SELF-REVEGETATION OF A SAGEBRUSH-BUNCHGRASS COMMUNITY AFTER SURFACE BLADING BY BULLDOZER

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of I. DUANE JACQUES find it satisfactory and recommend that it be accepted.

Chairman

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ABSTRACT

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This study was designed to obtain information on secondary succession in a community dominated by Artemisia tridentata Nutt. and Agropyron spicatum (Pursh) Scribn. and Smith, located on silt loam soils in which vegetational disturbance was caused by scraping of surface soil with a bulldozer. The study was conducted on portions of the Arid Lands Ecology Reserve which had been bulldozed to make fire lines during a 1981 range fire. Several micro-climatic parameters were evaluated for the bladed habitat and nearby burned and undisturbed control areas for comparison. These measurements included maximum and minimum temperatures at the soil surface, precipitation, soil moisture, soil texture, soil organic matter, and soil pH. Soil erosion was measured in bladed, burned and control areas for one year. The effects of burning and bulldozing on native vegetation were determined for the vascular plants and the cryptogam crust, a portion of the plant community commonly neglected by ecologists. In a second part of this study, 27 years of succession after bulldozer blading was evaluated.

Microclimate was not found to differ significantly on burned or bladed areas from that of the native undisturbed community. The bladed areas did, however, retain soil moisture longer into the growing season. Erosion by wind following the destruction of the cryptogam crust was greatest on the bladed areas until a rain crust formed on the soil surface. Following formation of the rain crust, no significant differences in erosion were observed. The annual grass, *Bromus tectorum* L., and a few annual forbs initially occupied the bulldozed areas. After the soil surface had stabilized, this early community was invaded by native perennial species - principally *Poa sandbergii* Vasey and *Artemisia tridentata* Nutt. After a period of 27 years, bladed areas had apparently returned to a vegetative structure similar to but not identical in species composition to the native community. Little difference in cryptogam crust development could be measured over the 27 year time interval of this study.

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INTRODUCTION

Approximately 24,000 square miles of the eastern portion of the state of Washington lies within the semi-arid shrubsteppe vegetation zone (Franklin and Dyrness 1973). During the early 1940's about 600 square miles of land in Benton County, Washington was acquired by the government to provide a location for the production of plutonium. In 1967, 120 square miles of land in the Rattlesnake Hills area was established as an ecological research area representing plant communities that once covered a great expanse of the West (O'Farrell 1973). This area is known as the Arid Lands Ecology (ALE) Reserve.

Fire is a natural component of the shrubsteppe ecosystem due to the severe desiccation of the foliage that occurs in late summer. Introduced annual weedy plant species have greatly added to the frequency of fires because of their rapid growth in the spring and the large amount of dried plant material remaining in late summer when fires are most prevalent. As the aliens, *Bromus tectorum* (cheatgrass) and *Sisymbrium altissimum* (tumblemustard) increased in abundance in shrubsteppe communities so did the occurrence of fires (Stewart and Hull 1949). On the ALE Reserve, releasing the land from grazing pressures has resulted in adding standing dead plant material. Fires are reoccurring events on the ALE Reserve. Although it has been demonstrated that burning does little lasting damage to the native flora of the shrubsteppe and in some cases, may have a positive effect (Vogl 1974; Daubenmire 1968a), it has been necessary to practice methods of range fire suppression on the ALE Reserve in order to protect property and human lives.

Fire suppression is primarily accomplished by the use of bulldozers which scrape aside the vegetation along with the upper several centimeters of soil in a swath that is approximately 3 meters in width. Two or more parallel and over-lapping swaths are sometimes used to create firebreaks that may be 10 meters or more in width. Firebreaks may be several kilometers long. These bulldozed firebreaks can be effective in stopping rangeland fires but they also create scars on the landscape that require years to become fully revegetated. The scars also provide areas of disturbed ground that can be invaded by the aggressive alien weed Bromus tectorum.

The purpose of this study was two-fold. First to describe and compare the effects of scraping with that of burning in terms of first year recovery of the vegetation, microclimate, soil erosion, and soil properties. Secondly, self-revegetation was documented on 1, 10, 18 and 27 year-old scraped areas in terms of the vascular plant community and the often overlooked layer of mosses and lichens that form a thin crust on soils of native communities of this region.

The Study Area

The study area is a mostly unburned portion of the ALE Reserve located on the United States Department of Energy's Hanford Site in Benton County, Washington (Figure 1). The ALE site lies in the rain shadow created by the Cascade Mountains 160 km to the west, and therefore receives an average of only 15 to 25 cm of annual precipitation, received mainly between the months of October and May (Thorp and Hinds 1977). The most striking topographical feature of the ALE Reserve is Rattlesnake Mountain, a long, anticlinal mountain with a crest elevation of 1100 meters. The south face of Rattlesnake Mountain lies outside of the Reserve and supports agriculture. The north slopes of Rattlesnake Mountain drop steeply (about 25°) to 650 m elevation, continues down at a 7° slope to about 350 m, and finally slopes

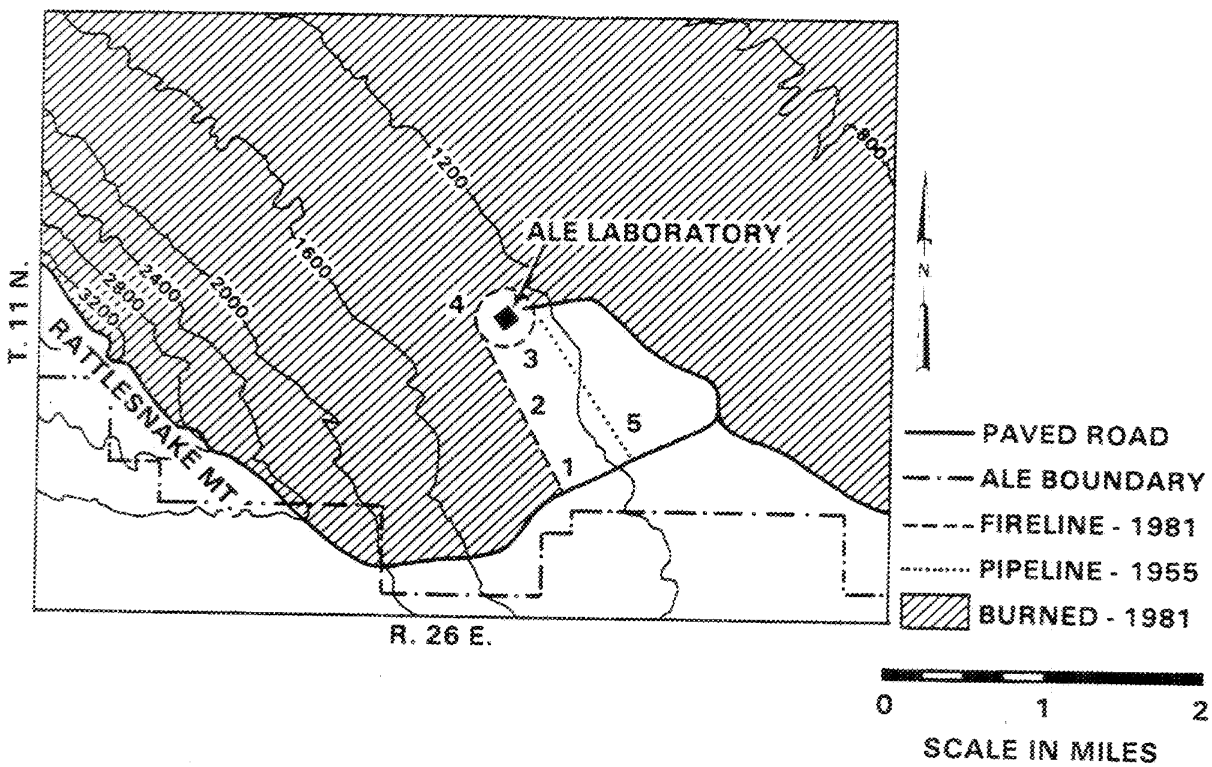

Figure 1. Location of Study Sites on the ALE Reserve

gently to the Cold Creek Valley at 150 m (Thorp and Hinds 1977). This blend of topography creates a diversity of microclimates on the ALE Reserve.

