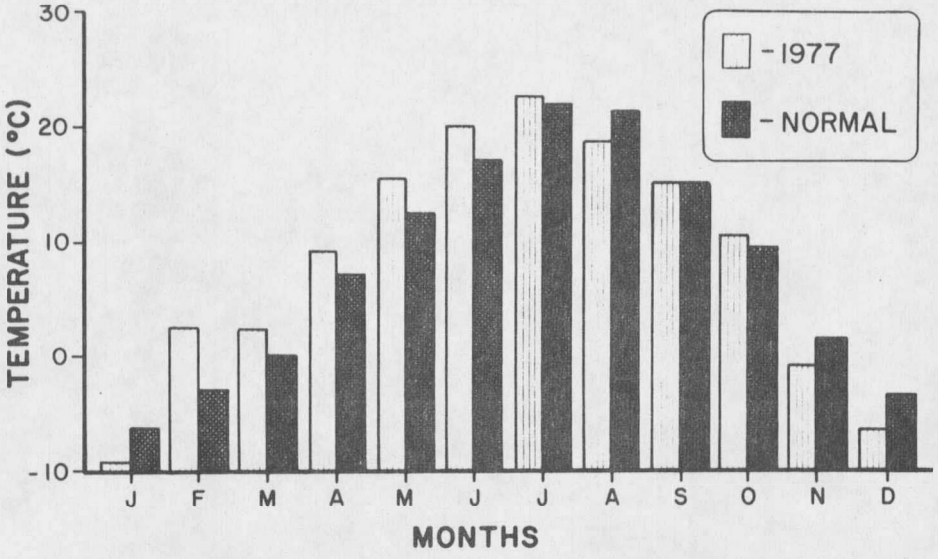


Figure 7. Monthly temperature averages for Colstrip, Montana.

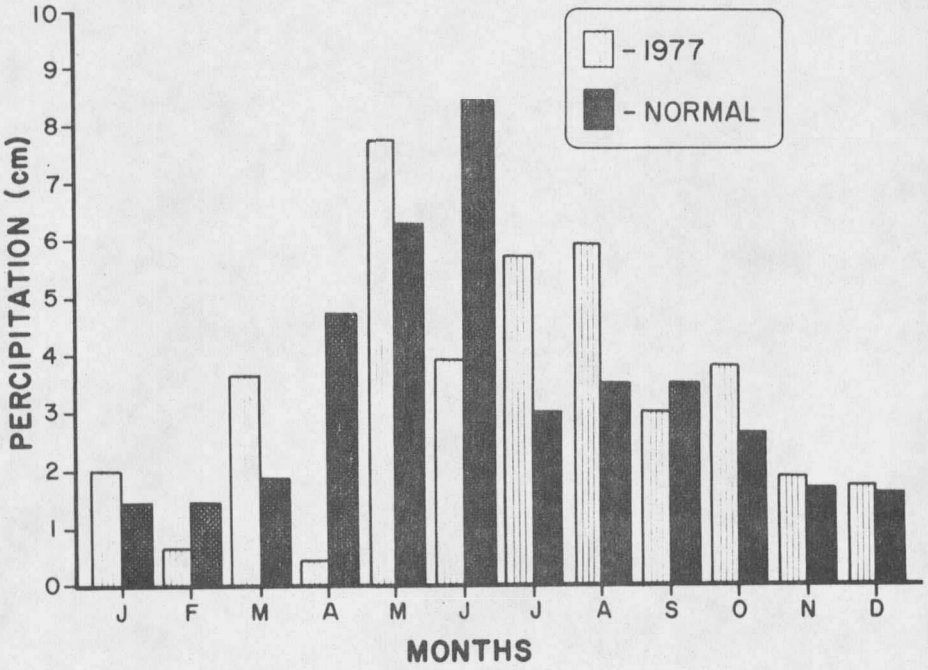


Figure 8. Monthly precipitation averages for Colstrip, Montana.

rates, soil moisture, and temperature. With thin vegetational cover, temperatures are greatest near the soil surface. As the height and density of plant cover increase, plant leaves intercept more solar radiation. Resulting temperatures are highest above the plant crown surface and lowest at the ground surface (Smith, 1974).

Soil properties also modified site microclimate. On light-colored sandy soils, an increase in solar reflection occurs; whereby a reduced amount of solar energy is absorbed. However, on sandy spoil soils, considerable amounts of coal were present which darkened the soil and probably increased the rate of heat absorption. Therefore, the surface temperatures of spoil soils were sometimes higher than the surface temperatures on native range soils.

Vegetation

The Colstrip area is located in the Eastern Montana ponderosa pine (*Pinus ponderosa*) savannah vegetation type (Payne, 1973). Although degraded sites are often dominated by xerophytic shrubs, halfshrubs, and annual grasses, mixed stands of cool and warm season grasses are dominant in the Colstrip area (Munshower and DePuit, 1975).

Important grasses are western wheatgrass, needleandthread, little bluestem, green needlegrass (*Stipa viridula*), blue grama,

prairie junegrass, and others. Important halfshrubs and shrubs are big sagebrush (*Artemisia tridentata*), silver sagebrush (*Artemisia cana*), skunkbush sumac (*Rhus trilobata*), and broom snakeweed (*Gutierrezia sarothrae*) (Munshower and DePuit, 1975). The climax species composition list for an area including Colstrip, Montana is presented in Table 2 (Ross and Hunter, 1976).

Study Site Vegetation

The five 0.6 ha waste mounds of excessive overburden have revegetated naturally. The composition of this vegetation was determined by the species that existed in the surrounding vegetation. Dominant species of each site are listed in Table 3. A complete species list for the study sites appears in Appendix A.

Soils

Soils of the Colstrip area developed directly from different geologic strata (Figure 9). Most soils are light colored due to high calcium or low organic matter content (Bennett et al., 1976). Where extensive beds of coal burned, adjacent shale strata were baked; this produced a reddish-colored iron-oxide porcellanite called scoria (Brown, 1971). Residual soils are located primarily on bedrock uplands, while alluvial soils appear on flood plains, valley bottoms, and upland terraces. Important soils in the Col-

Table 2. Dominants in the climax vegetation at Colstrip, Montana.

SCIENTIFIC NAME	COMMON NAME
Agropyron dasystachyum	Thickspike wheatgrass
Agropyron smithii	Western wheatgrass
Agropyron spicatum	Bluebunch wheatgrass
Andropogon gerardii	Big bluestem
Andropogon scoparius	Little bluestem
Artemisia cana	Silver sagebrush
Bouteloua gracilis	Blue grama
Carex filifolia	Threadleaf sedge
Eurotia lanata	Winterfat
Koeleria cristata	Prairie junegrass
Rhus trilobata	Skunkbush sumac
Stipa comata	Needleandthread
Stipa viridula	Green needlegrass
Symphoricarpos occidentalis	Western snowberry

Table 3. Dominant species on the Colstrip study sites during 1976 - 1977.

SITE	DOMINANT SPECIES	
	COMMON NAME	SCIENTIFIC NAME
1928-1	Falsetarragon sagewort Cheatgrass Japanese brome	*Artemisia dracunculus* *Bromus tectorum* *Bromus japonicus*
1928-2	Western wheatgrass Japanese brome Cheatgrass Prairie junegrass Needleandthread	*Agropyron smithii* *Bromus japonicus* *Bromus tectorum* *Koeleria cristata* *Stipa comata*
1928-3	Silver sagebrush Falsetarragon sagewort Cheatgrass	*Artemisia cana* *Artemisia dracunculus* *Bromus tectorum*
1928-4	Blue grama Threadleaf sedge Needleandthread	*Bouteloua gracilis* *Carex filifolia* *Stipa comata*
1928-5	Western wheatgrass Falsetarragon sagewort Prairie junegrass Needleandthread	*Agropyron smithii* *Artemisia dracunculus* *Koeleria cristata* *Stipa comata*
1928-6	Western wheatgrass Prairie junegrass Needleandthread Missouri goldenrod	*Agropyron smithii* *Koeleria cristata* *Stipa comata* *Solidago missouriensis*

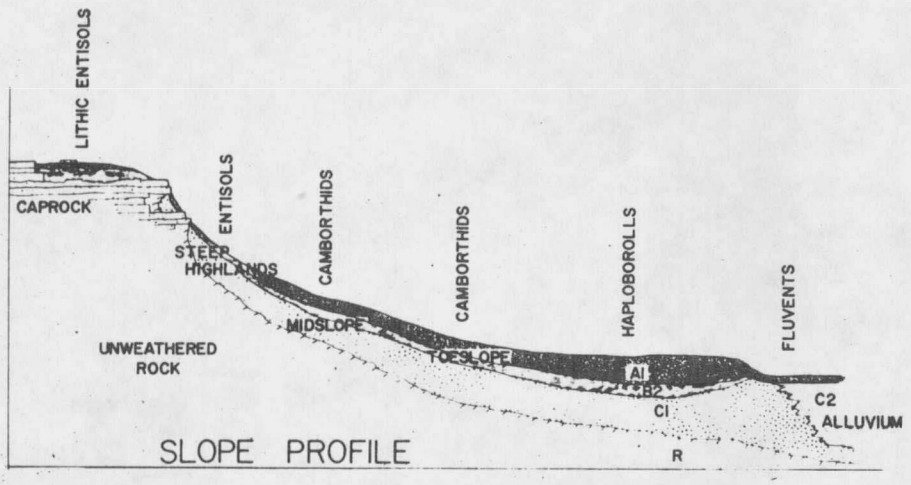


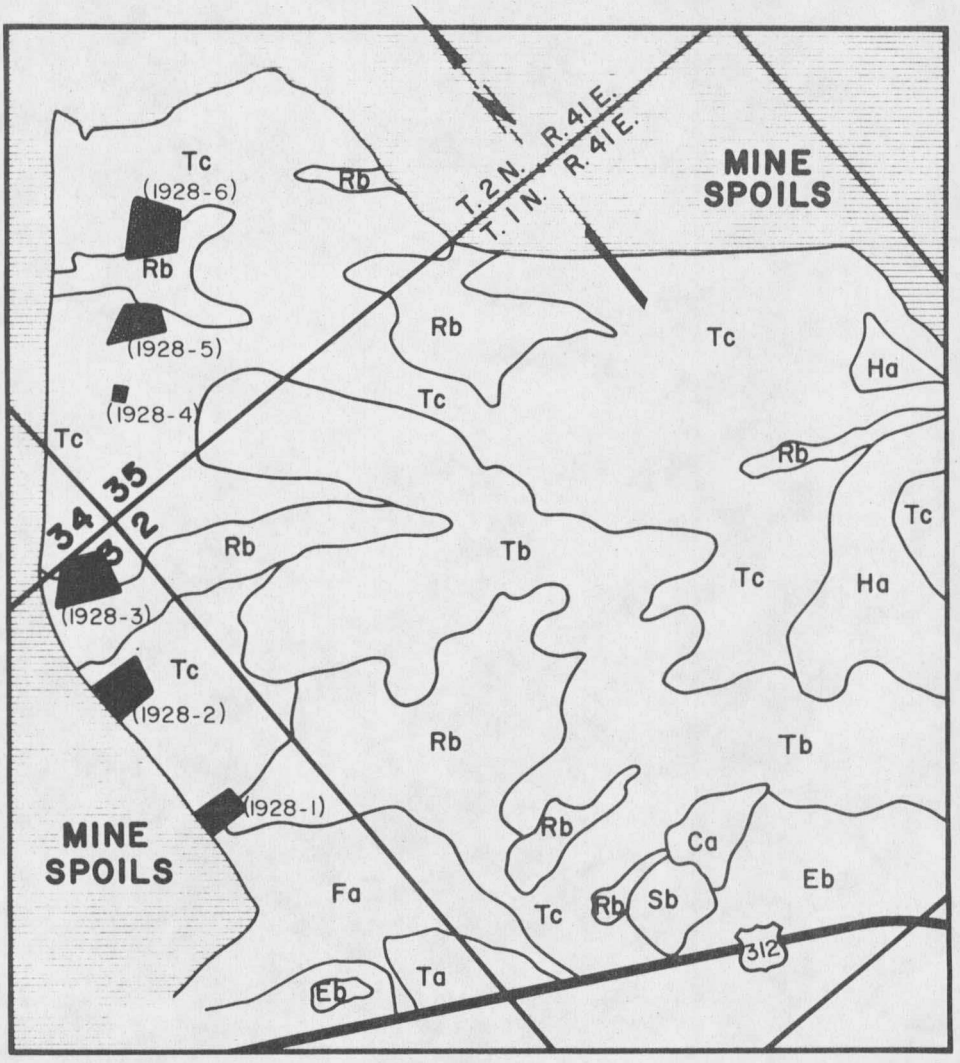
Figure 9. Slope profile of the Colstrip area Schafer et al., 1976).

strip area include Astic torriorthents, Borollic camborthids, and Aridic haplaborolls (Schafer et al., 1976). A soil survey of the Colstrip area is represented in Figure 10.

Study Site Soils

Because the waste mounds were constructed of the topmost five m of overburden material, soil of the waste mounds contained a high percentage of weatherable rock fragments, numerous contrasting soil textures, and very weak profile development (Schafer et al., 1977).

Evidence of carbonate movement, clay movement, and organic build-up was also detected in the waste mounds (Schafer et al., 1977). These characteristics indicate the beginning of a major soil development process.



Ca - Cushman loam (2-8% slopes)
Eb - Elso (4-15% slopes)
Fa - Fort Collins loam (0-2% slopes)
Ha - Heldt silty clay loam (2-8% slopes)
Rb - Remitt fine sandy loam (2-8% slopes)
Sb - Red Rock outcrop complex (steep)
Tb - Tullock complex (2-20% slopes)
Tc - Tullock fine sandy loam (4-15% slopes)

ROSEBUD MINE AREA E SOIL SURVEY

Figure 10. Soil survey of the Colstrip, Montana study site area. (Western Energy Company, 1973).

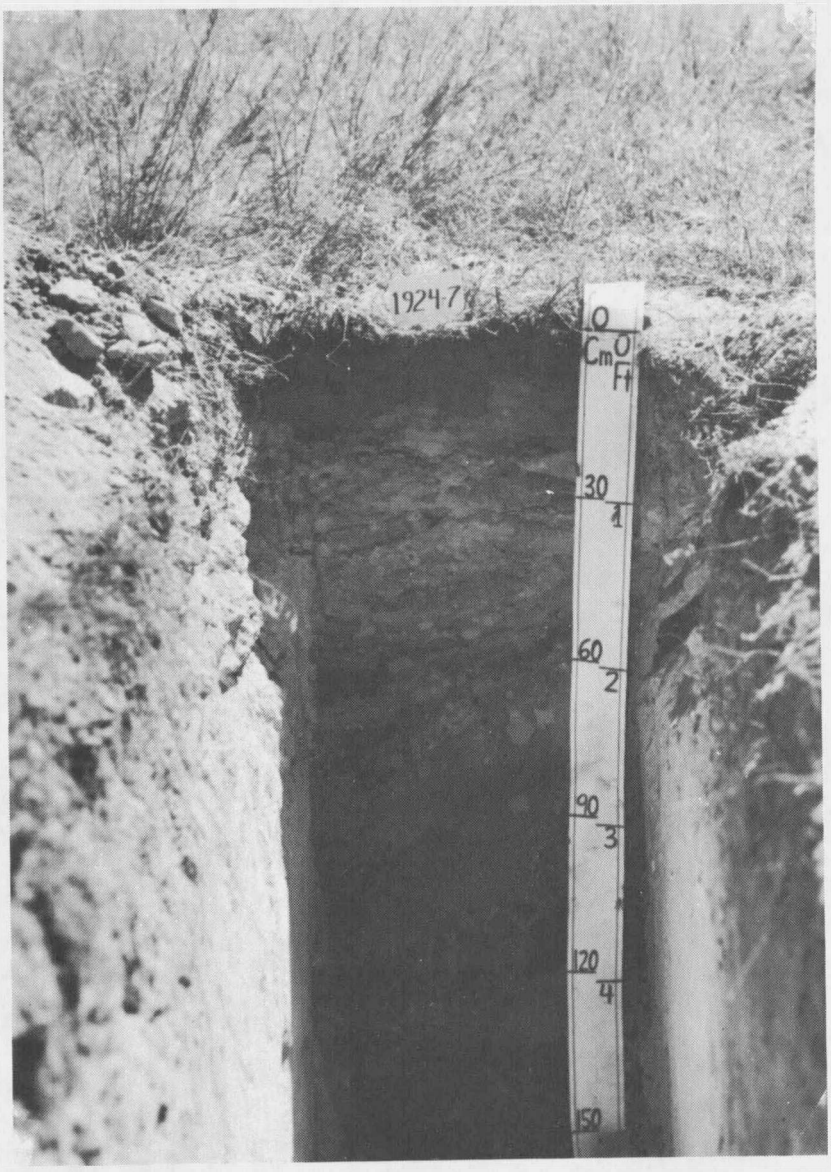


Figure 11. Soil profile of the Colstrip, MT study site soils.

