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


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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June, 1979

## ACKNOWLEDGEMENT

The author wishes to express appreciation to many individuals and organizations for their assistance with his research project. The author would like to thank the Division of Biomedical and Environmental Research, Department of Energy, for providing financial assistance for this research project and Western Energy Company and Burlington Northern, Inc. for providing study sites and mining/reclamation records.

In particular, the author expresses sincere appreciation to Dr. Brian W. Sindelar, his major advisor, for his wise counsel and constructive comments; to Alma and Patrick Plantenberg, Brad Berg, and Linda Gillam for their assistance in data collection; to Ron Thorson for computer programming and data analysis; to David Litz for draftsmanship; and most of all to Kathy Skilbred, his wife, for technical revision and manuscript preparation.

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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.

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# 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 micro-climate is altered. This alteration is responsible for increased evaporational losses which usually create a warmer and drier micro-environment. 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).

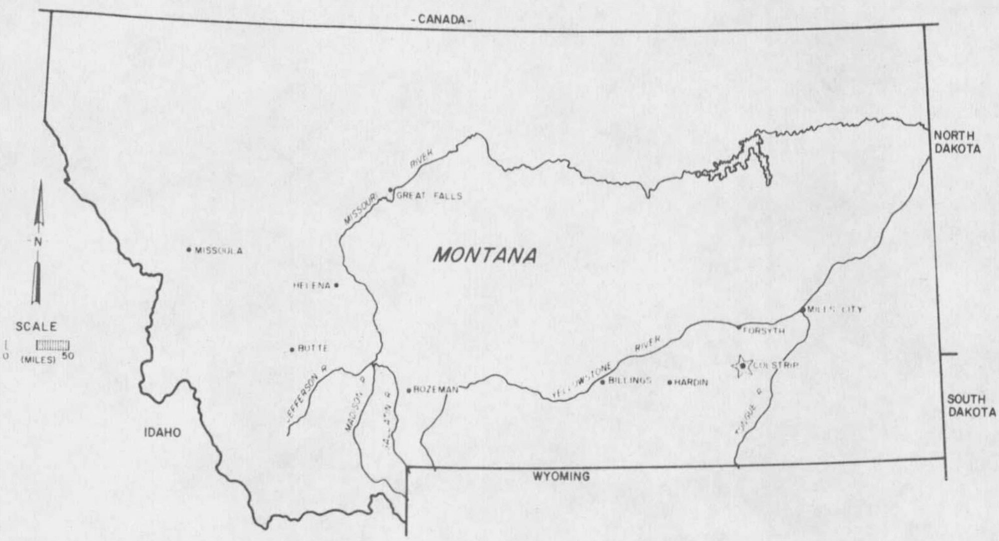


Figure 1. Location of Colstrip, Montana.

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