Most of the vegetation of the study area is representative of the Artemisia tridentata - Agropyron spicatum (sagebrush-bunchgrass) habitat-type as described by Daubenmire (1970). Portions of the study area support Artemisia tridentata (big sagebrush) with an understory of Poa sandbergii (Sandberg's bluegrass). Agropyron spicatum (bluebunch wheatgrass) is sparse or absent in these communities. There is also a small stand of the Eurotia lanata-Poa sandbergii (winter fat-Sandberg's bluegrass) habitat-type (Daubenmire 1970) located on the south-facing slopes of the major drainage way that courses through the study area. Some portions of the study area were heavily used by grazing livestock for 50 or more years prior to the establishment of the Hanford Site in 1943 (Hinds 1982). Since then the area essentially has not been grazed. The soil is classified as Ritzville silt loam (Wildung 1977).

Extensive wildfires have burned in and around the study area in the years 1957, 1973, and 1981. The 1981 fire burned portions of older burns as well as previously unburned portions of the sagebrush-bunchgrass community.

In the early 1950's a complex of buildings was constructed to provide housing for military personnel to man anti-aircraft missiles. These facilities were abandoned in the early 1960's and were subsequently re-furbished to provide office and laboratory facilities known as the ALE Laboratory in the 1970's and 1980's (Figure 1).

METHODS

Five places were selected for study. These are located in Figure 1. The study sites represent bladed areas of disturbance with ages ranging between 1 and 27 years. The elevation, exposure, and slope angle for each study site is summarized in Table 1.

TABLE 1. Elevation, Exposure, Slope and Years Post-blading for all Study Sites.

	Study Sites				
	1	2	3	4	5
Elevation (m)	412	403	375	375	400
Exposure	NE	E	E	NE	NE
Slope (°)	4	4	2	2	2
Years Post-blading	1	1	10	18	27

The oldest of the disturbed areas, at site 5, resulted from bulldozing during the placement of an underground water line in 1955 which extended several kilometers from Hodges Well to the ALE Laboratory (Figure 1). Site 3 was bladed in 1972 when an experimental mound was built to study the effect of contrasting slope exposure on the growth of cheatgrass (Hinds 1975). Site numbers 4, 2 and 1 were created as firebreaks by bulldozing during 1963 and 1981 respectively. Site numbers 1 and 2 represent replicates in the sagebrush-bunchgrass community burned by fire and scraped by bulldozing in 1981 (Figure 2). Microclimate, erosion, and soil properties were measured on each of these two study plots containing examples of native (control), burned, and disturbed (by blading) habitat.

In September 1981, 50-meter transect lines were staked out in each of the three study plots at sites 1 and 2. In each study plot, two transects

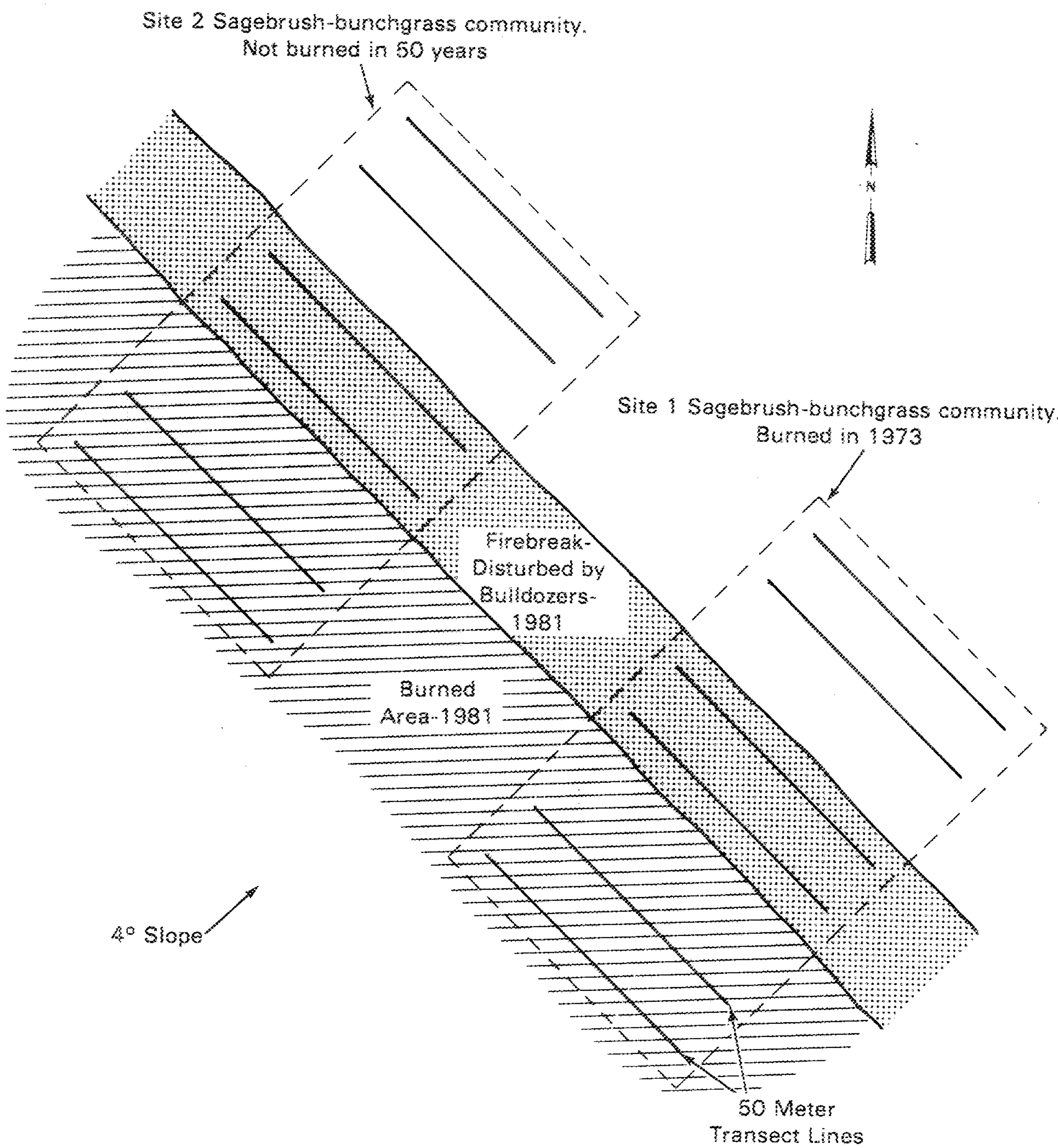

Figure 2. Arrangement of Study Plots Bladed, Burned and Control at Sites 1 and 2 in the ALE Reserve.

were laid out 10 meters apart (Figure 2) parallel to each other and to the disturbance. In May of 1982, transect lines were established at study sites 3, 4, and 5 in a similar manner.

Elevation was taken by plotting the location of each site on a U.S. Geological Survey Topographical map of the Prosser quadrangle. Aspect was determined with a Silva "Ranger" compass. The slope of each site was measured with a Leitz Topographic Abney Level.

Soil Moisture, Precipitation, and Temperature

In late September, 1981, gypsum moisture blocks were placed in a central location on each of the study plots at sites 1 and 2. The moisture blocks had been calibrated using soils from the study area. The following procedures were employed. Percent moisture was determined by weight of water loss under controlled conditions on a known amount of soil and correlated to measured ohms resistance. Next, using a pressure membrane device, moisture was extracted from a sample of Ritzville silt-loam soil, yielding a way to convert percent moisture measurements to soil water potential. Finally, ohms resistance as measured by a moisture meter was correlated to the measured soil water potentials. This procedure has been shown to give reasonably accurate measurement of the soil moisture available to plants and the pressures required to extract water from the soil (Daubenmire 1974).

The gypsum moisture blocks were buried at depths of 10 cm, 20 cm, 30 cm, 50 cm, and 100 cm. A rain gauge was also placed with its rim 18 inches above the soil surface. One "Six's" U-tube maximum and minimum thermometer was placed on the soil surface near the rain gauge and the moisture block locations. Each thermometer was precalibrated using an ice water bath and also at room temperature. The thermometers were shaded from direct insolation by a section of 4 in. white PVC pipe cut in half lengthwise. Recording of the data began on October 1, 1981 and continued at regular intervals (at least twice weekly) through July 1982.