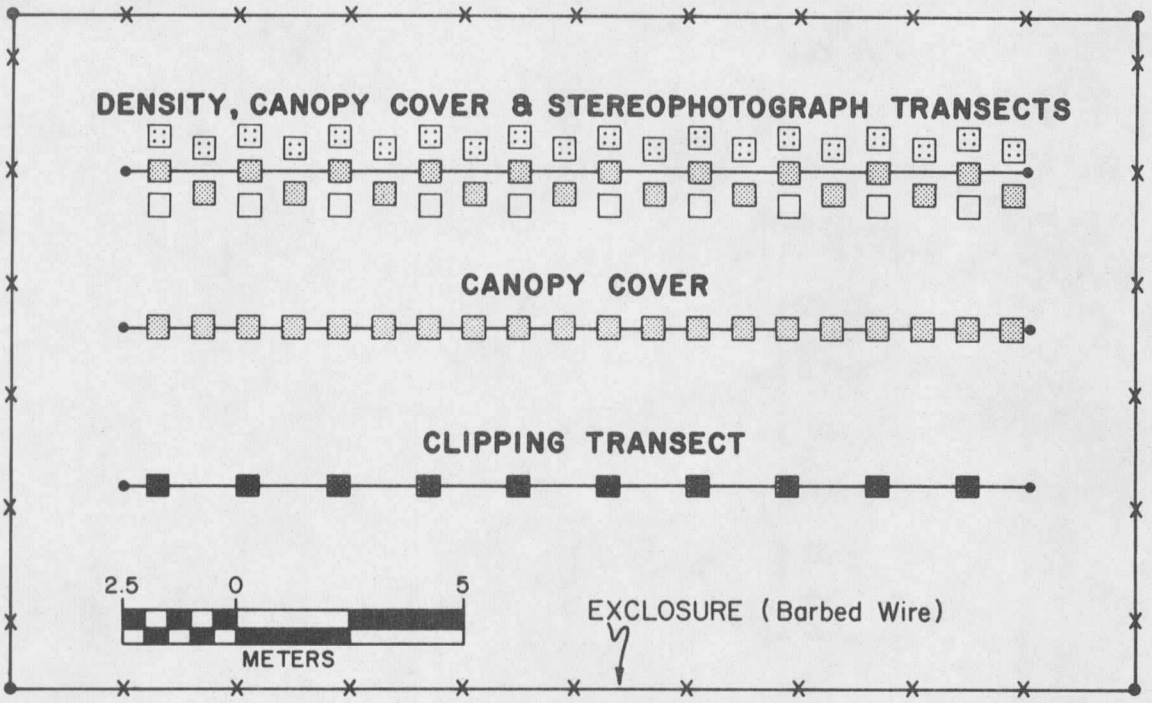
METHODS AND PROCEDURES

Reconnaissance of the study area showed that the established plant communities were dissimilar. The dominant species varied from shrubs to halfshrubs to perennial grasses to a combination of these. Since the 1928 sites appeared to be vegetationally dissimilar, various research techniques were incorporated into the 1976-1977 field work to analyze and evaluate this phenomenon.

Vegetational Sampling Within the Exclosure

To protect the study sites from outside disturbance, permanent exclosures were established. Exclosure locations were chosen which represented vegetation that was typical of each site. Although vegetation within each exclosure did not perfectly represent the plant communities under study, the degree to which the vegetation was similar between the exclosure and the surrounding community allowed for extrapolation and correlation with each exclosure's quantitative data.

A 15 x 25 m fenced exclosure was constructed on each site. Three permanent 20 m transects were located in each exclosure; a galvanized wire was stretched at ground-level between steel posts and marked at 1.0 m intervals. Figure 12 represents a sample exclosure and transect locations.



- .15 X .15 m DENSITY QUADRATS

- .20 X .50 m CANOPY COVER QUADRATS

- .50 X .50 m STANDING CROP CLIPPING QUADRATS

- .75 X .75 m STEREOPHOTOGRAPH QUADRATS

Figure 12. Representation of exclosure transects used at each study site.

Ten permanent 0.75-meter-square quadrats were stereophotographed twice during each growing season along one transect.

The direct harvest method was used to determine above ground biomass production estimates on a second transect (Milner and Hughes, 1968).

Ten 0.5-meter-square quadrats were harvested twice during each growing season -- June and July, 1976 and 1977. These sample dates were based on past studies in the Colstrip area; they included peak biomass yield of cool and warm season species (Sindelar and Plantenberg, 1977).

Plants were clipped at ground-level and separated by species. Litter and standing dead were also sampled. Biomass samples were oven-dried and weighed; yield averages were determined from these data.

Two transects were used for ground and canopy cover estimates. Forty permanently-located, 20 x 50 cm quadrats were sampled twice during the growing seasons. Cover estimates were made for each species and for mosses, lichens, fungi, litter, rock, and bare ground (Daubenmire, 1968). These estimates also provided frequency data.

Plant density estimates were made from 20 permanently-located, 15-cm-square quadrats along one transect. Density counts of all species occurring in the quadrats were made biweekly throughout the growing season. Nine sample dates were recorded during the 1976 field season while fifteen sample dates were recorded during the 1977 field season. These density counts provided frequency data and survival rates for certain species.

Plant species lists were made for each site and plant collections were made throughout the growing season. Specimens of each species were identified (scientific nomenclature--Hitchcock, C. L. and A. Cronquist, 1974). Dr. J. H. Rumely, Montana State University's Herbarium curator, verified these identifications.

Although species composition, biomass, cover, and frequency data provided quantitative relationships, these data did not reveal vegetational patterns. Therefore, aerial photographs and topographical maps were utilized in the construction of vegetative mosaic maps for Sites 1928-1, 1928-2, 1928-3, 1928-5, and 1928-6.

Vegetational Sampling Outside the Exclosure

To characterize the species present on the waste mounds and on the surrounding native range, forty-eight 25 m transects were established. Along each transect at 1.0 m intervals, a 2 x 5 cm quadrat was placed. Presence of species within or overhanging the quadrat was recorded. The collected data were used to estimate species frequency and abundance.

During the 1977 field season, species composition was determined and frequency data were recorded for thirty-five one-year and two-year old disturbed areas. This work was significant because it identified species that could have been pioneer invaders on the sites in 1928 and therafter.

During the field seasons of 1976 and 1977, numerous ground-level 35 mm color photographs were taken of each site and the surrounding areas. Color and infared aerial photographs and low-level helicopter photographs were also taken at each site.

Measurements of Physical Characteristics

Surveying instruments were used to determine the degree of surface slope on each waste mound. A level was centrally located and measurements were taken at each corner. These data and topographical maps were used to establish microtopographical descriptions of each site.

Soil samples were collected from Sites 1928-1, 1928-2, 1928-3, 1928-5, and 1928-6. A hand-auger was used to collect six samples at each depth: 0-10 cm, 25-35 cm, 50-60 cm, 75-85 cm, and 100-110 cm; thirty samples were obtained from each of the five study sites. A standard soil analysis was conducted on portions of these samples by the Montana State University Soil Testing Laboratory.

The soils from Sites 1928-1, 1928-2, and 1928-6 were analyzed and described by personnel from the Soil Conservation Service (SCS) Soil Characterization Laboratory at Lincoln, Nebraska. Additional detailed soil information on these three study sites was obtained from other researchers working in the Colstrip area (Schafer et al., 1977).

Soil moisture content was determined gravimetrically. During 1976, soil moisture samples were collected at depths of 0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm, and 40-50 cm at biweekly intervals at the 1928-1 and 1928-4 sites. Throughout the 1977 growing season, soil moisture samples were collected biweekly at each site at depths of 0-10 cm, 20-30 cm, 40-50 cm, 60-70 cm, 80-90 cm, and 100-110 cm for gravimetric determinations (Reynolds, 1970).

A rain guage was located at Site 1928-1. Moisture was checked biweekly throughout 1976 and 1977. Similarly, air temperature was monitored biweekly at Site 1928-3 with a thermograph.

RESULTS AND DISCUSSION

The Colstrip area provided an opportunity to study naturally revegetated spoil waste mounds. Five study sites and a native range site were located less than 1.4 km apart within the same management unit; and a visual survey revealed that the study sites were vegetationally dissimilar. Hence, the objectives of this research project were (1) to describe and identify each plant community and (2) to evaluate specific factors which may have affected succession of each community on the study sites.

Objective 1: Description and Identification of Each Plant Community

Plant communities are indicators of the environment. They respond not only to one environmental factor but to an interacting group of factors. Efforts to determine the reasons certain species occur in different ecological positions in different parts of a given region depend on an exact knowledge of the structure and composition of plant communities. Disturbances of the biological balance of a plant community are recognized by changes in the physiognomy, structure, and species composition of the communities' vegetation. Therefore, systematic and detailed descriptions of plant communities are essential in interpreting the function of a given ecosystem.

Site 1928-1

Halfshrubs, annual grasses, and shrubs were the dominant species on Site 1928-1 during 1976 and 1977 (Figure 13). The species list for Site 1928-1 contains 71 observed species (Appendix A). Study site 1928-1 and the surrounding area are depicted in a vegetative mosaic map (Figure 14).



Figure 13. Site 1928-1.

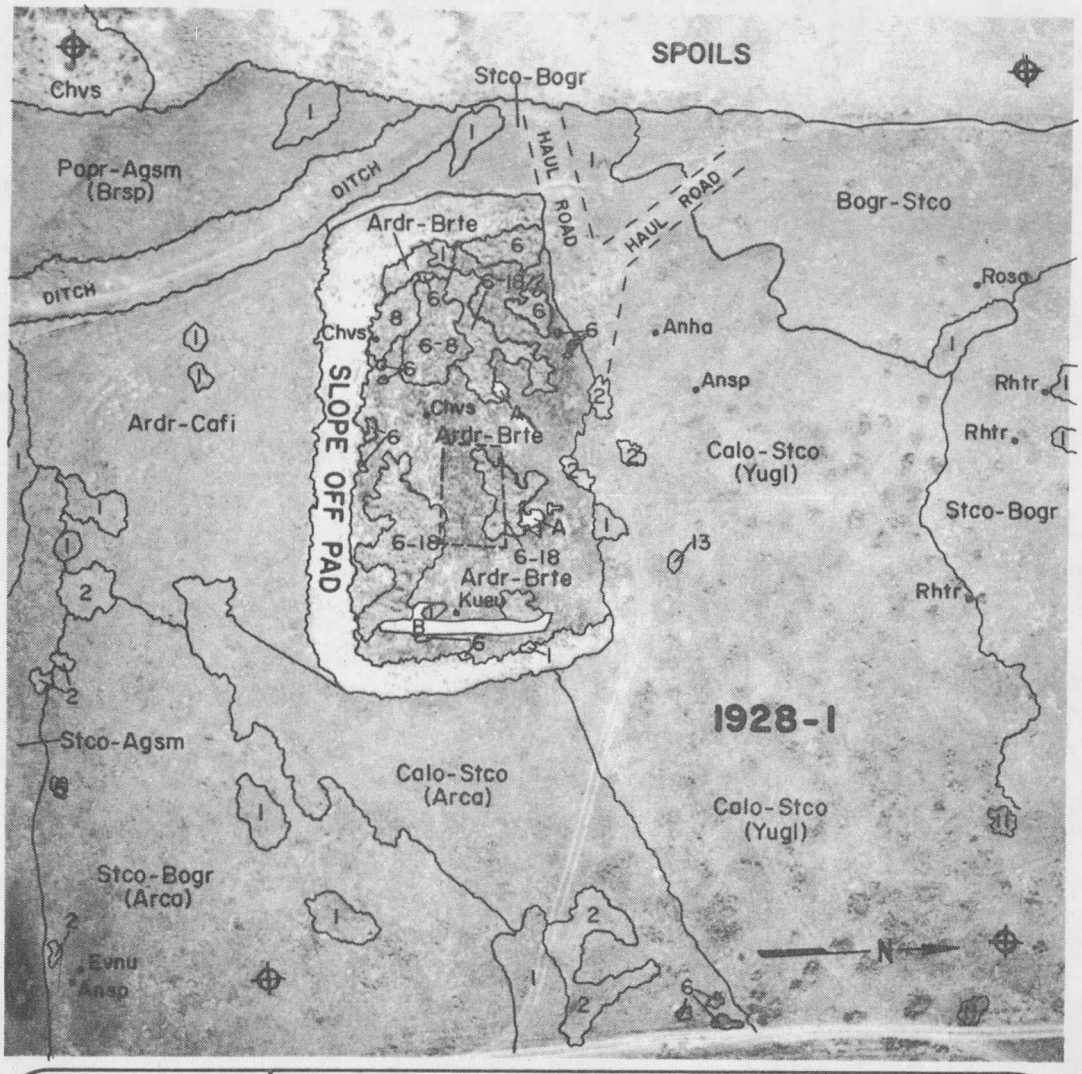


Figure 14. Vegetative mosaic map of Site 1928-1.

A summary of biomass and cover data for 1976 and 1977 is presented in Table 4. Based on these data, halfshrubs, annual grasses, and shrubs accounted for 74 percent of the canopy cover on June 24, 1976 and 88 percent of the canopy cover on June 8, 1977. Similarly, the same group of species accounted for 87 percent of the biomass on June 24, 1976 and 83 percent of the biomass on June 8, 1977. Litter materials comprised high cover percentages on Site 1928-1; they represented over 91 percent of the ground cover. Correspondingly, bare ground percentages were low; these were less than 6.1 percent.

Canopy cover data for 1976 and 1977 reveal that falsetarragon sagewort (*Artemisia dracunculus*), cheatgrass, Japanese bromegrass (*Bromus japonicus*), and silver sagebrush were the dominant species (Table 5). These four species comprised over 74 percent of the 1976 canopy cover and over 87 percent of the 1977 canopy cover. Two perennial grasses (needleandthread and western wheatgrass) and two forbs (western ragweed (*Ambrosia psilostachya*) and silverleaf scurfpea (*Psoralea argophylla*)) were the principal species associated with the dominant species on Site 1928-1.

Table 4. Biomass (kg/ha) and percent cover data summary for 1976 and 1977 on Site 1928-1.

SPECIES	YEAR	BIOMASS	COVER
Perennial Grasses	May, 1976	94	3
	June, 1976	98	3
	June, 1977	84	4
	July, 1977	66	2
Annual Grasses	May, 1976	555	5
	June, 1976	563	6
	June, 1977	204	10
	July, 1977		T
Annual Forbs	May, 1976	T	T
	June, 1976	4	T
	June, 1977	4	
	July, 1977		
Biennial Forbs	May, 1976	T	
	June, 1976	T	T
	June, 1977		T
	July, 1977	T	
Perennial Forbs	May, 1976	185	T
	June, 1976	105	9
	June, 1977	167	3
	July, 1977	122	1
Half Shrubs	May, 1976	1042	15
	June, 1976	1686	20
	June, 1977	978	31
	July, 1977	804	13
Shrubs	May, 1976	262	4
	June, 1976	65	9
	June, 1977	54	12
	July, 1977	6	8
Total Vegetation	May, 1976	2139	28
	June, 1976	2522	47
	June, 1977	1491	60
	July, 1977	997	25
Standing Dead	May, 1976	2251	
	June, 1976	1863	
	June, 1977	2304	
	July, 1977	1069	
Litter	May, 1976	5192	91
	June, 1976	6449	93
	June, 1977	4926	92
	July, 1977	4753	93
Bareground	May, 1976		4
	June, 1976		5
	June, 1977		4
	July, 1977		6

T = < 1% cover and < 1 kg/ha

Table 5. Species on 1928-1 with canopy cover 1% or higher on at least one sample date.

SPECIES	SAMPLE DATES			
	5/12/76	6/24/76	6/08/77	7/06/77
Agropyron smithii	--	--	1	--
Stipa comata	3	2	3	1
Bromus spp.	5	6	10	--
Ambrosia psilostachya	--	3	--	--
Psoralea argophylla	--	3	1	--
Artemisia dracunculus	15	20	31	13
Artemisia cana	4	9	12	8

Site 1928-2

Annual grasses, perennial grasses, and shrubs were the dominant species on Site 1928-2 (Figure 15). The species list for Site 1928-2 contains 71 observed species (Appendix A). Study site 1928-2 and the surrounding area are depicted in a vegetative mosaic map (Figure 16).



Figure 15. Site 1928-2.

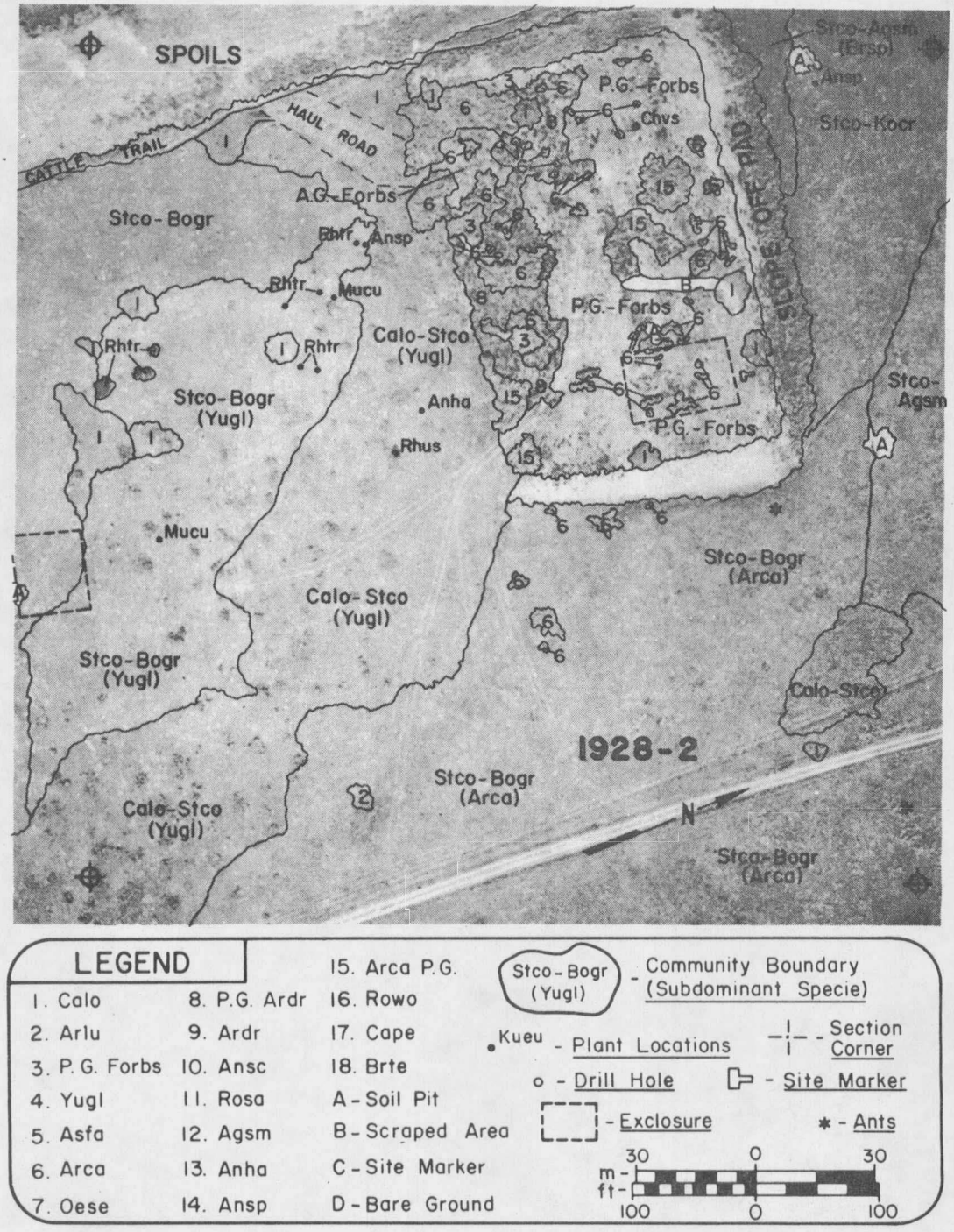


Figure 16. Vegetative mosaic map of Site 1928-2.

A summary of biomass and cover data for 1976 and 1977 is presented in Table 6. Based on these data, annual grasses, perennial grasses, biennial forbs, and shrubs accounted for 86 percent of the canopy cover on June 24, 1976 and 88 percent of the canopy cover on June 8, 1977. Similarly, the same group of species accounted for 86 percent of the biomass on June 24, 1976 and 56 percent of the biomass on June 8, 1977. Litter materials comprised high cover percentages on Site 1928-2; they represented over 80 percent of the ground cover. Correspondingly, bare ground cover percentages were less than 13 percent.

Canopy cover data for 1976 and 1977 reveal that cheatgrass, Japanese bromegrass, western wheatgrass, prairie sandreed (*Calamovilfa longifolia*), needleandthread, and silver sagebrush were the dominant species (Table 7). These six species comprised over 34 percent of the 1976 canopy cover and over 82 percent of the 1977 canopy cover. Two forbs (western ragweed and whiteprairie aster (*Aster falcatus*)), and one halfshrub (falsetarragon sagewort) were the principal species associated with the dominant species on Site 1928-2.

Table 6. Biomass (kg/ha) and percent cover data summary for 1976 and 1977 on Site 1928-2.

SPECIES	YEAR	BIOMASS	COVER
Perennial Grasses	May, 1976	281	6
	June, 1976	257	6
	June, 1977	261	8
	July, 1977	155	9
Annual Grasses	May, 1976	301	5
	June, 1976	303	9
	June, 1977	252	13
	July, 1977		2
Annual Forbs	May, 1976	15	T
	June, 1976	18	T
	June, 1977	2	T
	July, 1977	T	
Biennial Forbs	May, 1976	767	17
	June, 1976	920	30
	June, 1977	T	T
	July, 1977	T	
Perennial Forbs	May, 1976	84	6
	June, 1976	141	7
	June, 1977	17	3
	July, 1977	90	2
Half Shrubs	May, 1976	133	2
	June, 1976	68	2
	June, 1977	403	1
	July, 1977	182	2
Shrubs	May, 1976	41	7
	June, 1976	16	16
	June, 1977	42	16
	July, 1977	33	12
Total Vegetation	May, 1976	1621	44
	June, 1976	1690	70
	June, 1977	976	42
	July, 1977	450	26
Standing Dead	May, 1976	493	
	June, 1976	327	
	June, 1977	1434	
	July, 1977	643	
Litter	May, 1976	2223	85
	June, 1976	3786	80
	June, 1977	2581	87
	July, 1977	3153	90
Bareground	May, 1976		11
	June, 1976		13
	June, 1977		13
	July, 1977		9

T = < 1% cover and < 1 kg/ha

Table 7. Species on 1928-2 with canopy cover 1% or higher on at least one sample date.

SPECIES	SAMPLE DATES			
	6/07/76	6/24/76	6/08/77	7/06/77
Agropyron smithii	3	2	2	1
Calamovilfa longifolia	--	1	2	3
Stipa comata	3	2	3	3
Bromus spp.	5	9	13	2
Melilotus officinalis	17	30	--	--
Ambrosia psilostachya	2	1	--	--
Aster falcatus	4	3	1	1
Artemisia dracunculus	1	2	1	1
Artemisia cana	7	16	16	12

Site 1928-3

Halfshrubs, annual grasses, and shrubs were the dominant species on Site 1928-3 during 1976 and 1977 (Figure 17). The species list for Site 1928-3 contains 74 observed species (Appendix A). Study site 1928-3 and the surrounding area are depicted in a vegetative mosaic map (Figure 18).

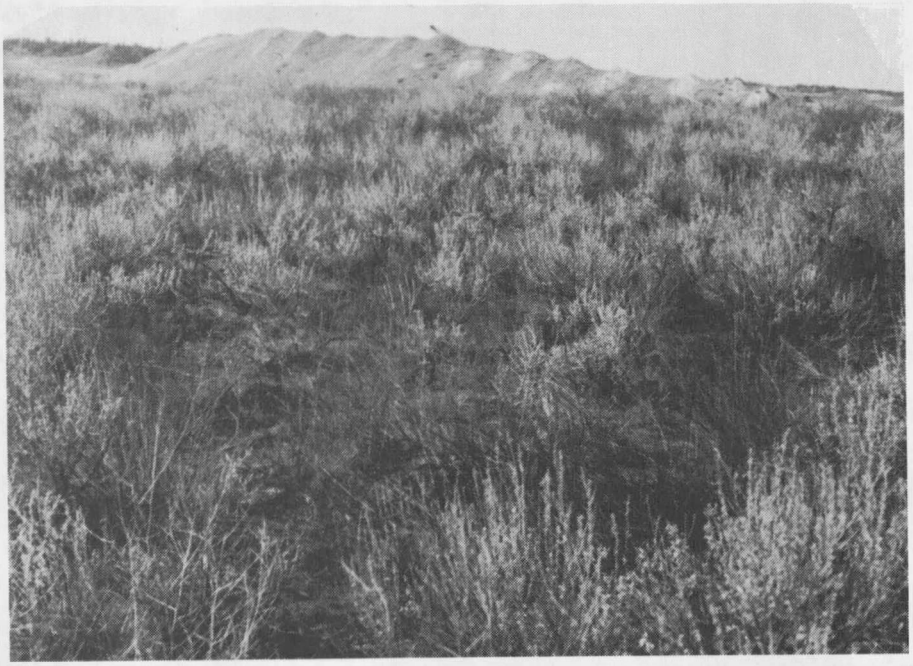


Figure 17. Site 1928-3.

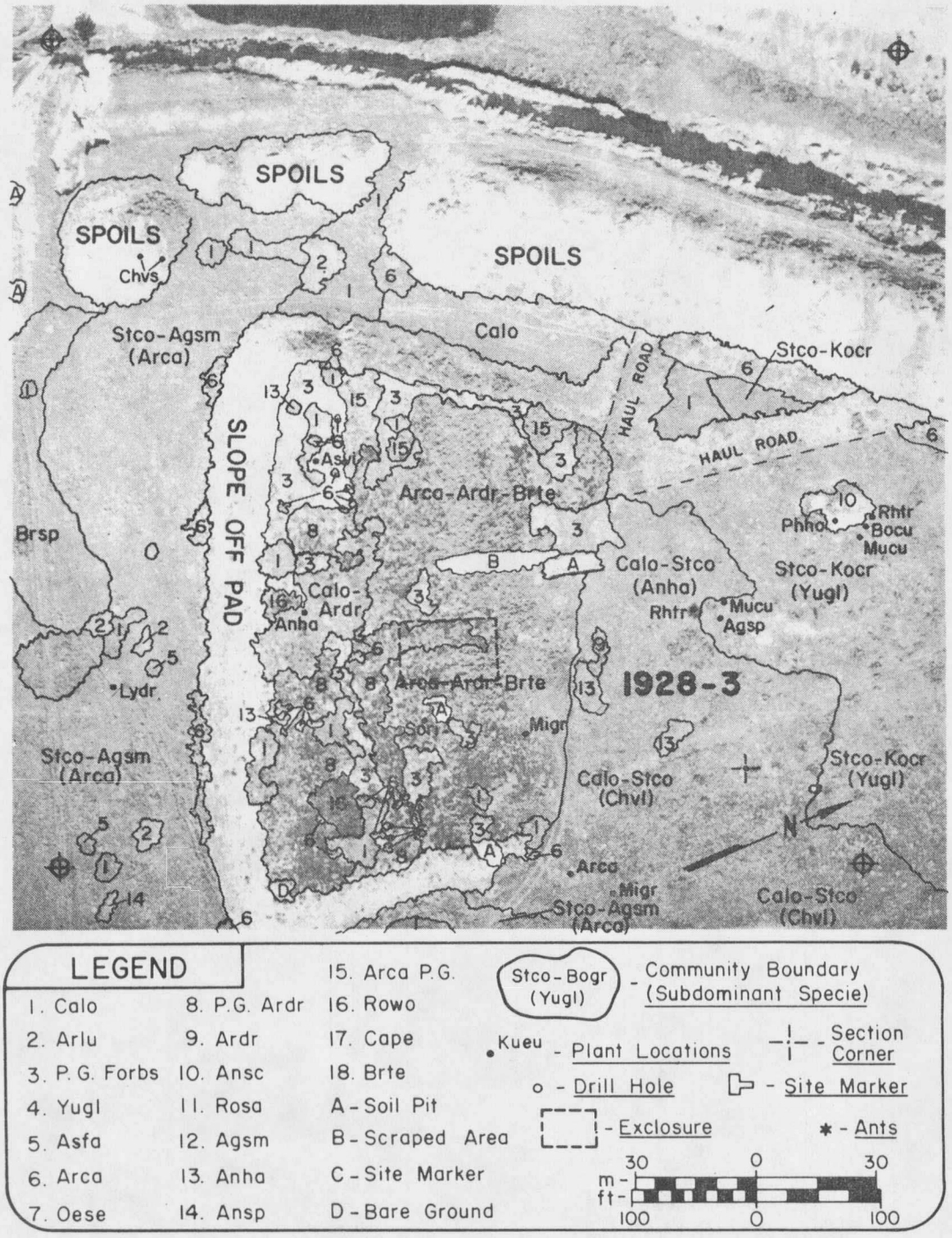


Figure 18. Vegetative mosaic map of Site 1928-3.

A summary of biomass and cover data for 1976 and 1977 is presented in Table 8. Based on these data, halfshrubs, annual grasses, and shrubs accounted for 80 percent of the canopy cover on May 28, 1976 and 75 percent of the canopy cover on June 8, 1977. Similarly, the same group of species accounted for 90 percent of the biomass on June 24, 1976 and 96 percent of the biomass on June 8, 1977. Litter materials comprised high cover percentages on Site 1928-3; they represented over 92 percent of the ground cover. Correspondingly, bare ground cover percentages were low; these were less than 6 percent.

Canopy cover data for 1976 and 1977 reveals that falsetarragon sagewort, cheatgrass, Japanese bromegrass, and silver sagebrush were the dominant species (Table 9). These four species comprised 79 percent of the 1976 canopy cover and over 73 percent of the 1977 canopy cover. One perennial grass (needleandthread) and six forbs (western ragweed, standing milkvetch (*Astragalus adsurgens*), white-prairie aster, hairy goldenaster (*Chrysopis villosa*), narrowleaf gromwell (*Lithospermum incisum*), and Missouri goldenrod (*Solidago missouriensis*)) were the principal species associated with the dominant species on Site 1928-3.

Table 8. Biomass (kg/ha) and percent cover data summary for 1976 and 1977 on Site 1928-3.

SPECIES	YEAR	BIOMASS	COVER
Perennial Grasses	May, 1976	63	3
	June, 1976	68	
	June, 1977	36	5
	July, 1977	34	2
Annual Grasses	May, 1976	479	9
	June, 1976	299	
	June, 1977	201	16
	July, 1977		T
Annual Forbs	May, 1976	T	T
	June, 1976		
	June, 1977		
	July, 1977		
Biennial Forbs	May, 1976	T	T
	June, 1976	28	
	June, 1977	9	T
	July, 1977		
Perennial Forbs	May, 1976	111	6
	June, 1976	100	
	June, 1977	60	11
	July, 1977	57	4
Half Shrubs	May, 1976	875	11
	June, 1976	1141	
	June, 1977	605	16
	July, 1977	882	11
Shrubs	May, 1976	534	19
	June, 1976	301	
	June, 1977	1939	17
	July, 1977	775	13
Total Vegetation	May, 1976	2061	49
	June, 1976	1936	
	June, 1977	2850	64
	July, 1977	1749	31
Standing Dead	May, 1976	1743	
	June, 1976	2556	
	June, 1977	13223	
	July, 1977	2883	
Litter	May, 1976	8041	99
	June, 1976	9595	
	June, 1977	9266	94
	July, 1977	8290	93
Bareground	May, 1976		T
	June, 1976		
	June, 1977		4
	July, 1977		6

T = < 1% cover and < 1 kg/ha

Table 9. Species on 1928-3 with canopy cover 1% or higher on at least one sample date.