Soil Erodibility and Erosion

In late September 1981, 8-in. long steel spikes fitted with galvanized metal washers were placed in the study plots to measure the amount of soil erosion. Ground level was permanently marked on each spike and the washer was used as an indicator of erosion (Figure 5). Using the calculated variance from a similar study of erosion on the ALE Reserve (Hinds and Sauer 1975), it was determined that 50 samples would be necessary to insure accuracy at the alpha = 0.05 level of significance. Sixty spikes were placed in each study plot with thirty spikes being randomly placed within 1-meter increments along each transect line. Soil loss was measured to the nearest millimeter on each of the spikes in July 1982.

Soil Analysis

In November 1981, samples of surface soil were taken from five different locations on each of the study plots. Samples were obtained at regular intervals in the zone between the two permanent transect lines at each of the study plots (Fiture 2). One-hundred gram samples were taken at the following depths: 0-1 cm, 2-3 cm, and 4-5 cm. All samples were analyzed for particle size distribution by dry sieving to evaluate the distribution of the sand and silt contingent down to a size of 0.075 mm. The percent of particles smaller than 0.075 mm was determined by a hydrometer analysis (Chapman 1976). The pH of all samples was measured to an accuracy of 0.1 by the use of a 2 to 1 wet paste. All samples were analyzed for organic matter content by acid digestion (Chapman 1976).

Cryptogam Crust Analysis

In March 1982, the amount of cryptogam crust on the study plots at sites 1 and 2 was measured. Ten round, disk-like samples of the soil surface measuring 9 cm in diameter x 1 cm deep were randomly taken along each of the 50 meter transect lines. A 1 cm layer of soil just beneath each disk sample was also collected in order to obtain a measure of the organic matter content of the underlying soil. Crust samples were taken along the left hand side of the transect line nearest to the specified meter mark from areas at spaces between plants. Sampling was easiest when done shortly after a rain when the soil was wet. All samples were air dried at 105°C for 48 hours and allowed to cool to room temperature in a desiccator. The samples were then put into crucibles and weighed. Each sample was heated to 700°C in a muffle furnace and remained for 1 hour in order to burn off all organic matter (Cox 1967). Samples were cooled to room temperature and weighed to determine the weight loss on ignition. By comparing the organic matter in the surface crust sample to that of the sample taken just below the sampled disk, a measure of the organic matter contribution of the cryptogam crust was obtained (Fletcher and Martin 1948). This procedure was repeated on sites 3, 4, and 5 in May 1982.

Vegetational Analysis

Canopy cover was measured by estimating the percent of total area covered for each species located within a 5 dm x 2 dm metal frame placed at systematic intervals along each transect (Daubenmire 1959). All species within each frame were assigned a number corresponding to the following cover classes - 1: 0-5%; 2: 5-25%; 3: 25-50%; 4: 50-75%; 5: 75-95%; 6: 95-100%. A preliminary study done in July 1981 using 50 meter transects placed at varying distances from an ecotone between a native stand of vegetation and an annual community on an old field showed that a minimum of 35 to 50 plot frames were necessary to distinguish between the two communities. Using this information, it was decided to double the number of plot frames. Fifty frames were taken at 1-meter intervals along each transect giving a total of 100 frames for each study plot. Canopy cover was estimated for all transects in sites 1, 2, 3, 4, and 5 in May 1982 and again in July 1982 to accomodate the few species that matured later in the growing season.

RESULTS

Microclimate and Soil Water

Temperature, precipitation, and soil water measurements were made on the three study plots at sites 1 and 2. During fall and winter, the bladed and burned plots showed slightly higher maximum temperatures than the control area (Figure 3). During the spring and summer months, higher maximum temperatures were recorded on the burned and control plots than on the bladed plots. Minimum temperatures on the burned and control plots were lower than on the disturbed plots during this time. Minimum temperatures on the control plots were consistently lower than on the other plots throughout the study (Figure 3). A summary of average monthly maximum and minimum temperatures (°C) is shown in the Appendix.

Precipitation varied between plots and was greater in the control plots (Table 2). The bladed plots received slightly more precipitation than the burned plots.

Average monthly soil moisture readings for all study plots are summarized in Appendix Table 2. When the average percent soil water was greater than the wilting coefficient, the soil was considered to hold sufficient moisture to sustain plant growth. There was no measureable difference in the maximal depth of moisture penetration in any of the soil profiles (Figure 4). This particular year appears to be somewhat atypical in the amount and the timing of the precipitation. During a more typical year once the soil began to dry in the spring, no significant additional precipitation would occur until the following September or October. However, a heavy rainfall in late June completely wetted the soil profile. After this rainfall event the soil slowly dried during the remainder of the study period. During the month of February the upper 2-3 cm of soil was frozen.

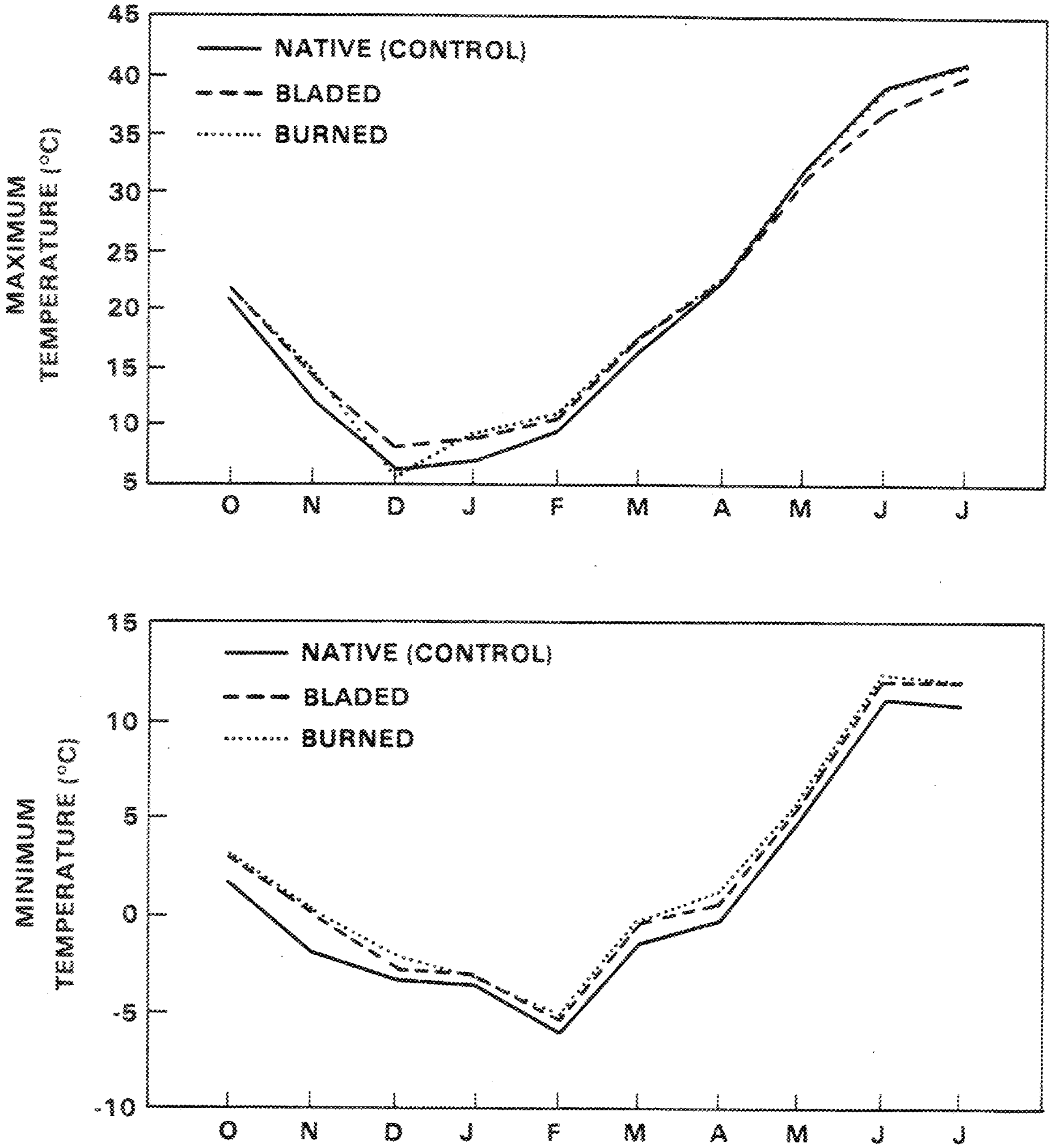

Figure 3. Monthly Average Maximum and Minimum Temperatures for Each Treatment Area (°C).

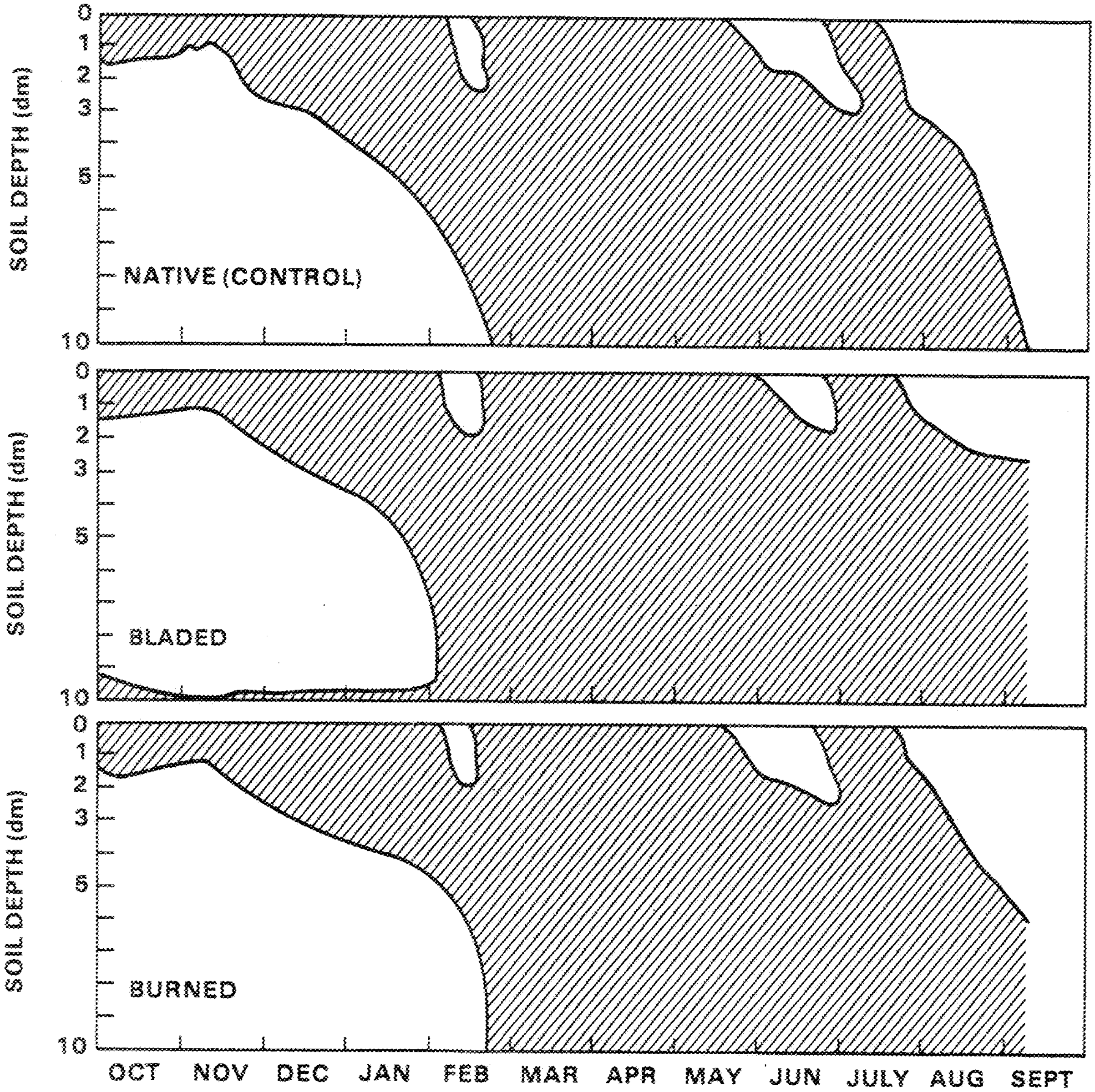

Figure 4. Depth of Soil Moisture Available for Each of the Treatment Areas. Hatched Areas Contain Moisture Above the Permanent Wilting Percentage.

TABLE 2. Monthly Precipitation (mm) for Each Treatment Area.

Months	Control		Bladed		Burned	
	1	2	1	2	1	2
Sep[1]	10.4	10.4	10.4	10.4	10.4	10.4
Oct	17.3	18.0	16.0	16.0	15.2	15.8
Nov	20.8	22.6	20.8	19.6	20.6	19.8
Dec	28.7	31.5	26.7	24.9	25.9	22.9
Jan	24.1	33.8	25.4	23.4	23.6	24.1
Feb	23.3	25.2	23.4	22.1	23.1	21.6
Mar	13.4	15.0	15.2	13.5	14.5	13.5
Apr	24.2	35.8	34.5	32.0	34.0	30.2
May	2.6	4.1	3.6	3.3	3.6	2.5
Jun	21.0	31.8	31.8	29.0	31.5	27.2
Jul	0.8	1.3	0.8	0.8	0.8	0.8
Bioyear[2]	167.7	187.0	165.5	154.8	160.5	150.4
Total	209.9	230.5	208.6	195.0	203.2	188.8

[1]The values in September are from a standard rain gauge at the ALE Laboratory.
[2]The bioyear is October to May

This was interpreted as being "dry" as there was no water available to the plants. By late summer the soil profile of the control plots had dried to permanent wilting to a depth of 1 meter. Some moisture was still available in the burned plots at a depth of about 5 dm. The bladed plot soil continued to retain soil moisture deeper than 3 dm for the remainder of the summer season.

Soil Particle Size Distribution

The clay content of each of the study plot soils increased with depth as did the pH (Table 3). The silt content, however, generally decreased with increased depth. The amount of sand remained fairly constant for each study site regardless of sample depth. The organic content of all soils also decreased with depth.

The organic matter content of the 0-1 cm layer on the burned plot was significantly higher than that of other plots (Table 3). The organic

TABLE 3. Average Soil pH, Organic Matter Content and Percentages of Sand, Silt and Clay in Control, Bladed and Burned Portions of a Stand of the *Artemisia-Agropyron* Association Sites 1 & 2.

Soil Properties	Soil Depth 0-1 (cm)	Soil Depth 2-3 (cm)	Soil Depth 4-5 (cm)
Control pH	6.2	6.4	6.6*
Bladed pH	6.5*	6.7	6.9
Burned pH	6.2	6.5	6.9
Control OM%	1.81	1.03	0.87
Bladed OM%	1.83	1.65	1.29*
Burned OM%	2.61*	1.39	0.98
Control % Sand	37.0	36.7	37.0
Bladed % Sand	38.7	39.0	37.1
Burned % Sand	36.5	36.5	36.9
Control % Silt	56.4	55.7	54.7
Bladed % Silt	55.2	53.9	55.8
Burned % Silt	57.1	56.2	54.5
Control % Clay	6.6	7.6	8.3
Bladed % Clay	6.1	7.1	7.1*
Burned % Clay	5.8	7.3	8.6

*Significant at the $\alpha = 0.05$ level.

matter content of the bladed study plots was greater at 4-5 cm as compared to the control and burned study plots (Table 3).

The particle size distribution for the soil of the bladed plots deviated slightly from that of the control plots (Table 4). The bladed plots showed a larger percentage of particles in the .075 - .106 mm size class and a smaller percentage of particles in the .002 - .075 mm size class at the surface (0-1 cm). This difference can also be noted by the slightly higher percentage of particles lumped into the sand portion of the texture analysis and the slightly lower percentage of silt particles. The differences here, however, were not statistically significant. The amount of particles in the .075 - .106 mm size range was consistently lower in the control plot soils than in the bladed and burned plot soils. In contrast, the percentage of particles in the .002 - .075 mm size class was consistently higher for the control plots than in the bladed and burned plots.