SPECIES	SAMPLE DATES			
	5/28/76	NOT SAMPLED	6/08/77	7/07/77
Stipa comata	3		5	2
Bromus spp.	9		16	--
Ambrosia psilostachya	1		1	1
Astragalus adsurgens	1		1	--
Aster falcatus	--		2	1
Solidago missouriensis	3		4	2
Artemisia dracunculus	11		15	11
Artemisia cana	19		16	13

Site 1928-4

Perennial grasses and a perennial sedge were the dominant species on the native range site, Site 1928-4, during 1976 and 1977 (Figure 19). The species list for Site 1928-4 contains 80 observed species (Appendix A).



Figure 19. Site 1928-4.

A summary of biomass and cover data for 1976 and 1977 is presented in Table 10. Based on these data, perennial grasses and a sedge accounted for 76 percent of the canopy cover on June 24, 1976 and 87 percent of the canopy cover on June 8, 1977. Similarly, the same group of species accounted for 79 percent of the biomass on June 8, 1977. Litter materials and bare ground comprised moderately high cover percentages on Site 1928-4 -- over 57 percent and 13 percent, respectively.

Canopy cover data for 1976 and 1977 reveal that blue grama, prairie sandreed, prairie junegrass, needleandthread, and threadleaf sedge (*Carex filifolia*) were the dominant species (Table 11). These five species comprised over 75 percent of the 1976 canopy cover and over 85 percent of the 1977 canopy cover. One shrub (yucca (*Yucca glauca*)), one halfshrub (falsetarragon sagewort), and one forb (hairy goldenaster) were the principal species associated with the dominant species on Site 1928-4.

Table 10. Biomass (kg/ha) and percent cover data summary for 1976 and 1977 on Site 1928-4.

SPECIES	YEAR	BIOMASS	COVER
Perennial Grasses and Sedges	May, 1976	557	15
	June, 1976	641	18
	June, 1977	758	30
	July, 1977	567	27
Annual Grasses	May, 1976	23	T
	June, 1976	3	T
	June, 1977	24	
	July, 1977		
Annual Forbs	May, 1976	T	T
	June, 1976	12	T
	June, 1977	1	T
	July, 1977	1	
Biennial Forbs	May, 1976	2	T
	June, 1976	6	T
	June, 1977	T	T
	July, 1977		T
Perennial Forbs	May, 1976	67	T
	June, 1976	80	2
	June, 1977	37	1
	July, 1977	35	1
Half Shrubs	May, 1976	66	2
	June, 1976	41	1
	June, 1977	2	1
	July, 1977	64	1
Shrubs	May, 1976		3
	June, 1976	25	2
	June, 1977	128	4
	July, 1977	20	3
Total Vegetation	May, 1976	716	26
	June, 1976	809	31
	June, 1977	951	48
	July, 1977	688	41
Standing Dead	May, 1976	192	
	June, 1976	88	
	June, 1977	267	
	July, 1977	188	
Litter	May, 1976	1050	67
	June, 1976	826	85
	June, 1977	730	81
	July, 1977	1146	57
Bareground	May, 1976		25
	June, 1976		13
	June, 1977		15
	July, 1977		23

T = < 1% cover and < 1 kg/ha

Table 11. Species on 1928-4 with canopy cover 1% or higher on at least one sample date.

SPECIES	SAMPLE DATES			
	5/14/76	6/24/76	6/07/77	7/06/77
Bouteloua gracilis	8	8	11	9
Calamovilfa longifolia	--	3	4	3
Koeleria cristata	1	2	4	3
Stipa comata	6	6	12	11
Carex filifolia	5	5	12	9
Chrysopsis villosa	1	1	1	1
Artemisia dracunculus	1	1	1	1
Yucca glauca	2	1	3	3

Site 1928-5

Perennial grasses, halfshrubs, and shrubs were the dominant species on Site 1928-5 during 1976 and 1977 (Figure 20). The species list for Site 1928-5 contains 78 observed species (Appendix A). Study site 1928-5 and the surrounding area are depicted in a vegetative mosaic map (Figure 21).



Figure 20. Site 1928-5.

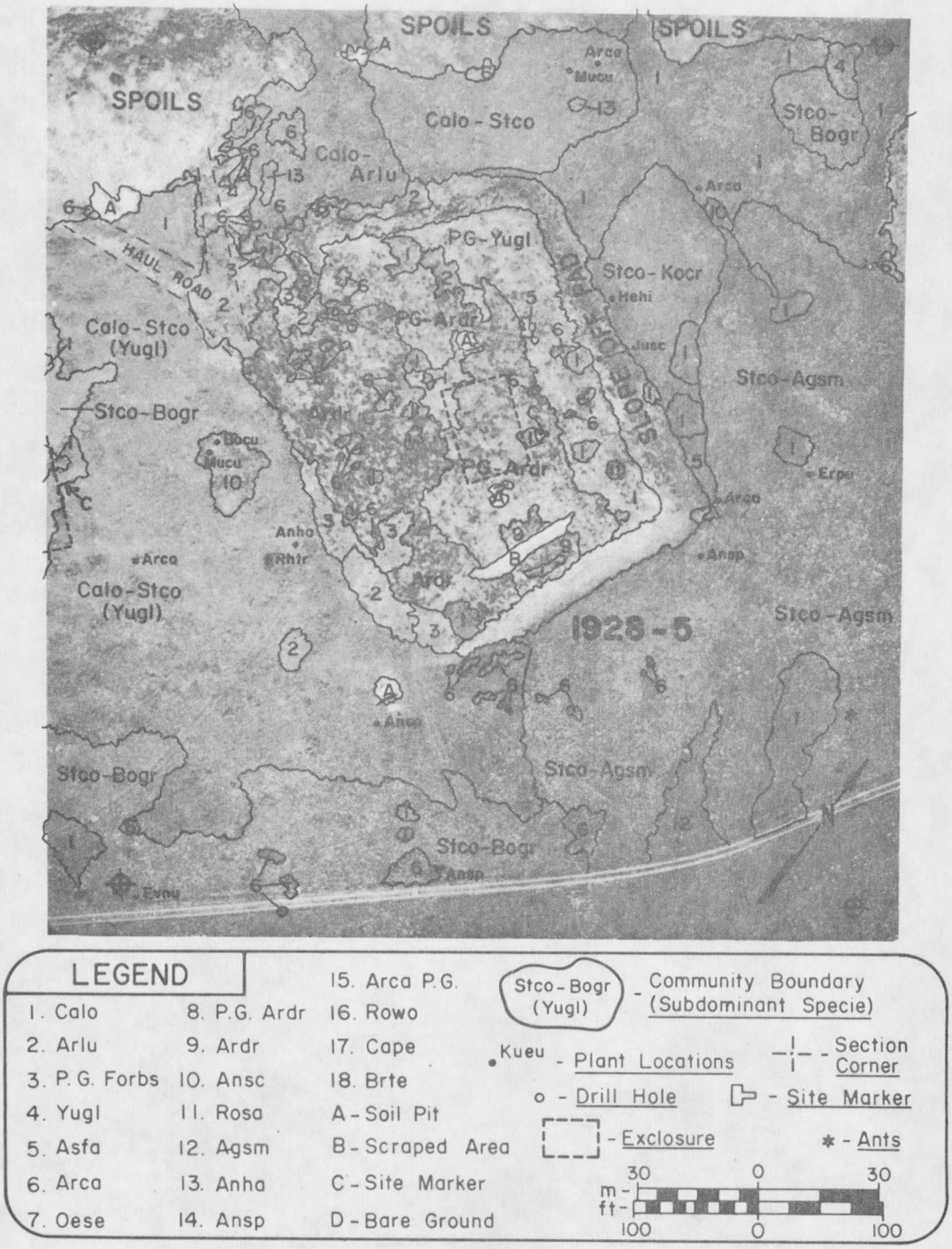


Figure 21. Vegetative mosaic map of Site 1928-5.

A summary of biomass and cover data for 1976 and 1977 is presented in Table 12. Based on these data, perennial grasses, halfshrubs, and shrubs accounted for 57 percent of the canopy cover on June 24, 1976 and 74 percent of the canopy cover on June 8, 1977. Similarly, the same group of species accounted for 46 percent of the biomass on June 24, 1976 and 60 percent of the biomass on June 8, 1977. Litter materials and bare ground comprised moderately high cover percentages on Site 1928-5; they represented over 74 percent and 22 percent, respectively.

Canopy cover data for 1976 and 1977 reveal that western wheatgrass, prairie junegrass, needleandthread, falsetarragon sagewort, and yucca were the dominant species (Table 13). These five species comprised over 54 percent of the 1976 canopy cover and over 72 percent of the 1977 canopy cover. Two annual grasses (cheatgrass and Japanese bromegrass) and three forbs (yellow sweetclover (*Melilotus officinalis*), western ragweed, and whiteprairie aster) were the principal species associated with the dominant species on Site 1928-5.

Table 12. Biomass (ka/ha) and percent cover data summary for 1976 and 1977 on Sites 1928-5.

SPECIES	YEAR	BIOMASS	COVER
Perennial Grasses	May, 1976	406	9
	June, 1976	431	8
	June, 1977	232	12
	July, 1977	221	5
Annual Grasses	May, 1976	172	2
	June, 1976	262	2
	June, 1977	134	5
	July, 1977		
Annual Forbs	May, 1976	T	T
	June, 1976	14	T
	June, 1977	T	T
	July, 1977		T
Biennial Forbs	May, 1976	83	3
	June, 1976	146	8
	June, 1977	26	1
	July, 1977	T	T
Perennial Forbs	May, 1976	225	5
	June, 1976	307	8
	June, 1977	149	5
	July, 1977	24	3
Half Shrubs	May, 1976	53	5
	June, 1976	169	6
	June, 1977	105	8
	July, 1977	543	7
Shrubs	May, 1976		6
	June, 1976	13	9
	June, 1977	134	11
	July, 1977	183	10
Total Vegetation	May, 1976	940	33
	June, 1976	1343	42
	June, 1977	780	41
	July, 1977	972	27
Standing Dead	May, 1976	483	
	June, 1976	459	
	June, 1977	671	
	July, 1977	925	
Litter	May, 1976	2725	75
	June, 1976	3283	87
	June, 1977	2249	87
	July, 1977	4766	72
Bareground	May, 1976		22
	June, 1976		10
	June, 1977		11
	July, 1977		26

T = < 1% cover and < 1 kg/ha

Table 13. Species on 1928-5 with canopy cover 1% or higher on at least one sample date.

SPECIES	SAMPLE DATES			
	5/28/76	6/24/76	6/07/77	7/06/77
Agropyron smithii	2	2	3	1
Koeleria cristata	3	3	4	2
Stipa comata	4	3	5	3
Bromus spp.	2	2	5	2
Cirsium undulatum	1	1	1	--
Melilotus officinalis	3	7	--	--
Ambrosia psilostachya	1	4	1	1
Aster falcatus	3	1	1	1
Artemisia dracunculus	4	6	8	7
Yucca glauca	6	9	10	9

Site 1928-6

Perennial grasses and halfshrubs were the dominant species on Site 1928-6 during 1976 and 1977 (Figure 22). The species list for Site 1928-6 contains 78 observed species (Appendix A). Study site 1928-6 and the surrounding area are depicted in a vegetative mosaic map (Figure 23).



Figure 22. Site 1928-6.

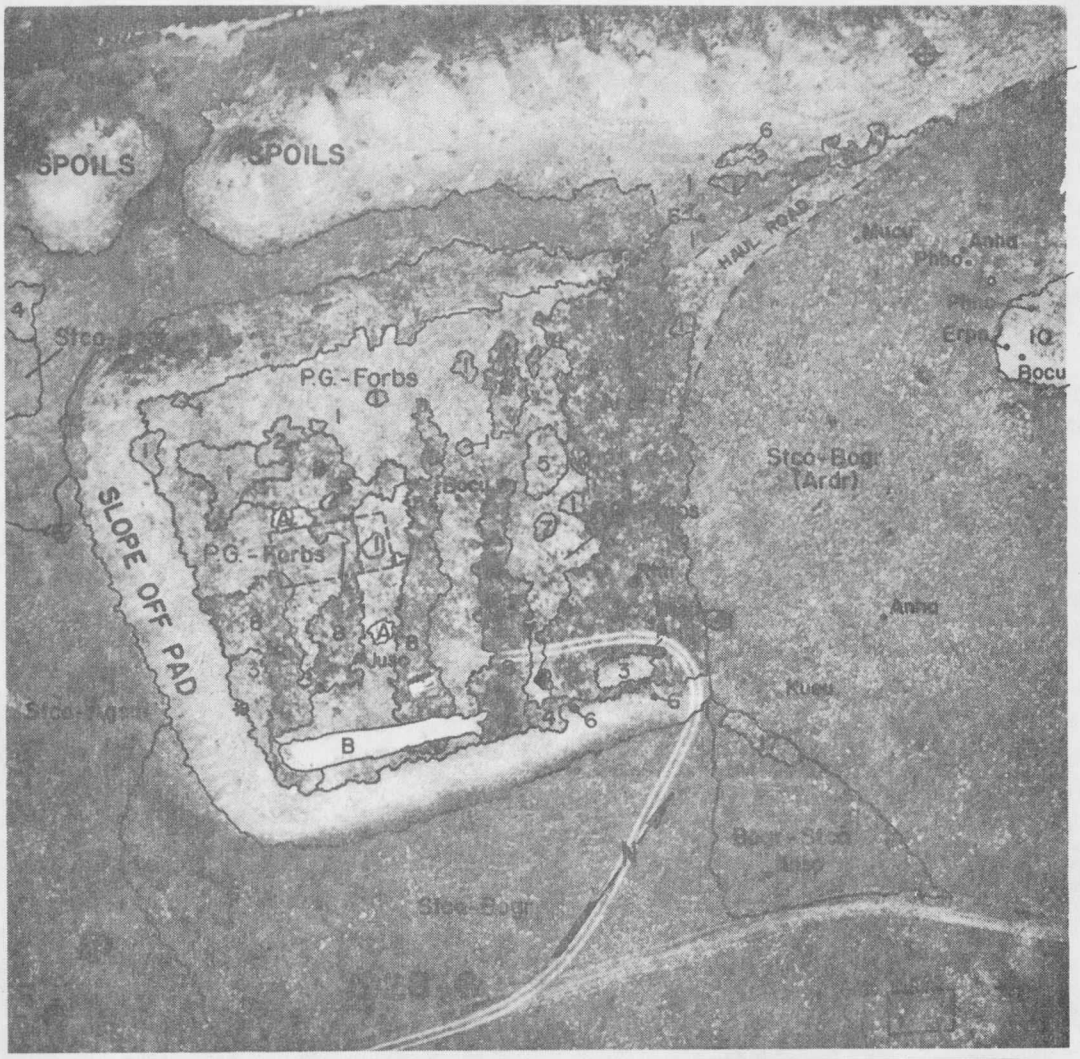


Figure 23. Vegetative mosaic map of Site 1928-6.

A summary of biomass and cover data for 1976 and 1977 is presented in Table 14. Based on these data, perennial grasses and halfshrubs accounted for 41 percent of the canopy cover on June 23, 1976 and 69 percent of the canopy cover on June 8, 1977. Similarly, the same group of species accounted for 58 percent of the biomass on June 23, 1976 and 72 percent of the biomass on June 8, 1977. Litter materials and bare ground comprised moderately high cover percentages on Site 1928-6; they represented over 73 percent and 13 percent, respectively.

Canopy cover data for 1976 and 1977 reveal that western wheatgrass, prairie sandreed, prairie junegrass, needleandthread, false-tarragon sagewort, and broom snakeweed were the dominant species (Table 15). These six species comprised over 45 percent of the 1976 canopy cover and over 72 percent of the 1977 canopy cover. Two annual grasses (cheatgrass and Japanese bromegrass) and three forbs (yellow sweetclover, western ragweed, and Missouri goldenrod) were the principal species associated with the dominant species on Site 1928-6.

Table 14. Biomass (kg/ha) and percent cover data summary for 1976 and 1977 on Site 1928-6.