Erosion

Soil loss occurred in all study plots and was quite variable (Table 5). Loss was greatest in the bladed plots of both sites 1 and 2. The control plots showed less soil loss than the bladed plots but more than the burned plots. This trend held for both sites 1 and 2. The erosion on any one plot was not significantly different from any other. The total erosion occurring on site 1 was greater than that of Site 2.

TABLE 4. Soil Particle Size Distribution for Each Treatment Area of Sites 1 and 2.

		Sieve Size (mm)						
Plot	Depth (cm)	.850	.425	.250	.106	.075	.002	<.002
Control	0-1	0.0	0.2	0.8	13.1	11.9	67.4	6.6
Bladed	0-1	0.0	0.3	0.8	14.1	20.4*	58.3*	6.1
Burned	0-1	0.0	0.1	0.7	14.1	14.6	64.7	5.8
Control	2-3	0.0	0.2	0.6	14.9	16.8*	59.9*	7.6
Bladed	2-3	0.0	0.4	0.9	14.5	23.2	54.0	7.1
Burned	2-3	0.0	0.1	0.6	15.5	22.2	54.3	7.3
Control	4-5	0.0	0.2	0.7	17.7	21.5*	51.6	8.3
Bladed	4-5	0.0	0.3	0.6	15.6	23.7	52.7	7.1*
Burned	4-5	0.0	0.0	0.6	16.4	24.9	49.5	8.6

*Significant at the $\alpha = 0.05$ level.

Cryptogam Crust

The percent organic matter obtained for the lower sample layer was subtracted from the percent organic matter obtained for the surface layer. Thus the bottom figure for each study plot gives the average amount of organic matter content that is contributed by the cryptogam crust ± the standard error. The percent of cryptogam crust for the bladed plots was much less than the percent crust of the study plots (Table 5). The percent of crust for the control plot at site 2 was significantly higher than that of the other plots. The standard error for this sample was also high. The amount of lichen and mosses in samples beneath the canopy of any particular *Artemisia* shrub was much greater than that in the open areas between the shrubs.

Table 6 shows a similar evaluation of the cryptogam crust at study sites 3, 4, and 5. Although a measurable increase in the cryptogam crust was found over a span of 27 years, it was still only a fraction of that of the control plots.

Vegetational Analysis

The results of the vegetational analysis of the study plots at sites 1 and 2 are given in Table 5. The canopy cover of the perennial species was greatly reduced by blading. Annual grasses and forbs provided a correspondingly greater portion of the canopy cover in bladed plots one year after blading than they did the other study plots. The burned plots showed little difference in the canopy cover of perennial species with the exception of *Artemisia tridentata*, which had been eliminated by the fire. Percent cover decreased for perennial grasses while annual grasses and forbs increased (Table 5).

As the time since last disturbance increased, the composition of the community changed (Table 6). The general trend was for fewer annual species and more perennial species. Total cover also tended to increase as the age of the community increased. The diversity of the community on site 5 shows a large decrease. This is primarily the result of a decline of both annual and perennial forbs.

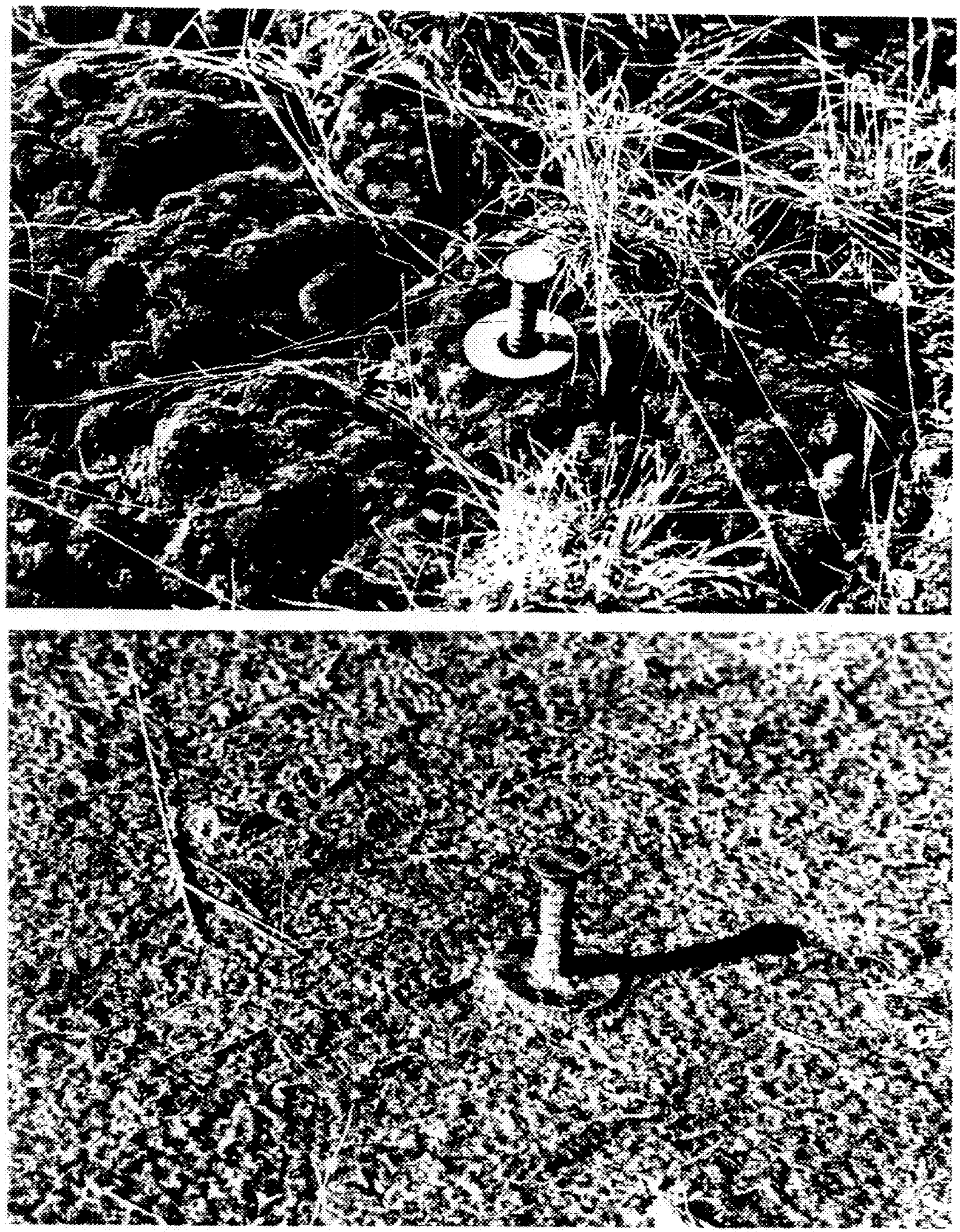

Figure 5. Photographs Showing Steel Spikes Used to Measure Soil Erosion. The Upper Photograph Shows the Cryptogam Crust from the Control Plot of Site 1. The Lower Photograph shows the Rain Crust from the Disturbed Plot of Site 1.

TABLE 5. Vegetational Analyses in Adjacent Control, Bladed and Burned Portions of a Sagebrush-Bunchgrass Community. Percent Cover is to the Left of the Slash, Frequency to the Right. Organic Matter Content of Cryptogam Crust and Loss of Soil from Erosion Shown for Each Treatment.