SPECIES	YEAR	BIOMASS	COVER
Perennial Grasses	May, 1976	219	8
	June, 1976	324	12
	June, 1977	260	17
	July, 1977	215	11
Annual Grasses	May, 1976	218	3
	June, 1976	193	2
	June, 1977	93	T
	July, 1977		T
Annual Forbs	May, 1976	2	T
	June, 1976	T	T
	June, 1977		
	July, 1977	T	
Biennial Forbs	May, 1976	27	2
	June, 1976	213	9
	June, 1977	1	T
	July, 1977	34	
Perennial Forbs	May, 1976	129	2
	June, 1976	127	8
	June, 1977	99	7
	July, 1977	51	4
Half Shrubs	May, 1976	139	2
	June, 1976	546	3
	June, 1977	390	5
	July, 1977	296	5
Shrubs	May, 1976	14	T
	June, 1976	92	2
	June, 1977	50	2
	July, 1977	2	2
Total Vegetation	May, 1976	747	18
	June, 1976	1495	36
	June, 1977	906	33
	July, 1977	598	23
Standing Dead	May, 1976	503	
	June, 1976	607	
	June, 1977	830	
	July, 1977	513	
Litter	May, 1976	2705	75
	June, 1976	3764	85
	June, 1977	2082	74
	July, 1977	3329	74
Bareground	May, 1976		22
	June, 1976		13
	June, 1977		23
	July, 1977		24

T = < 1% cover and < 1 kg/ha

Table 15. Species on 1928-6 with canopy cover 1% or higher on at least one sample date.

SPECIES	SAMPLE DATES			
	5/14/76	6/23/76	6/07/77	7/06/77
Agropyron smithii	2	1	2	1
Calamovilfa longifolia	--	1	1	1
Koeleria cristata	5	7	10	6
Stipa comata	1	1	3	2
Bromus spp.	3	2	1	1
Melilotus officinalis	2	9	--	--
Ambrosia psilostachya	--	2	--	--
Solidago missouriensis	1	4	4	2
Artemisia dracunculus	2	3	5	5
Gutierrezia sarothrae	--	2	2	2

Objective 2: Evaluation of Specific Factors Affecting Successional Advancement of Each Community

A summary of the descriptive and quantitative data for the 1928 sites emphasized the vegetational dissimilarity of the study sites. Dominant species varied from shrubs to halfshrubs to perennial grasses to annual grasses to a combination of these.

The following quantitative data indicated unique structural differences among the naturally-revegetated 1928 sites. These differences were related to physiographical, edaphic, physiological, and/or land management factors.

Background Data

As mining progressed in Pit One, excess overburden material was removed and deposited outside the mining area (Figure 24). Because of the nature of the mining/dumping process, excess overburden material was deposited once to several times during a thirteen-month period on some sites. Mining records show that the approximate chronosequence for formation of the 1928 sites was between October 13, 1927 and November 18, 1928.

Site 1928-2 was completed in June, 1928; Site 1928-5 was completed in July, 1928; Site 1928-1 was completed in August, 1928; Site 1928-3 was completed in September, 1928; and Site 1928-6 was completed in November, 1928.



Figure 24. Excess overburden material removed and deposited outside the mining area near Pit One.

Vegetational Data

Vegetation on the five sites was compared using an intersite similarity coefficient based on species frequency values (Table 16). The similarity matrix showed that no two sites were more than 75 percent similar to one another. Further examination of the similarity matrix on the naturally revegetated sites revealed two distinct groupings: Sites 1928-1 and 1928-3 were 70 percent similar to one another and were dominated by falsetarragon sagewort, silver sage-

Table 15. Percent frequency of the leading species on the 1928 study sites (Sornsen's Index Similarity; Thatcher, 1959).

SPECIES	1928-1	1928-2	1928-3	1928-5	1928-6
Agropyron smithii	45.0	82.5	7.5	82.5	80.0
Agropyron spicatum		2.5	2.5		7.5
Aristida longiseta		5.0			2.5
Koeleria cristata		5.0	5.0	60.0	72.5
Stipa comata	82.5	75.0	67.5	80.0	55.0
Poa pratensis	2.5	10.0			
Poa sandbergii	7.5	2.5	10.0	5.0	
Festuca octoflora		75.0	7.5		
Bromus spp.	100.0	97.5	100.0	92.5	95.0
Camelina microcarpa	27.5	5.0	5.0	15.0	12.5
Descurainia pinnata	2.5	5.0		2.5	
Eriogonum annuum	5.0	7.5	2.5	7.5	7.5
Helianthus petiolaris		7.5		5.0	
Plantago patagonica	5.0	10.0		2.5	
Cirsium undulatum			2.5	5.0	5.0
Erysimum asperum	7.5	7.5	17.5	17.5	2.5
Lactuca serriola	30.0	10.0	5.0	7.5	2.5
Melilotus officinalis	2.5	87.5	15.0	35.0	95.0
Tragopogon dubius	7.5		2.5		2.5
Ambrosia psilostachya	67.5	85.0	62.5	87.5	60.0
Astragalus adsurgens	2.5		10.0	5.0	
Aster falcatus	10.0	42.5	10.0	45.0	7.5
Astragalus missouriensis		7.5	7.5		2.5
Chrysopsis villosa	12.5	5.0	17.5	10.0	17.5
Lithospermum incisum	20.0	10.0	5.0	7.5	2.5
Penstemon albidus		2.5	5.0		2.5
Psoralea argophylla	15.0	15.0		10.0	10.0
Solidago missouriensis			32.5	7.5	40.0
Taraxacum officinale			5.0		12.5
Artemisia dracunculus	95.0	20.0	70.0	27.5	45.0
Artemisia frigida	2.5	40.0	12.5	15.0	2.5
Gutierrezia sarothrae		22.5		15.0	32.5
Yucca glauca	2.5	2.5	2.5	10.0	
Artemisia cana	25.0	17.5	60.0	7.5	

brush, and *Bromus* spp. Sites 1928-2, 1928-5, and 1928-6 were greater than 66 percent similar to one another and were dominated by perennial grasses (Table 17).

Table 17. Indices of stand similarity (numbers are in percent).

SITES	1928-2	1928-5	1928-6	1928-1	1928-3
1928-2	--	75	66	61	56
1928-5		--	74	66	61
1928-6			--	58	61
1928-1				--	70
1928-3					--

Species percent cover varied significantly among the naturally revegetated 1928 sites. The results of Duncan's New Multiple Range Test (procedure in Steel and Torrie, 1960) on the significance of cover differences are given in Table 18. In summary, perennial grass cover was greatest on Site 1928-6 and least on Site 1928-1. Annual grass cover was greatest on Site 1928-3 and least on Site 1928-6. Forb cover was greatest on Site 1928-2 and least on Site 1928-1. Shrub cover was greatest on Sites 1928-1 and 1928-3 and least on Site 1928-6.

Table 18. Mean cover values of the 1928 sites (values in percent). Means in columns not followed by the same letter are significantly different at the 0.05% level (Duncan's New Multiple Range Test).

YEAR	SITE	PERENNIAL GRASSES	ANNUAL GRASSES	FORBS	SHRUBS
1976	1928-1	3.0 c	5.0 b	.8 d	18.9 b
1976	1928-2	5.8 b	4.5 b	23.6 a	9.3 c
1976	1928-3	3.0 c	9.2 a	6.2 b	30.0 a
1976	1928-5	9.3 a	2.4 b	8.7 b,c	10.5 b,c
1976	1928-6	8.2 a	2.6 b	4.0 b,c,d	2.5 c
1977	1928-1	3.8 c	9.7 b,c	3.3 b	42.9 a
1977	1928-2	7.9 b	13.1 a,b	2.8 b	17.6 b
1977	1928-3	5.1 b,c	16.0 a	10.8 a	32.3 a
1977	1928-5	12.2 a	5.1 c,d	5.6 b	18.5 b
1977	1928-6	17.0 a	.8 d	7.1 a,b	7.6 b

Biomass production on the 1928 sites also varied significantly (Table 19). Sites 1928-1 and 1928-3 produced the greatest biomass yields. These two sites were dominated by halfshrubs, shrubs, and annual grasses; biomass yields for Sites 1928-1 and 1928-3 averaged 2,099 kg/ha in 1976 and 2,170 kg/ha in 1977. The lowest biomass yields were recorded on Sites 1928-5 and 1928-6. These two sites were dominated by perennial grasses and their biomass yields averaged 843 kg/ha in 1976 and 1977. Average total yields on the naturally revegetated 1928 sites was 1,501 kg/ha in 1976 and 1,400

kg/ha in 1977 while the surrounding native range was 715 kg/ha in May, 1976 and 780 kg/ha in June, 1977.

Table 19. Above ground mean biomass production (kg/ha). Means in columns not followed by the same letter are significantly different at the 0.05% level (Duncan's New Multiple Range Test).

SITE	MEAN BIOMASS PRODUCTION			
	May, 1976	June, 1976	June, 1977	July, 1977
1928-1	2139 a	2521 a	1491 b	947 b
1928-2	1621 a,b	1690 a,b	976 b	460 b
1928-3	2061 b	1936 b	2850 a	1749 a
1928-5	940 c	1343 b	780 b	972 b
1928-6	747 c	1495 b	906 b	598 b

A contradiction seemed to occur in the relationship of biomass to seral stages. Biomass production has been used as a measure of stability with increased production implied for advanced seral stages (Whittaker, 1970). But in this study, highest production was associated with Sites 1928-1 and 1928-3, the least successionally advanced of the five study sites.

The presence of shrubs and halfshrubs in a community plays a strong role in altering soil chemistry. The deep-rooting habit of

shrubs permits the exploitation of nutrients in the soil below the rooting depth of most herbaceous species. By bringing nutrients from deep in the soil and releasing them through leaf fall and subsequent decay, essential minerals are placed in the soil surface. This increase in soil surface nutrient quality enhanced the productivity of species growing in the proximity of shrubs. Also, there is evidence of nitrogen fixation by *Artemisia* spp. (Farnsworth, 1979). Because soil nitrogen is often limiting for plant growth, increases in nitrogen would facilitate increased biomass production. For example, shrub-influenced soils in Washington provided a soil media richer in mineral nutrition than adjacent grass-dominated areas (Rickard et al., 1973).

Additionally, two major changes in yield were noted at the 1928 sites from 1976 to 1977: (1) yellow sweetclover was abundant on some sites in 1976 but was absent in 1977; and (2) yield on all sites was lower in 1977. The variation in production that commonly occurs at any location from one year to another is probably the result of differences in precipitation and soil-water status (Figure 25).

The basic harvest approach does not take fully into account the heterogeneous nature of these communities; different species can attain peak biomass at different times during the growing season.

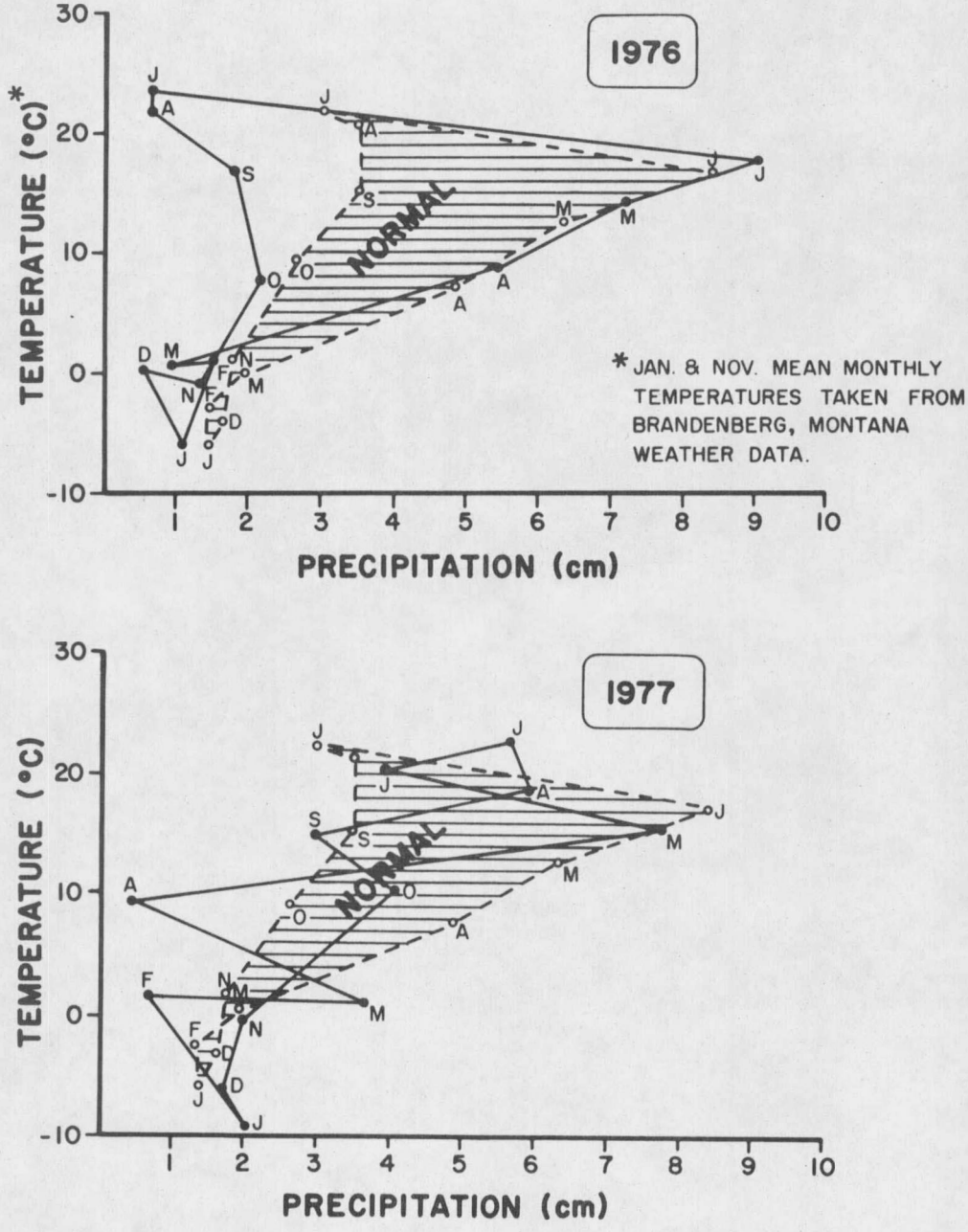


Figure 25. Climographs of temperature and precipitation at Colstrip, MT in 1976 and 1977 compared to normal.

For this reason, the production data reported here must be considered minimum estimates.

Species composition and diversity are two important structural features of a community (Odum, 1960; Bonham, 1974). Successional status of the 1928 communities was determined by diversity indices and measurement of similarity in species composition to the area's climax vegetation.

Although percent composition of species varied among the 1928 sites, floristic similarity between sites was strong. Sites 1928-1 and 1928-3 were dominated by falsetarragon sagewort, silver sagebrush, and cheatgrass; but perennial grasses were also present. Sites 1928-5 and 1928-6 were dominated by perennial grasses; yet shrubs and halfshrubs were also present. In summary, the dominant vegetation of each site reflects changes in the relative importance of individual species rather than changes in the floristic composition.

Species diversity is also an important measure of community change (Shafi and Yarranton, 1972). Odum (1969) suggested that species diversity should increase rapidly during early successional stages, level off in later stages, and decline somewhat at "climax". Because diversity is a function of species numbers and has been implied to result from successional advancement, diversity indices were

used in establishing the successional status of the 1928 communities (MacIntosh, 1967; Whittaker, 1965).

Data in Table 20 reveal that species diversity varied significantly among the sites. Site 1928-4, native range, was most successionally advanced and its diversity indices were lower than those on Sites 1928-5 and 1928-6. This trend is similar to diversity changes occurring with successional advancement reported by Odum (1969), Reiners et al. (1971), and Shafi and Yarranton (1972). In summary, diversity indices were highest on Site 1928-6 and lowest on Site 1928-1 and reflect a linear successional gradient (Figure 26).

Table 20. Diversity indices and standard errors calculated from cover data by the Shannon-Weiner Method ($\log_2$).

SITE	5/76	6/76	6/77	7/77
1928-1	1.8146	2.1919	1.7945	1.4076
	.1145	.1046	.1290	.1642
1928-2	2.4417	2.1061	1.9773	1.7688
	.1596	.1763	.1513	.2433
1928-3	2.3314	Not Sampled	2.4357	1.8705
	.0940	Not Sampled	.0803	.1544
1928-4	2.3829	2.6507	2.2839	2.2597
	.0839	.1758	.1071	.1136
1928-5	2.7112	2.9306	2.5123	2.3881
	.1592	.1222	.1660	.1826
1928-6	2.6262	3.0846	2.7065	2.8177
	.2317	.1020	.1406	.1426

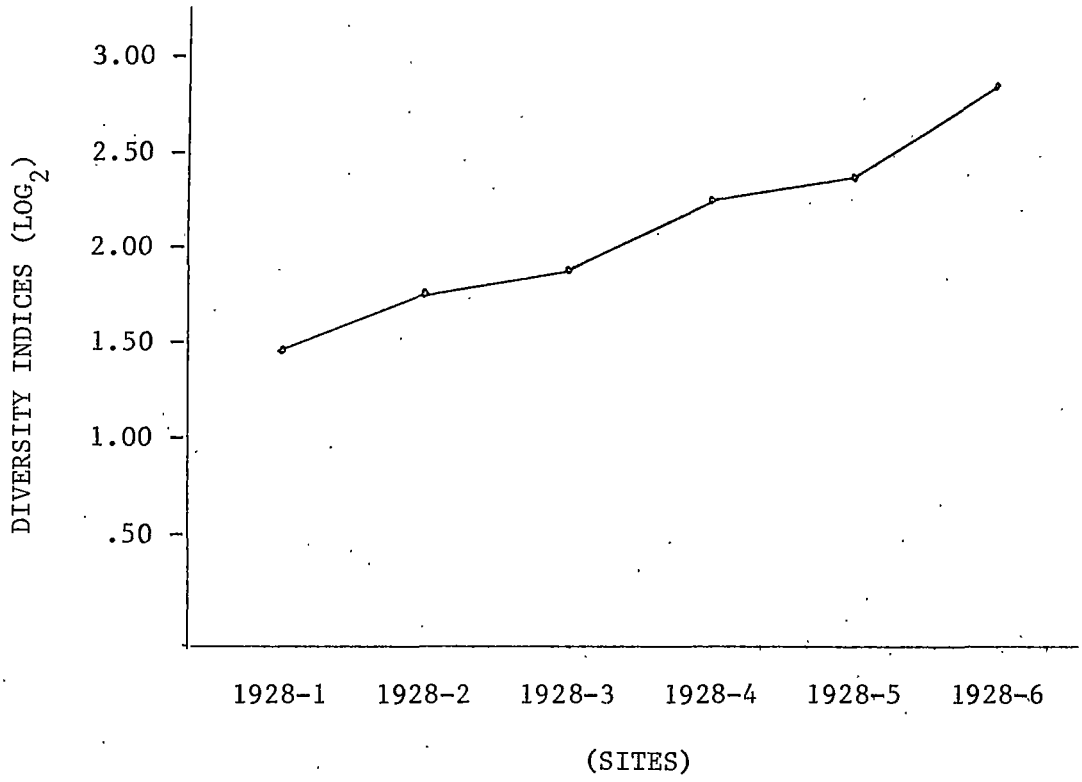


Figure 26. Diversity indices of study sites showed a strong linear relationship.

Soil Conservation Service (SCS) range condition guidelines were used to determine successional advancement toward climax (Table 21). Since the area's dominant climax vegetation consisted of perennial grasses, sites which had the greatest abundance of perennial grasses were believed to be the most successionally advanced. Based on these data and the diversity indices, Sites 1928-5 and 1928-6 were the most successionally advanced and Sites 1928-1 and 1928-3 were the least successionally advanced.

Table 21. Summary of dominant species, range condition, and soil texture on naturally revegetated spoils and native range in 1977.

SITES	DOMINANT SPECIES	RANGE CONDITION[1] CLASS & PERCENT[2]		DOMINANT SOIL TEXTURE
1928-1	Halfshrubs, annual grasses, and shrubs	Poor	6	Sandy loam
1928-2	Annual and perennial grasses, and shrubs	Poor	22	Sandy loam
1928-3	Shrubs, halfshrubs, and annual grasses	Poor	1	Sandy loam
1928-4	Perennial grasses and perennial sedges	Fair	47	Sandy loam
1928-5	Perennial grasses, halfshrubs, and shrubs	Fair	27	Sandy loam
1928-6	Perennial grasses and halfshrubs	Fair	25	Sandy loam

[1]Based on 1977 yield and SCS Range Condition Guidelines.

[2]Class and Percent: Poor = 0-25%; Fair = 25-50%; Good = 50-75%; Excellent = 75-100%.

Physiographic, Edaphic, and Land Management Data

The complex interrelationships between plant growth and plant distribution on the 1928 sites were influenced by slope, exposure, soil parent material, texture, soil moisture availability, and land management practices.

Slope and Exposure

Slope gradient influences soil stability, erosion, runoff, and accessibility to grazing animals; whereas exposure influences the amount of insolation received (Dix, 1958). Slope gradient varied only slightly among the 1928 sites; the maximum slope of any of the sites was less than 5 percent. Anderson (1957) found that a slope exceeding 25 percent was required to induce a change in the dominant vegetation present. Hence, the effect of slope on species composition among the 1928 sites appeared to be minimal.

The topographic relationships of the study sites are diagrammed in Figure 27. From these data, it is evident that runoff from the surrounding upland areas contributed to the 1928 sites' soil moisture recharge. Also, seepage from higher topographic positions into the subsoil could have been an important factor on the 1928 sites.

The 1928 study sites varied in aspect. Sites 1928-2 and 1928-5 had southern aspects. Sites 1928-1, 1928-3, and 1928-6 had northern

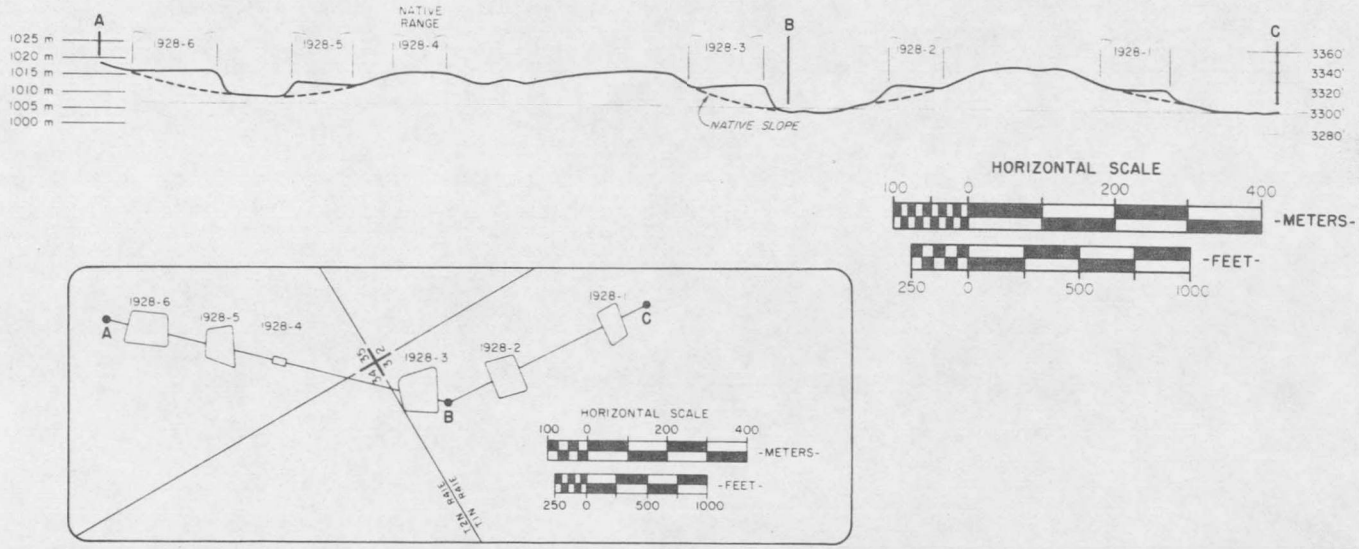


Figure 27. Topographical relationships of the 1928 study sites.

aspects. The contrasting vegetational characteristics of northern-southern exposures are apparent in Figures 28 and 29. Soil moisture loss is more rapid on southern exposures than on northern exposures (Parker, 1952). Therefore, exposure was a factor in species composition of the 1928 sites.

Parent Material and Texture

The 1928 sites were constructed of excess overburden material. On the average, this material was less than 5 m thick and consisted of shallow soil and sandrock.

The SCS Soil Characterization Laboratory described soils on Sites 1928-1, 1928-2, and 1928-6 as slightly weathered unconsolidated calcareous sandstone and interbedded shale and siltstone. Buried A_1 horizon material was common in the profile. Some soil forming processes were measurable; the most important included lowered bulk density, organic matter enrichment, weak structural development, and rock fragment weathering (Table 22).

Analysis of particle size distributions of soils of each site showed that all of the 1928 sites had a sandy loam texture. Sandy loam soils have higher infiltration rates, deeper penetration of water, and greater moisture availability, but less water retaining capacity than heavier soils (Salter and Williams, 1965; Redmann, 1975). Because of these soil characteristics, water moves more deeply into the



Figure 28. Northern exposure on Site 1928-5.



Figure 29. Southern exposure on Site 1928-1.

Table 21. Major soil properties on Sites 1928-1, 1928-2, and 1928-6.

CHARACTERISTICS	DEPTH (cm)	SITE 1928-1[1]	N[2]	SITE 1928-2[1]	N[2]	SITE 1928-6[1]	N[2]
Color dry	0-10	brown-light br gray	4	pale brown-brown	4	lt brown gray-lt gray	5
	10-200	light gray	4	pale red & brown-lt yel br	4	lt brown gray-lt gray	3
moist	0-10	brown-light olive br	5	brown	4	dk gray brown-lt br gray	5
	10-200	gray brown-lt yel br	6	yellow brown-gray	4	lt br gray-dk gr br	3
Texture	0-10	SaL (8),LSa(4),SaCL(1)	13	SaL	12	SaL(8),LSa(5)	13
	10-200	SaL(32)LSa(6)	38	SaL(26)LSa(9),SaCL(1)	36	SaL(25)LSa(10)	35
Structure		wk fine platy & gran <5 cm; mod med platy 5-20 cm; massive	10	massive 0-1&>20 cm; wk-mod,fine-course platy 1-20 cm	8	massive 0-1&10-200 cm wk-mod, very fine-very course platy 1-10 cm	8
Consistence dry	0-10	soft	5	soft (3) - loose (1)	4	slightly hard(4)-soft	5
	10-200	soft,slightly hard-firm	5	slightly hard(3)-soft(1)	4	slightly hard	3
moist	0-10	very friable	5	very friable(3)-loose(1)	4	v friable(4)-friable	5
	10-200	very friable-friable	5	friable(3)-v friable(1)	4	very friable	3
Bulk Density	0-10	1.26 - 1.60 g/cc	12	1.27 - 1.52 g/cc	11	1.35 - 1.62 g/cc	11
	10-200	1.38 - 1.78 g/cc	26	1.20 - 1.71 g/cc	26	1.27 - 1.69 g/cc	19
$CaCo_3$	0-10	mildly (1cm)-mod calcar	5	moderately calcareous	4	mildly(1cm)-mod calcar	5
	10-200	violently calcareous	5	violently calcareous	4	moderately calcareous	5
Alkalinity		mod (0-5cm)pH 8.0-8.5	4	mod (0-5cm)pH 8.2-8.4	4	mildly(0-1cm)pH 7.6 (0-110cm)pH 8.2	7
		strong(>5cm)pH 8.8-9.0	7	strong(5-200cm)pH 8.6-8.9	9	strong pH 8.6-9.1	5
Organic Matter	0-10	.7 - 8.0%	5	1.4 - 2.8%	5	.5 - 2.1%	6
	10-200	.2 - .9%	8	.2 - .8%	8	<.2%	7
C:N Ratio	0-10	13 - 17	4	12 - 16	4	13 - 17	5
	10-200	12 - 13	4	9 - 12	4	11 - 14	3
Roots		many fine roots-20 cm	5	many fine roots-10cm	4	common fine roots-10cm	5
		common fine roots 10-200	5	common-many fine 10-20cm	4	few fine 10-200cm	3
		few fine & med>20cm	2	few fine 10-200 cm	3		
Available Water Holding Capacity	0-10	4.6 - 10.7%	5	6.2 - 6.6%	2	5.8 - 9.2%	3
	10-200	6.1 - 9.1%	6	4.6 - 7.7%	6	5.7 - 6.5%	4
Drainage		somewhat excessively		somewhat excessively		somewhat excessively	

[1]Spoil analyzed by SCS Soil Characterization Lab

[2]N represents sample numbers

sandy-loam soil profile; deep-rooted species are thus favored (Coupland, 1961). For example, Sites 1928-1 and 1928-3 were dominated by two deep-rooted species, silver sagebrush and falsetarragon sagewort.

In comparison, another spoil area (Site 1930) near the 1928 study sites showed the importance of heavier texture in successional advancement. Site 1930's soil material was a loam texture while the 1928 sites had sandy loam texture. As a result, available soil water throughout the root zone on Site 1930 was greater than on the 1928 sites. Perennial species were able to establish and persist on the 1930 site. Although the 1930 site was three years younger than the 1928 sites, it was successionally more advanced due to increased soil water holding capacity, seed source proximity, and limited livestock grazing (Sindelar and Plantenberg, 1978).

Furthermore, the silt-clay content of the soil is a key factor influencing species composition, dominant species, and the rate of plant succession of species (Bramble and Ashley, 1955; Odum, 1960; Bronson et al., 1965). With increases in clay content, water holding capacity and base exchange capacity of the soil are increased. Since water holding capacity and base exchange capacity are important in plant growth, a major component of the soil which must be analyzed is the clay fraction.

Data on the clay content of the 1928 sites were compared by Duncan's New Multiple Range Test (Table 23). This test showed that no significant difference occurred in clay content on the 1928 sites at depths 0 - 110 cm; clay percentages of all sites were similar. Therefore, clay content was not a significant factor in influencing species composition among the study sites.

Table 23. Mean percent of clay content and standard deviations of the 1928 study site soils (Duncan's New Multiple Range Test). NOTE: Significant differences were not present between means at the 0.05% level.

SITE	SOIL DEPTH IN CM				
	0 - 10	25 - 35	50 - 60	75 - 85	100 - 110
1928-1	11.1 ± 2.4	11.8 ± 3.1	12.3 ± 2.9	11.5 ± 2.5	10.5 ± 1.2
1928-2	11.8 ± 3.1	12.1 ± 3.7	13.0 ± 1.4	11.8 ± 2.1	11.5 ± 1.2
1928-3	12.3 ± 2.9	11.8 ± 3.9	13.0 ± 1.6	11.3 ± 1.7	11.8 ± 2.1
1928-5	11.5 ± 2.5	11.6 ± 3.5	12.0 ± 1.0	11.6 ± 2.4	11.0 ± 2.2
1928-6	10.5 ± 1.2	11.8 ± 2.7	13.3 ± 1.8	11.1 ± 1.4	11.3 ± 2.5

Rogers (1951) stated that the rate of succession and density of vegetation on naturally revegetated spoil banks is dependent on acidity, texture, and the stability of the banks. Froleck and Keim (1933) found soil texture to be one of the chief factors which

determines the existence of distinctive plant communities. Soil texture affects the moisture characteristics of the soil as well as plant distribution.

Additional studies have shown the significance of soil texture on deep-rooted species growth. For example, Thatcher's (1959) study in Wyoming found that silver sagebrush occurred on two basic types of parent material, sandstone and gravel. This conclusion corresponds with data noted at the study sites near Colstrip; mining records indicated that 57 percent of the material hauled to the 1928 sites was sandrock. Therefore, it is not surprising that silver sagebrush was dominant on some 1928 sites and present on other sites.

In addition, Tomanek and Albertson (1957) found that roots of falsetarragon sagewort exceeded depths of 2 m in sandy loam soils. This factor is important in providing falsetarragon sagewort a competitive advantage over shallower-rooted species; and it is significant to this research project because the 1928 sites were composed of sandy loam soils.

Further analysis of soils on the five naturally revegetated sites showed no serious elemental deficiency or toxicity (unpublished data).

Soil Moisture Availability

The amount of water which a soil can hold depends primarily on

texture and organic matter content. In soils with adequate drainage, each textural class of soil has a field capacity; this is the amount of soil moisture held against the force of gravity. Water held in the soil at field capacity has been divided into two categories: (1) available water -- water held in the soil at less than -15 bars, and (2) unavailable water -- water held in the soil at greater than -15 bars.