	Control		Bladed		Burned	
	1	2	1	2	1	2
Perennial Grasses						
Poa sandbergii	24/100	33/95	7/56	8/94	22/100	19/95
Agropyron spicatum	38/98	+/2	4/22	0	30/92	+/1
Sitanion hystrix	0	3/24	0	+/8	0	+/4
% Cover	62	36	11	8	52	19
Annual Grasses						
Bromus tectorum	0	5/70	3/20	43/99	0	4/39
Festuca microstachys	+/5	2/56	2/24	22/100	1/31	2/26
Festuca octoflora	0	0	0	0	1/23	+/83
% Cover	+	7	6	65	1	6
Perennial Forbs						
Crepis atrabarba	6/61	4/26	6/43	3/17	6/70	3/22
Lomatium macrocarpus	+/5	1/16	0	+/4	+/1	+/3
Lupinus sulphureus	6/27	22/74	2/28	6/27	1/9	6/25
Lupinus leucophyllus	0	0	+/3	0	0	1/2
Helianthella uniflora	+/2	+/5	0	+/2	+/3	0
Calochortus macrocarpus	+/2	+/5	+/9	0	+/7	+/2
Achillea millefolium	+/1	+/1	0	0	+/1	0
Antennaria dimorpha	+/3	0	0	0	+/1	0
% of Cover	12	26	8	9	7	10
Annual Forbs						
Tragopogon dubius	0	0	1/5	1/18	+/2	+/2
Descurainia pinnata	0	0	+/6	1/18	+/1	1/8
Gilia minutiflora	+/7	0	6/17	+/3	+/8	2/6
Draba verna	0	+/2	0	+/3	+/1	+/9
Sisymbrium altissimum	0	0	+/4	3/30	0	3/15
Chenopodium leptophyllum	0	0	2/29	+/4	0	0
Salsola kali	0	0	2/9	0	0	0
Lactuca serriola	0	0	+/2	+/2	0	0
Solanum triflorum	0	0	+/2	0	0	0
% of Cover	+	+	11	5	+	6
Perennial Shrub						
Artemisia tridentata	0	29/51	0	1/18	0	0
% of Cover	0	29	0	1	0	0
Total Cover	74	98	36	88	60	41
Number of Species	11	14	17	18	15	15
Organic Matter %						
Surface Soil	4.31	7.82	3.26	4.03	4.58	5.41
Subsurface Soil	2.94	4.34	2.84	3.56	3.22	3.86
Cryptogam crust	1.37±0.42	3.48±1.03	0.42±0.17	0.47±0.40	1.36±0.37	1.55±0.46
Soil Loss to Erosion (cm)	0.333±0.055	0.308±0.096	0.439±0.096	0.334±0.079	0.277±0.062	0.187±0.047

TABLE 6. Vegetational Analyses of 4 Sites of Different Chronological Age Post-Bulldozer Blading and the Organic Matter Content of Soil and Cryptogamic Crust. Percent Cover is to the Left of the Slash, Frequency to the Right.

	Site Location			
	2	3	4	5
	Years Post-blading			
	1	10	18	27
Perennial Grasses				
Poa sandbergii	8/94	10/95	19/100	15/100
Agropyron spicatum	0	9/41	2/13	1/2
Sitanion hystrix	+/8	+/4	+/1	1/13
Stipa thurberiana	0	+/3	+/1	0
Oryzopsis hymenoides	0	0	2/10	0
% Cover	8	19	23	17
Annual Grasses				
Bromus tectorum	43/99	14/98	7/76	2/44
Festuca microstachys	22/100	3/100	2/62	2/74
Festuca octoflora	+/8	0	0	0
% Cover	63	17	9	4
Perennial Forbs				
Crepis atrabarba	3/17	24/93	4/48	4/40
Lomatium macrocarpum	+/4	1/11	0	+/2
Erigeron filifolius	0	7/66	6/53	1/22
Lupinus sulphureus	6/27	0	1/1	16/55
Lupinus leucophyllus	0	0	1/13	0
Helianthella uniflora	+/2	0	0	+/4
Castilleja lutescens	0	0	+/1	0
Calochortus macrocarpus	0	+/3	+/4	0
Achillea millefolium	0	2/21	+/3	0
Antennaria dimorpha	0	0	+/1	0
% Cover	9	34	12	21
Annual Forbs				
Tragapogon dubius	1/18	+/6	+/5	0
Descurainia pinnata	1/18	0	0	0
Gilia minutiflora	+/3	+/5	+/1	0
Draba verna	+/3	+/2	0	0
Sisymbrium altissimum	3/30	0	0	0
Chenopodium leptophyllum	+/4	+/1	0	0
Lactuca serriola	+/2	+/2	0	0
Plantago patagonica	0	+/1	+/3	0
Holosteum umbellatum	0	+/1	0	0
% Cover	5	+	+	0
Perennial Shrub				
Artemisia tridentata	1/18	0	8/31	30/71
% Cover	1	0	8	30
Total Cover %	88	70	52	72
Number of Species	18	18	19	11
Organic Matter %				
Surface Soil	4.03	3.34	3.37	3.69
Subsurface Soil	3.56	2.77	2.78	3.07
Cryptogam crust	0.47±0.40	0.57±0.23	0.59±0.29	0.62±0.26

DISCUSSION

Microclimate in Relation to Community Disturbance

Temperature has been shown to be a primary factor controlling the growth, germination and maturation of *Bromus tectorum* (Uresk, Cline, and Rickard 1979). *B. tectorum* was able to germinate and begin growth at temperatures of 2-3 °C lower than seedlings of the perennial grass *Agropyron spicatum* (Harris 1967).

Diurnal temperature fluctuations are more extreme at the surface of a soil than either above the surface or below it (Collier, Cox, Johnson and Miller 1973). Any large differences in temperature at the soil surface would be accompanied by smaller differences at levels both above and below the surface from reradiation of the absorbed heat energy. Therefore it was believed that temperatures taken at the soil surface would be more sensitive in detecting differences than measurements taken at any other level. Also since seedling establishment occurs at or near the soil surface, surface measurements are the most relevant.

Removal of vegetation from a native stand of the sagebrush-bunchgrass community, whether by burning or by bulldozing, affected temperatures at the soil surface (Figure 3). Temperatures averaged about 1 °C higher on bladed ground than on vegetated ground during the fall, winter and early spring. Bladed soils absorbed greater amounts of insolation than vegetated soils. Much of the heat transfer on a vegetated area occurs at the top of the plant canopy and is reradiated downward toward the soil surface (Daubenmire 1974) whereas heat transfer occurs directly at the surface of a bladed area. Surface temperatures were consistently higher on the burned soils than on the bladed soils, probably a result of the darkening of the soil surface from ash accumulations (Daubenmire 1968a). Darkening had mostly disappeared by the following spring. With regrowth of the vegetation during the spring and early summer, the differences in maximum temperature between the unburned (native) and the burned plots diminished.

During the summer the burned and native plots showed higher maximum temperatures than the bladed plots. This was probably a result of the lack of mixing and circulation of air caused by the larger boundary layer of the vegetated areas. At night cool air would tend to move down slope from the bladed areas and become trapped in the denser vegetation of the control areas resulting in the lowering of temperatures.

The net effect of these trends was that temperatures may have slightly favored the growth and germination of <u>Bromus tectorum</u> and other annuals on the bladed areas. In the fall, winter and spring higher temperatures may increase the germination rate and allow competitive advantage of early seedling growth. In the summer, lower temperatures on the bladed plots may tend to lengthen the growth period as long as moisture remains available. The differences I found were below the range shown to be effective by Harris (1967) and therefore are probably not great enough to explain the large differences in community structure between the native and bladed plots.

Temperature is also an important factor in effective precipitation owing to the increased rates of evaporation and transpiration at higher temperatures (Daubenmire 1974). Higher temperatures might cause less moisture to be available on the bladed plots during the critical growth periods of fall and early spring. Again, differences as small as the ones that I recorded probably would not cause significant differences in effective precipitation between the study plots.

My data showed that more precipitation fell in the native plots than in the bladed and burned plots. Two factors could be important in understanding this phenomenon. The native plots accumulated more snow during the winter than the other plots. Being closer to the native plots, the bladed plots in turn accumulated slightly more snow than did the burned plots. The slowing of winds by the vegetative canopy might explain the larger accumulations of snow. Rainfall was also greater in the native plots than on the other two plots. The rain gauges in the native plots were placed in the open areas between shrubs to avoid interception of precipitation by the vegetation canopy. It is possible that rainfall as measured was greater in the control plots than on the bladed plot due to the reduced wind speed. The rain gauges used were only about 1-3/4 in. wide at the mouth and interception of rain could have been significantly affected by the angle at which precipitation struck the rain gauge opening. The amount of precipitation in the bladed areas tended to reflect the effects of both the open and the vegetated cover areas.

Precipitation is probably the most important environmental factor affecting growth and seedling establishment of perennial plants in the shrubsteppe (Cable 1975). Precipitation is also the principal agent of soil erosion. Differences of 15-20 mm of rainfall as observed in this study are a substantial portion of the total precipitation and could be expected to have an effect on the growth and phenology of plant communities.