Trends in soil water status were measured at the 1928 study sites during 1976 and 1977. Fluctuations in soil water were greater near the surface at all sites. By July, 1977, soil moisture was below -15 bars at a depth of 0 - 20 cm on all sites and soil moisture remained below -15 bars on all sites at this depth until late September, 1977. The fact that surface moisture was unavailable near the surface during critical periods of the growing season limited the survival of perennial grass seedlings on the 1928 sites.

Soil water potential was greater than -15 bars at depths 20 - 100 cm on Sites 1928-2, 1928-5, and 1928-6 during the 1977 growing season. On Sites 1928-1 and 1928-3, soil moisture was below -15 bars at depths 20 - 100 cm from July to October, 1977. This steady utilization of deep soil moisture on these sites can be attributed to the physiological activities of the dominant species present -- silver sagebrush, falsetarragon sagewort, and annual grasses.

Where regional precipitation and other climatic factors are similar, an increase in the supply of moisture in the soil indicates vegetative structural differences (Hanson and Whitman, 1938). Research has shown that silver sagebrush occurs primarily on sites with increased moisture availability (Patten, 1963) and/or on soils influenced by high water tables (Thatcher, 1959). These factors are significant in influencing the distribution of silver sagebrush in the 1928 study area.

Land Management Practices

The history of livestock grazing on the study area dates back to the 1880's. The Green Mountain Stock Ranching Company was one of the first large cattle companies to move into the Colstrip area (Bennett et al., 1976). Other ranching operations soon followed and large numbers of horses, sheep, and cattle were raised in the Colstrip area. Ranching records indicate that more cattle were shipped out of the Colstrip area than any other location in Montana in the 1930's (Eastgate, 1978).

Following mining operations of the 1920's, the first documented use of the study area was from 1950 - 1955 by the Schulenberg dairy. From 1955 - 1973, Louis Eastgate used the study sites during the summer for grazing; and from 1973 - 1977, the study area was grazed year-round by 70 head of cattle (Bishop, 1977).

A 1911 land survey described the vegetation of the area adjacent to the study area (T1N, R41E) as a fair growth of bunch and buffalo grass (any small grasses) on rolling areas, but on the gentle slopes the growth is very poor -- there being a great deal of salt sage (silver sagebrush). Because of extensive livestock use on the 1928 study area and the adjacent land, considerable portions of the vegetation were modified.

Basically, the vegetation that was present on the study area prior to mining operations was presumed to have been characteristic of a heavily grazed, disturbed area. Therefore, the overburden material which formed the 1928 study sites contained a mixture of seeds, roots, and rhizomes of species characteristic of a heavily grazed area; this mixture comprised the first species which became established on the bare areas of the study sites.

Research has shown that species already present on a site exert some influence on the probabilities of success among the various species appearing subsequently; species present might influence germination (Sagar and Harper, 1960; Keever, 1950; Brown, 1967) and seedling survival (Cavers and Harper, 1967). Consequently, early established perennial species may be controlling factors in determining the pattern a given succession takes because of their ability to invade and hold space (Davis and Cantlon, 1969).

Grazing also affected species distribution on the study sites by its influence on seed sources surrounding each study site. Leisman (1957) noted that the nature of pioneer vegetation which invaded any bare or disturbed area was limited to plants which exist in the surrounding vegetation. Western Energy Company (1973) stated that heavily grazed areas in the Colstrip region were invaded by shrubs and annual grasses. Sagebrush and sagewort (*Artemisia* spp.) were dominant or present on most areas subjected to moderate or heavy grazing. Cheatgrass was a dominant where perennial grass cover was sparce due to overgrazing.

These data corresponded with the distribution of species on the 1928 sites. Sites 1928-1 and 1928-3 were subjected to moderate to heavy grazing pressure and sagebrush and sagewort were the dominant species. Sites 1928-2, 1928-5, and 1928-6 were probably subjected to light grazing pressure and perennial grasses were dominant.

Figures 30, 31, and 32 show a portion of the area near study sites 1928-2 and 1928-3 where an abundance of increaser species (annual grasses, silver sagebrush, and yucca) was present. Figure 33 shows a portion of the study area near Sites 1928-5 and 1928-6 which reflects the absence of yucca and silver sagebrush.

The presence of the increaser species near study sites 1928-1

and 1928-3 can be attributed to heavier grazing pressure there than proximal to Sites 1928-5 and 1928-6. The increased grazing pressure near these sites can be attributed to the fact that from 1928 to 1973 the only water available in this management unit was located between Sites 1928-2 and 1928-3. Ellison (1960) stated the existence of well-defined trails suggests excessive grazing use. Figure 34 shows the trail cattle made in order to reach water near Site 1928-3.

In conclusion, the invading pioneer vegetation of the 1928 study sites consisted of (1) species which surrounded each study site and (2) species which were present in the overburden material that was used to form the study sites.

Physiological and Morphological Factors

Because the 1928 sites were formed from the same parent material at approximately the same time in the same management unit, plant communities on all five study sites should have been similar. Yet a major contrast in successional development was apparent among the 1928 sites. Two successional seral stages were evident; Sites 1928-2, 1928-5, and 1928-6 reached the perennial grass/forb seral stage whereas Sites 1928-1 and 1928-3 stagnated at the halfshrub/shrub/annual grass seral stage.

The competitive relationship of annual grasses and woody species to perennial grasses was an important factor in successional develop-

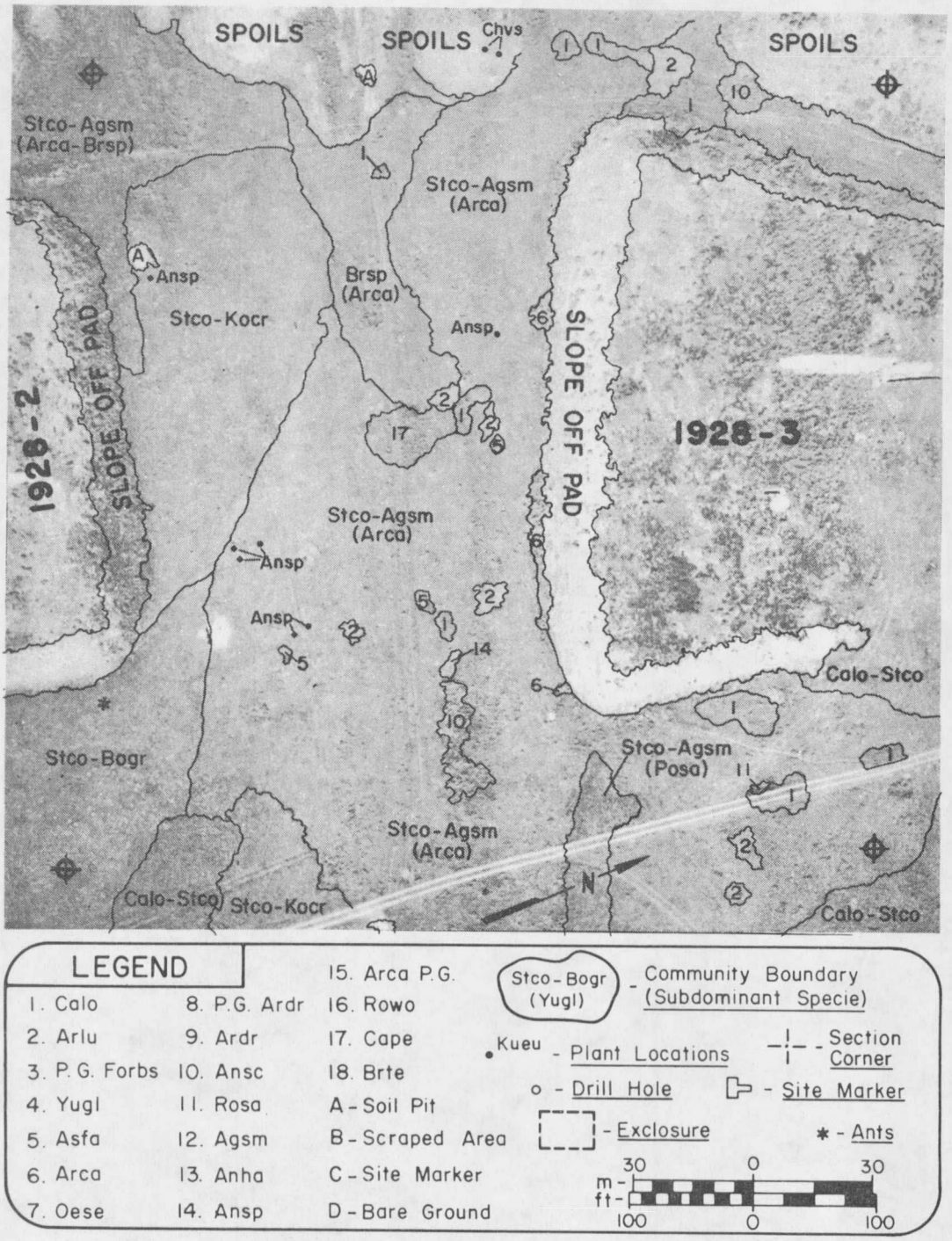


Figure 30. Vegetative mosaic map between Sites 1928-2 and 1928-3.



Figure 31. Range surrounding Site 1928-1.



Figure 32. Range surrounding Site 1928-3.

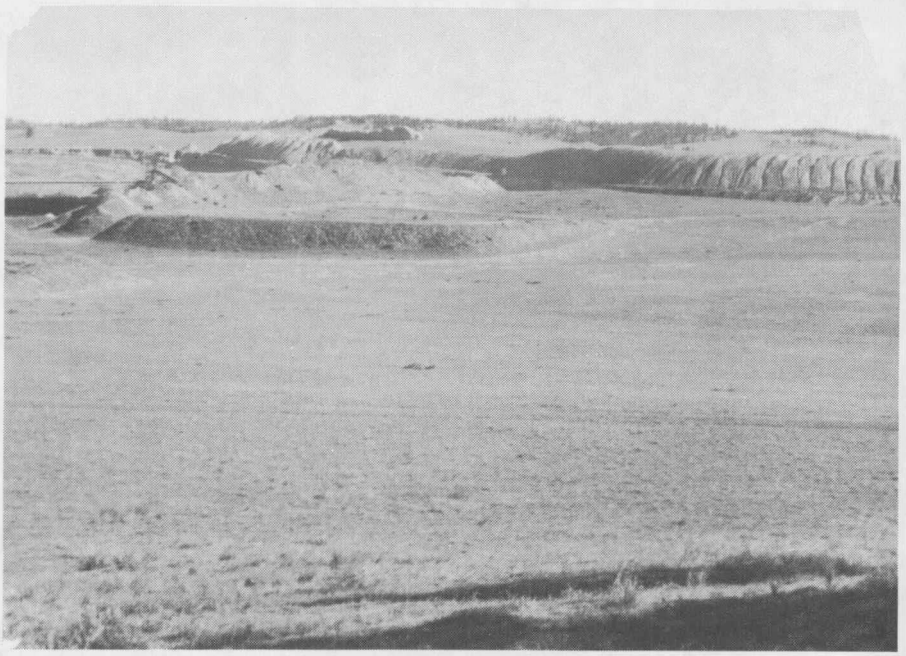


Figure 33. Range surrounding Sites 1928-5 and 1928-6.



Figure 34. Cattle trail near Site 1928-3.

ment on the 1928 sites. Also, differences in seral stage development were the result of dominant species present on the sites.

On the 1928 sites, dominant species determined whether a community was closed or open. For a community to be closed, it must have established an environment within itself which allows the growth of its own associated species and which tends to exclude others. An open community is a community where significant fluctuations of species composition occur.

Sites 1928-1 and 1928-3 were considered closed communities because the dominant species associated with these sites were probably utilizing all the resources available on the sites; thus, other species were excluded. A factor associated with the exclusion of other species on Sites 1928-1 and 1928-3 was the competitive relationship of annual grasses and woody species to perennial grass seedling establishment.

Annual grass seedlings have a competitive advantage over perennial grass seedlings for moisture and nutrients. Key characteristics which account for this advantage are rapid rates of root growth and early seedling development of annual species (Harris and Wilson, 1970). Rapid root elongation enables annual grasses to utilize more soil moisture. Daubenmire (1959) proposed that where available water is not present throughout the summer, the relative

rapidity of root penetration is generally the most important factor governing the success of seedlings.

Dense populations of annual grasses restrict the establishment of perennial grass seedlings (Evans and Young, 1970). Harris (1967) examined a series of fields in Washington which had been abandoned for up to 40 years. Fields abandoned for 1 year were dominated by cheatgrass as were fields abandoned for 40 years. No evidence could be found that perennial grasses were invading the area.

Competition between shrub seedlings and perennial grasses is intense due to the similarity of root distribution; both *Artemisia* species and perennial grasses utilize the same soil moisture area (Cook and Lewis, 1963; Frischknecht, 1963). When woody species become established and gain canopy height and rooting depth advantages, they dominate the herbaceous cover. Hence grass seedlings have reduced chances for survival (Shubert, 1969).

Blaisdell (1949) stated that the effect of sagebrush competition on perennial grasses depends chiefly upon the age of the sagebrush. The older the stand of sagebrush, the less chance there is for successful grass establishment and production. As young sagebrush plants become larger, their presence and litter accumulation make microclimatic conditions more favorable to the establishment of their own seedlings as well as annual grasses.

Cheatgrass often grows more luxuriously near shrubs than on the adjacent open ground (Rickard et al., 1973). This growth was attributed to a more favorable microclimate created by the physical presence of shrubs and their accumulated litter. Young and Evans (1972, 1975) found more cheatgrass caryopses under shrub canopies than between shrubs. They concluded that sagebrush litter provided a safer microsite where annual grasses could germinate and become established.

In contrast, Weaver and Rowland (1952) found that excessive litter accumulations (12,000 lb/acre) resulted in the formation of a nearly pure, but somewhat thinner-than-normal stand of *Andropogon* in Nebraska. Hence, excessive litter accumulations caused blue grama, little bluestem, and prairie junegrass to disappear from the *Andropogon* community. Comparatively, litter accumulations on Sites 1928-1 and 1928-3 totaled 8,313 kg/ha and 22,499 kg/ha respectively. Hence, litter may have been an important factor in the lack of perennial grasses on these sites.

Reid (1965) found that aqueous litter extracts of big sagebrush, silver sagebrush, black sagebrush (*Artemisia nova*), and threetip sagebrush (*Artemisia tripartita*) inhibited germination of smooth brome (*Bromus inermis*), squirreltail (*Sitanion hystrix*), and slender wheatgrass (*Agropyron trachycaulum*). He suggested that

inhibitors in these shrubs may affect the distribution pattern of some native grasses. Similarly, Schlatterer and Tisdale (1969) found that litter of big sagebrush affected the germination and early growth of perennial grasses. Robertson and Pearse (1945) concluded that well-established, undisturbed stands of sagebrush and cheatgrass are essentially closed to perennial seedling establishment.

During 1975 yellow sweetclover invaded the entire 1928 study area. This biennial forb was abundant during 1976 on Sites 1928-2, 1928-5, and 1928-6, but was scarce on Sites 1928-1 and 1928-3. Since minimum amounts of yellow sweetclover existed on Sites 1928-1 and 1928-3, these were considered closed communities. The absence of yellow sweetclover on these two sites can be attributed to the total utilization of resources by the dominant halfshrubs, shrubs, and annual grasses present on Sites 1928-1 and 1928-3.

In contrast, Sites 1928-2, 1928-5, and 1928-6 were open communities. The abundance of yellow sweetclover on these sites indicated that the perennial grass communities associated with Sites 1928-2, 1928-5, and 1928-6 were not utilizing all available resources.

Because of the physiological and morphological characteristics of the dominant species associated with Sites 1928-2, 1928-5, and

1928-6, succession advanced to the perennial grass/forb seral stage. However, the competitive abilities of silver sagebrush and cheatgrass combined with possible alleopathic effects of silver sagebrush litter and excessive litter accumulations on sites have resulted in Sites 1928-1 and 1928-3 stagnating at the halfshrub/shrub/annual grass seral stage.

SUMMARY AND RECOMMENDATIONS

Succession is a process of ecosystem change resulting from large numbers of plant-environment interactions. Factors influencing successional relationships of plant species on naturally revegetated mine spoils must be understood thoroughly if more than trial-and-error attempts at restoration of spoil areas are to be made.

Because vegetation of any disturbed area undergoes changes in composition with time, numerous plant-environment interactions are involved. Succession on mined land encompasses characteristics of both primary and secondary succession. Therefore, studies of succession have provided useful insights into many aspects of ecosystem organization and dynamics.