There was little difference in the intake of moisture into the soil profiles of the three study plots (Figure 4). Water usage on the native and burned plots appeared to be slightly greater than on the bladed plots due to the greater amounts of vegetation, especially the deep rooted perennials. This was seen by the fact that it took somewhat longer for the native and burned areas to reach a point where the moisture content of the entire soil profile was above the permanent wilting point. Earlier and more rapid depletion of water from the soil profiles of the native and burned study plots in the spring indicated more effective soil water usage than in the bladed study plots. The burned study plots received less precipitation than the native plots and should show signs of a more rapid depletion of moisture. The smaller amount of vegetative cover between the native plots and the burned plots may account of this lack of difference.

Rainfall in June replenished soil water. This was an unusual occurrence and it retarded the depletion pattern of moisture loss from the soil profiles. Moisture was extracted from the profile of the bladed plots only to a depth of about 3 dm. This was apparently due to the shallow root systems of the predominantly annual plants and the fact that they were near senescence by the time of the June rainfall. Perennial species would have had sufficient supplies of moisture to continue to grow into summer. This was especially evident with the two species of Lupinus that were found in the bladed areas. Growth of these two species continued later into the summer than did similar species on the control areas. In contrast, the perennial plants had extracted most of the available moisture on the native and burned plots by September.

The presence of a continuous layer of mosses and lichens has been shown to increase the rate of water infiltration into the soil profile (Shields and Durrell 1964). This factor may also account for the lack of differences exhibited between the soils. Although the bladed soils had less water usage, especially in the fall, less moisture actually entered the soil due to the decreased infiltration rate. The infiltration rate may have been greater in the native and burned plots than in the bladed areas as a result of the cryptogam crust.

Erodibility and Erosion of Disturbed Habitat

Wind erosion involves the movement and removal of soil particles. Soil particles that fall into the range of 0.075 - 0.400 mm in size are affected by the forces of moving air with the fraction of particles ranging in size from 0.10 - 0.15 mm being the most important (Chepil 1945b). Soil particles are either moved slowly across the surface (creep) or are moved by successive hops (saltation). Particles in the size range of 0.10 - 0.15 mm are the first ones to begin movement, requiring winds at the surface to be in the neighborhood of 12 - 15 mph, depending on the soil surface and the vegetative cover. Removal of vegetation and a smooth surface tends to increase wind speed and therefore increases particulate movement (Dregne 1976). The movement of these soil particles initiates movement of the other sized particles on the soil surface (Chepil 1945a). Table 7 shows the erodible fraction of the upper centimeter of the soil profile for each of the treatment areas. Fractions of soil particles in the 0.075 - 0.400 mm range have been combined to show differences in the erodibility of each of the three soils in question. The soil of the upper centimeter of the bladed plots has a significantly larger fraction of particles falling in this size range than the other plots and would therefore be more susceptible to erosion under the same climatic conditions. This proved to be the case. Strong winds in mid-September raised dust.

Heavy rains beginning in late September and continuing throughout the winter months compacted the soil particles on the bladed plots and a hard surface crust developed as discussed by Goodall and Perry, (International Biome Program 1979). After the development of the rain crust in late September and October, very little wind erosion was observed on the bladed plots.

TABLE 7. Erodible Fraction of the Upper cm of Soil for Each Treatment Area by the Two Principal Agents of Erosion: Wind and Water.

	Moved by:					
Study Plots	>0.425	Wind	<0.750	>0.106	Water	<0.002
Native (control)	0.2	25.8	74.0	14.1	79.3	6.6
Disturbed	0.3	35.3*	64.4	15.2	78.7	6.1
Burned	0.1	29.4	70.5	14.9	79.3	5.8

*Significant at $\alpha = 0.05$ level

Stabilization of soil by the cryptogam crust also inhibits particle movement by wind (Dregne 1976). This was especially observable in the burned plot at site 2. The cryptogam crust was not continuous in this area. Where a sagebrush had once stood before the fire, there was little if any cryptogam crust. These areas were rapidly eroded by wind. Adjacent areas that had once supported a cryptogam cover did not show as much wind erosion.

Erosion caused by the movement of water over the soil surface involves the removal of particles of different sizes than that caused by wind. The size fraction of the soil particles in the range of 0.002 - 0.100 mm are the most susceptible to movement by water (Wischmeier and Smith 1978). Table 7 also shows the fraction of the upper centimeter of the soil profile erodible by water for each of the study plots. In this table, the fractions of soil particles in the range of 0.002 - 0.106 mm have been combined. The erodible fraction was quite large on all treatments. No significant difference in erodibility by water was apparent between any of the soils in the study plots.

Several factors other than erodible fraction may influence erosion by water in the shrubsteppe community. The cryptogam crust reduces erosion by increasing the rate of infiltration (Shields and Durrell 1964). On the other hand, the development of a rain crust, as was observed on the bladed plots, decreases the rate of infiltration and thereby increases erosion (International Biome Program, 1979). Rapid melting of snow cover while the soil remains frozen is the principal erosive event in this habitat. As has been mentioned, the control plots showed greater accumulations of snow than bladed and burned plots. Moreover a large rain event, such as the one occurring in late June, can cause significant erosion (McCool, Malnau, Papendick and Brooks 1973).

Water was the principal agent of erosion on all study plots. As the figures in Table 5 indicate, erosion was not significantly different in any of the plots. This coincides well with the data showing the particle size fractions erodible to water. Some erosion by wind occurred early in the study on the bladed plots but it did not continue. This might explain the somewhat larger amount of erosion on the two bladed plots as compared to the other plots. Also the decrease in infiltration rate caused by the removal of the cryptogam crust and the subsequent rain crust tended to increase soil losses to erosion on the bladed areas.

Erosion was greater in the control plots than in the burned plots. The accumulations of snow were significantly greater in these plots than in the burned plots. The control plots of site 2 showed slightly less erosion than the native plots of site 1, even though it received more precipitation. The greater amounts of vegetative cover and cryptogam crust may account for this difference. The two burned plots received the least amounts of precipitation and showed correspondingly less soil erosion.

Erosion probably does not account for any differences in vegetation. The increased erosion immediately following disturbance by blading may have a positive effect on establishment of annual seedlings but only for the short time necessary for the development of a stabilizing rain crust. After the rain crust is formed, erosive events generally will be small and local in extent.

Reconstitution of the Cryptogam Crust

Figure 6 shows 27 years of recovery of the cryptogam crust after blading disturbance and suggests that reconstitution of the crusts proceeds at a very slow rate. The relatively large amount of organic matter occurring after only one year post-blading may be partly the result of an initial bloom of soil algae. Algae growth has been shown to be substantial during the first few years after a soil disturbance and is considered the initial colonizer of disturbed soils (Shields and Durrell 1964). This large figure may also represent some buried organic debris caused by the blading. Although the cryptogam crust was somewhat more apparent to the eye on the surface of the older disturbed areas, it is interesting that there was little or no significant difference in the percent of organic matter content of the surface of these soils as compared to the newly bladed soils.

It was not clear from the data what time period might be necessary for the cryptogam crust to reach the same condition as that found in the native habitat. Lichen and moss growth occurs mainly during the early spring months when temperatures remain cool and the soil surface is wet. Growth was also noticed later in the spring after heavy rainfall. This, however, was generally restricted to zones that were shaded by large shrubs or clumps of perennial grasses. As previously discussed, erosion on these soils was not significantly increased after removal of either the vegetative cover or the cryptogam crust. This factor, along with the slow recovery rate of the cryptogam species indicated that the cryptogam crust developed as a result of stable soil conditions and was not a major factor in aiding soil stabilization.

The soils of the control area of site 2 contained a well-developed but quite variable cryptogam crust (Table 5). This crust was most developed in the areas between closely spaced Artemisia tridentata shrubs. Although not shown in these data, the diversity of moss species on the ground between shrubs was relatively large. The cryptogam crust was poorly developed directly beneath sagebrush shrubs where a deposit of leaf litter had accumulated. In these areas annuals such as Bromus tectorum and Festuca octoflora (six-weeks fescue) were most abundant. Where the cryptogam crust was present, few annuals were represented. The cryptogam crust is thought to act as an effective barrier to invasion by annual species (Shields and Durrell 1964).