The objectives of this research project were two-fold. The first objective was to analyze structural and functional characteristics of naturally revegetated mine spoils after fifty years of succession. The second objective was to evaluate factors which may have affected succession on these fifty-year-old communities.

During the spring of 1976, a survey of surface mined land near Colstrip, Montana revealed the vegetational dissimilarity of five naturally revegetated spoil deposits. Although plant communities were the same relative age and were located on sites composed of

similar spoil material in the same grazing management unit, different successional seral stages had evolved.

During 1976 and 1977 two approaches were used to obtain data for estimation of origin and maintenance of communities on the five spoil deposits. One approach utilized exclosures and permanent quadrats whereby an intensive study of structural and functional components of each community could be made. Here, data were collected on species numbers, frequency, distribution, cover, and biomass as well as on soils and soil moisture. The second approach focused on the analysis of past mining procedures and land management practices. Information collected on the formation of the study sites ranged from origin of the spoil material to removal and placement of the spoil material on native rangeland. Information on vegetation and grazing in the study area before, during, and after mining operations of the 1920's was also collected.

Interpretation of data indicated that plant communities on the 1928 sites were distinctively different in structure, species dominance, and diversity. Sites 1928-1 and 1928-3 were dominated by shrubs, halfshrubs, and annual grasses. Sites 1928-2, 1928-5, and 1928-6 were dominated by perennial grasses and forbs.

Factors which affected the present distribution of vegetation on the 1928 study sites and succession within each community were

reviewed. The following were major factors which affected succession and distribution of vegetation on the 1928 study sites:

(a) Grazing affected succession on the 1928 sites in two ways. Overgrazing of the study area in the 1920's prior to mining operations probably influenced the original species composition of the study area and adjacent abandoned mine spoils. If so, it also affected seed sources available for colonization of the 1928 study sites. Continual overgrazing of the study area following mining operations influenced species composition on all sites. Probable effects of overgrazing on species composition were most apparent on Sites 1928-1 and 1928-3 because of their proximity to the only water available within the range management unit from 1928 to 1973.

(b) Strip-mining processes affected succession on the 1928 study sites by mixing seeds, roots, and rhizomes within the overburden material. For example, the present distribution of silver sagebrush on the native range surrounding Sites 1928-1, 1928-2, and 1928-3 suggests that this shrub was abundant on a portion of the range management unit prior to mining operations of the 1920's. Consequently, the overburden material used for formation of Sites 1928-1, 1928-2, and 1928-3 probably contained numerous propagules necessary for the establishment of silver sagebrush on these sites.

(c) Seed source proximity influenced succession on the 1928

study sites by providing different sources of disseminules of herbaceous and shrubby species for invasion on all sites. Silver sagebrush was more abundant on native range near Sites 1928-1, 1928-2, and 1928-3 than on native range surrounding Sites 1928-5 and 1928-6. Hence, more silver sagebrush grew on Sites 1928-1, 1928-2, and 1928-3 than on Sites 1928-5 and 1928-6.

(d) The dominance of certain life forms having particular physiological and morphological characteristics influenced species composition and succession on some of the 1928 sites. Silver sagebrush, falsetarragon sagewort, and annual grasses on Sites 1928-1, and 1928-3 appeared to utilize site resources completely; thus most other species were excluded. Sites where these species were not abundant (Sites 1928-2, 1928-5, and 1928-6) were dominated by perennial grasses and forbs.

(e) It is likely that drought conditions during the late 1920's and early 1930's affected species composition on the study area; moisture stress during these drought periods probably encouraged the invasion of weedy species on all sites.

(f) Sandy loam soil texture influenced succession on all study sites by its influence on available soil moisture.

Additionally, analysis of land-use practices, mining records, quantitative vegetational and soil data, and topographical relation-

ships allowed interpretation of succession on fifty-year-old spoil deposits.

In summary, the most significant factors which affected the origin of vegetation on the 1928 study sites at Colstrip, Montana, appeared to be overgrazing prior to mining, plant materials incorporated into overburden during mining, and seed source proximity. Major factors which affected successional development on the 1928 study sites were the physiological and morphological characteristics of the dominant species on each site coupled with climatic and edaphic factors and continued overgrazing.

Intensive and detailed analyses of plant succession on fifty-year-old spoils aided in determination of causal factors. Elements of both primary and secondary succession were identified. Such successional studies are important in evaluating success of current reclamation practices. Furthermore, successional studies on naturally revegetated spoils enhance comprehension of the complex interrelationships occurring within plant communities on mined lands.

As a result of extensive data collection, analysis, and observations on naturally revegetated fifty-year-old mine spoils near Colstrip, Montana, the following recommendations could be incorporated into future reclamation practices:

(1) Water-holding capacity of surface soils should be

considered in the determination of seeding mixtures and seeding rates for the Colstrip area. Succession may be slower on excessively sandy soils. Consequently, selective overburden handling may be necessary to improve surface soil textures thereby affecting successional rates.

(2) Management methods for litter reduction (i.e., burning, grazing, etc.) would reduce litter accumulation and enhance growing conditions whereby other species could flourish. On the 1928 study sites, excessive litter accumulations appeared to reduce perennial grass seedling establishment.

(3) Competitive relationships and alleopathic effects of shrubs should be evaluated in order to determine amounts and varieties of shrubs used for reseeding on reclamation projects. Possible alleopathic effects of some shrubs (i.e., *Artemisia* spp.) and the competitive characteristics of various shrub seedlings influence the establishment, growth, and persistence of native perennial grasses.

(4) The following species were abundant on naturally revegetated fifty-year-old spoils: *Agropyron smithii, Agropyron spicatum, Andropogon scoparius, Calamovilfa longifolia, Carex filifolia, Carex pensylvanica, Helianthus petiolaris, Koeleria cristata, Petalostemon candidum, Petalostemon purpureum, Poa sandbergii, Psoralea argophylla, Stipa comata, Artemisia ludoviciana,* and *Artemisia cana.*

These species may be suitable for reclamation purposes on similar spoils within the Colstrip, Montana area.

(5) Management techniques for control of annual grasses may be necessary to reduce interspecific competition between annual grasses and perennial seedlings. Dense populations of annual grasses (*Bromus tectorum* and *Bromus japonicus*) can restrict the establishment and survival of perennial seedlings.

APPENDIX

APPENDIX A. List of plant species collected on the 1928 study sites near Colstrip, MT.

SCIENTIFIC NAME	CODE	COMMON NAME	1928 SITES 1	2	3	4	5	6
Agropyron smithii	AGSM	Western wheatgrass	x	x	x	x	x	x
Agropyron spicatum	AGSP	Bluebunch wheatgrass		x	x	x	x	x
Amaranthus graecizans	AMGR	Prostrate pigweed			x			
Ambrosia psilostachya	AMPS	Western ragweed	x	x	x	x	x	x
Andropogon hallii	ANHA	Sand bluestem			x	x		
Andropogon scoparius	ANSC	Little bluestem				x	x	x
Apocynum medium	APME	Intermediate dogbane				x		
Aristida longiseta	ARLO	Red threeawn	x	x	x	x	x	x
Artemisia campestris	ARCM	Common sagewort				x		
Artemisia cana	ARCA	Silver sagebrush	x	x	x	x	x	x
Artemisia dracunculus	ARDR	Falsetarragon sagewort	x	x	x	x	x	x
Artemisia frigida	ARFR	Fringed sagewort	x	x	x	x	x	x
Artemisia ludoviciana	ARLU	Prairie sagewort	x	x		x	x	x
Asclepias pumila	ASPU	Plains milkweed				x	x	x
Asclepias speciosa	ASSP	Showy milkweed	x		x			
Asclepias viridiflora	ASVI	Green milkweed			x			
Aster campestris	ASCA	Meadow aster		x	x		x	x
Aster falcatus	ASFA	Whiteprairie aster	x	x	x	x	x	x
Astragalus adsurgens	ASAD	Standing milkvetch	x	x	x	x	x	x

APPENDIX A (Continued)

SCIENTIFIC NAME	CODE	COMMON NAME	1928 SITES 1	2	3	4	5	6
Astragalus crassicarpus	ASCR	Groundplum milkvetch			x	x	x	
Astragalus gracilis	ASGR	Slender milkvetch				x		
Astragalus gilviflorus	ASGI	Threeleaved milkvetch					x	x
Astragalus lotiflorus	ASLO	Lotus milkvetch	x	x	x	x	x	x
Astragalus missouriensis	ASMI	Missouri milkvetch			x			
Bouteloua curtipendula	BOCU	Sideoats grama				x		x
Bouteloua gracilis	BOGR	Blue grama	x	x	x	x	x	x
Bromus japonicus	BRJA	Japanese brome	x	x	x	x	x	x
Bromus tectorum	BRTE	Cheatgrass	x	x	x	x	x	x
Bryun spp.	--	(moss)	x	x	x	x	x	x
Calamagrostis montanensis	CAMO	Plains reedgrass					x	
Calamovilfa longifolia	CALO	Prairie sandreed	x	x	x	x	x	x
Calochortus nuttallii	CANU	Sego mariposalily				x		x
Camelina microcarpa	CAMI	Littlepod falseflax	x	x	x		x	x
Carex filifolia	CAFI	Threadleaf sedge	x	x	x	x	x	x
Carex pensylvanica	CAPE	Penn sedge	x	x	x	x	x	
Chenopodium leptophyllum	CHLE	Narrowleaf goosefoot	x	x			x	
Chrysopsis villosa	CHVL	Hairy goldaster	x	x	x	x	x	x
Chrysothamnus viscidiflorus	CHVS	Green rabbitbrush	x	x				

APPENDIX A (Continued)

SCIENTIFIC NAME	CODE	COMMON NAME	1928 SITES 1	2	3	4	5	6
Cirsium flodmanii	CIFL	Flodman thistle				x		
Cirsium undulatum	CIUN	Wavyleaf thistle	x	x	x	x	x	x
Coryphantha missouriensis	COMI	Yellow pincushion cactus	x	x	x	x	x	x
Cryptantha celosioides	CRCE	Miners candle					x	
Descurainia pinnata	DEPI	Pinnate tansymustard	x	x		x	x	x
Echinacea pallida	ECPA	Purple coneflower					x	x
Erigeron divergens	ERDI	Spreading fleabane				x		
Erigeron pumilus	ERPU	Low fleabane				x	x	
Eriogonum annuum	ERAN	Annual buckwheat	x	x	x	x	x	x
Erysimum asperum	ERAS	Plains wallflower	x	x	x	x	x	x
Euphorbia glyptosperma	EUGL	Ridgeseed spurge		x	x			
Festuca octoflora	FEOC	Sixweeks fescue	x	x	x	x	x	x
Gaura coccinea	GACO	Scarlet gaura	x	x	x	x	x	x
Geum triflorum	GETR	Prairiesmoke		x				
Glycyrrhiza lepidota	GLLE	Wild licorice			x			
Grindelia squarrosa	GRSQ	Curlycup gumweed	x					x
Gutierrezia sarothrae	GUSA	Broom snakeweed	x	x	x	x	x	x
Haplopappus spinulosus	HASP	Spiny goldenweed	x			x		
Helianthus petiolaris	HEPE	Prairie sunflower	x	x	x	x	x	x

APPENDIX A (Continued)

SCIENTIFIC NAME	CODE	COMMON NAME	1928 SITES 1	2	3	4	5	6
Juniperus scopulorum	JUSC	Rockymountain juniper					x	x
Kochia scoparia	KOSC	Summer cypress						x
Koeleria cristata	KOCR	Prairie junegrass	x	x	x	x	x	x
Kuhnia eupatorioides	KUEU	False prairie boneset	x					x
Lactuca pulchella	LAPU	Blue lettuce		x	x	x	x	x
Lactuca serriola	LASE	Prickly lettuce	x	x	x	x	x	x
Lepidium densiflorum	LEDE	Prairie pepperweed	x		x	x	x	
Leucocrinum montanum	LEMO	Common starlily	x		x	x		
Liatris punctata	LIPU	Dotted gayfeather	x	x		x		x
Linum perenne	LIPE	Perennial flax						x
Linum rigidum	LIRI	Stiffstem flax		x	x	x	x	x
Lithospermum incisum	LIIN	Narrowleaf gromwell	x	x	x	x	x	x
Lygodesmia juncea	LYJU	Rush skeletonplant	x	x	x	x	x	x
Medicago sativa	MESA	Alfalfa	x					
Melilotus alba	MEAL	White sweetclover	x	x		x	x	x
Melilotus officinalis	MEOF	Yellow sweetclover	x	x	x	x	x	x
Mentzelia decapetala	MEDE	Tenpetal mentzelia	x	x	x		x	x
Microsteris gracilis	MIGR	Pink microsteris			x			
Mirabilis linearis	MILI	Narrowleaf four o'clock	x	x	x		x	x

APPENDIX A (Continued)

SCIENTIFIC NAME	CODE	COMMON NAME	1928 SITES 1	2	3	4	5	6
Myosotis micrantha	MYMI	Blue scorpiongrass		x				
Nostoc spp.	--	(algae)	x	x		x		
Oenothera albicaulis	OEAL	Prairie evening-primrose	x					
Oenothera nuttallii	OENU	Nuttall evening-primrose	x		x		x	x
Oenothera serrulata	OESE	Shrubby evening-primrose				x	x	x
Opuntia fragilis	OPFR	Brittle pricklypear	x	x	x	x	x	x
Orthocarpus luteus	ORLU	Yellow owlclover			x			
Oryzopsis hymenoides	ORHY	Indian ricegrass	x	x	x		x	x
Oxytropis besseyi	OXBE	Bessey loco	x	x	x			
Paremlia chlorochroa	PACH	(lichen)				x		x
Penstemon albidus	PEAL	White penstemon	x	x	x	x	x	x
Petalostemon candidum	PECA	White prairieclover		x	x	x	x	x
Petalostemon purpureum	PEPU	Purple prairieclover	x	x	x	x	x	x
Phlox hoodii	PHHO	Hoods phlox				x		
Plantago patagonica	PLPA	Woolly plantain	x	x	x	x	x	x
Poa juncifolia	POJU	Alkali bluegrass		x				
Poa pratensis	POPR	Kentucky bluegrass	x	x	x	x	x	x
Poa sandbergii	POSA	Sandberg bluegrass	x	x	x	x	x	x
Pollybastia obsoleta	POOB	(lichen)				x		

APPENDIX A (Continued)

SCIENTIFIC NAME	CODE	COMMON NAME	1928 SITES 1	2	3	4	5	6
Psoralea argophylla	PSAR	Silverleaf scurfpea	x	x	x	x	x	x
Psoralea esculenta	PSES	Common breadroot scurfpea	x			x		x
Psoralea tenuiflora	PSTE	Slimflower scurfpea						x
Ratibida columnifera	RACO	Prairie coneflower				x		x
Rhus trilobata	RHTR	Skunkbush sumac	x	x	x	x	x	x
Rosa woodsii	ROWO	Woods rose		x	x	x	x	
Salsola kali	SAKA	Russian thistle			x	x	x	x
Sitanion hystrix	SIHY	Bottlebrush squirreltail	x	x			x	x
Solanum triflorum	SOTR	Cutleaf nightshade		x				x
Solidago missouriensis	SOMI	Missouri goldenrod	x	x	x	x	x	x
Solidago mollis	SOMO	Velvety goldenrod	x	x	x		x	x
Solidago rigida	SORI	Stiff goldenrod			x			
Sphaeralcea coccinea	SPCO	Scarlet globemallow	x	x		x	x	x
Sporobolus cryptandrus	SPCR	Sand dropseed	x	x	x		x	
Stipa comata	STCO	Needleandthread	x	x	x	x	x	x
Stipa viridula	STVI	Green needlegrass		x			x	
Taraxacum officinale	TAOF	Common dandelion	x	x	x	x	x	x
Thermopsis rhombifolia	THRH	Prairie goldenpea				x		
Tortula spp.	--	(moss)					x	

APPENDIX A (Continued)

SCIENTIFIC NAME	CODE	COMMON NAME	1928 SITES 1 2 3 4 5 6
Tradescantia bracteata	*TRBR*	Bracted spiderwort	x x x
Tragopogon dubius	*TRDU*	Yellow salsify	x x x x x x
Tulostoma spp.	--	(fungi)	x x x x
Yucca glauca	*YUGL*	Yucca	x x x x x x

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