In contrast to the sagebrush community, the control and burned areas of site 1 contained a relatively thin but continuous cryptogam crust. The near absence of annual species in these areas suggests the effectiveness of this layer as a barrier to their invasion.

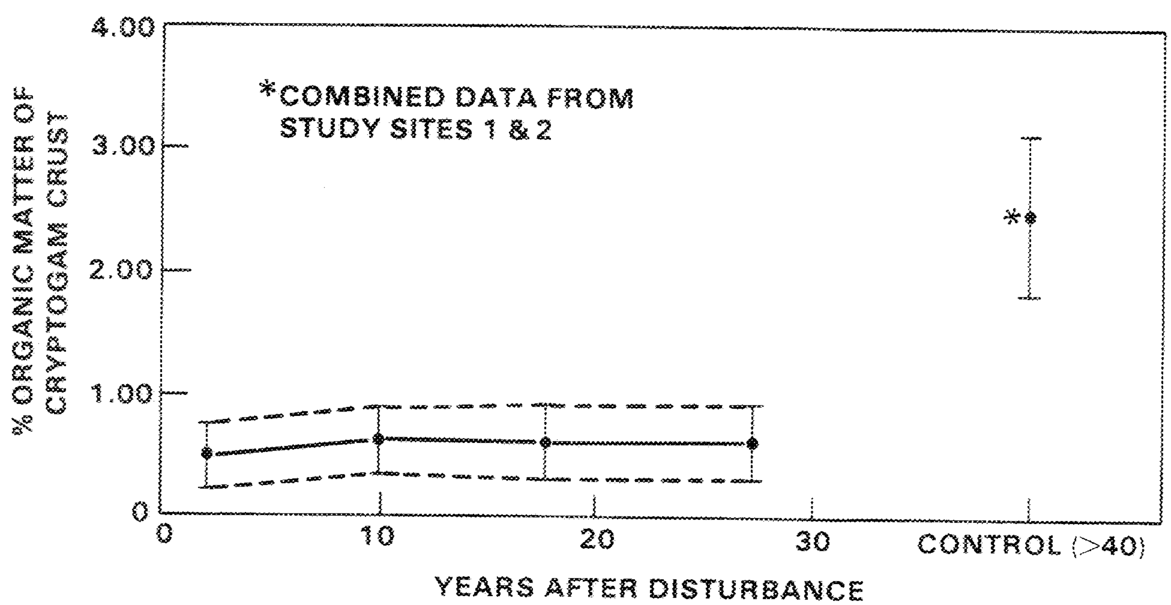

Figure 6. Reconstitution of Crytogam Crust on Disturbed Areas.

Fire appears to affect the cryptogam crust by eliminating the most conspicuous species but not the integrity of the crust. Temperatures of a grass fire seldom reach levels that are critical to vegetation directly at the soil surface (Daubenmire 1968a). This might account for the apparent resistance of the smaller moss species to burning. In burned areas that had a high density of sagebrush shrubs, the amount and continuity (Table 5) of the cryptogam crust was significantly reduced. Areas that had once been covered by a single sagebrush plant were often completely bare, the plant and litter having been consumed by the fire. Annual plants readily invaded these areas, but they were relatively unsuccessful in the areas where the cryptogam crust remained intact.

My data suggest that the cryptogam crust is effective as a barrier to annual plant invasion. The study of the reconstitution of the cryptogam crust on bladed areas gives evidence to the slow growth rate of this layer in shrubsteppe communities. A true successional study of the cryptogam crust would need to include taxonomic descriptions of the moss and lichen species but this was beyond the scope of this study. Careful investigation of the cryptogam crust is necessary, particularly in regard to species diversity of various native communities and the effects of fire and disturbance on species composition.

Self-Revegetation of the Vascular Plant Community on Disturbed Habitat

The vegetative changes occurring on disturbed ground in the shrub-steppe seem to be fairly well understood and documented. A study by Daubenmire (1975) showed that abandoned agricultural land had been self-colonized and occupied for 50 years by *Bromus tectorum*. Succession usually begins with populations of *Salsola kali* (tumbleweed) and *Sisymbrium altissimum* and then proceeds quickly to a community dominated by *B. tectorum* that is slowly invaded by the shrubs *Chrysothamnus* spp. (rabbit brush) and *Artemisia tridentata* (Stewart and Hull 1949).

A possible competitive advantage of *B. tectorum* lies in this plant's ability to produce large quantities of viable seed from year to year (Daubenmire 1968b), coupled with the ability to remain viable in the soil for more than one year (Evans and Young 1972). *B. tectorum* seeds have a high rate of germination (Stewart and Hull 1949). Due to their comparatively early germination and rapid growth, *B. tectorum* seedlings have the ability to out-compete seedlings of the predominant native perennial grass, *Agropyron spicatum*, for soil water (Harris 1967). Perennial grasses may require at least occasional years of above average precipitation in order to compete with *B. tectorum* for seedling establishment (Cline, Uresk and Rickard, 1977).

For *B. tectorum* seeds to germinate they must be deposited in a safe site that protects them from rodents and more importantly, supplies sufficient moisture. Several conditions may provide *B. tectorum* seeds with these necessary safe sites. The accumulation of a layer of litter on the soil surface has been shown to be highly advantageous to the germination success of *B. tectorum* and other similar annuals (Evans and Young 1972). Once established, *B. tectorum* continues to supply a large amount of litter that insures seedling success. Soil movement has also been shown to be beneficial to the establishment of alien annuals (Evans and Young 1972). Areas of sandy, erodible soils are very susceptible to colonizing by *B. tectorum* and other annuals. In a study of secondary succession on a highly erodible soil, Hinds and Sauer (1974) found a direct correlation between aeolian erosion during the first year after a wild fire and species able to grow there. Growth of B. tectorum and Sisymbrium altissimum was enhanced by erosion until the erosion loss was so severe that seeds were displaced.

Suitable safe sites can also be found on non-erosive soils. Repeated wetting and drying along with freezing and thawing of the soil surface can cause cracking of the upper few centimeters of the soil surface, providing safe sites for wind blown seeds. Consequently, even undisturbed native communities of the shrubsteppe may have a small contingent of stunted annual plants.

In contrast to highly erodible soils, the study by Evans and Young (1972) also showed that seeds of B. tectorum and S. altissimum exhibited poor germination success on smooth, hard soil surfaces. In shrubsteppe communities, two factors have been discussed that could contribute to this type of soil condition. The cryptogam crust may act as a barrier to alien seedling establishment. The rain crust that develops on silty soils after disturbance and heavy rains may also act as a barrier to the establishment of seedlings.

Figure 7 shows 27 years of secondary succession of the vascular plant community on four study areas that received blading by bulldozing. The percent of vegetative cover for the sagebrush-bunchgrass control community of site 2 is shown on the right of the graph. Most of the native perennials were severely damaged or destroyed during bulldozer scraping. In contrast, the annual species were greatly benefitted by one blading. This trend correlates well with other studies indicating that the increase in seedling safe sites by either removal of the cryptogam crust or erosion of the surface results in an increase in the density of annual species (Evans and Young 1972). These data also indicated that within a span of 27 years this trend has been altered to a condition that begins to approximate the native condition in comparison of the ratio of annual species to perennial species. My data on soil erosion for these areas indicated that the soils quickly stabilized after shallow blading. This condition favored the slow reinvasion of native perennial species. Years of above average precipitation would be advantageous to the invasion by perennial species. Once established my data have shown that soil moisture would be sufficient to support perennial species. Piemeisel (1951) found that bare ground would be colonized by native perennial species in the absence of alien annual species.

Most of the annual plants represented on the disturbed areas are grasses. The removal of competition by perennial species probably enhanced this rapid increase in annual grass species. *Bromus tectorum* is the principal species with *Festuca microstachys* (Nuttall's fescue) and *F. octoflora* present in the early stages of revegetation. *F. microstachys* and *F. octoflora* are considered to be native annual colonizers of disturbed areas in this habitat (Mack 1981). Most of these seeds would already have been present on the soil prior to disturbance. In site 1, the disturbance was so severe that most seeds were removed.

The data in Table 6 show that *F. microstachys* and *F. octoflora* are not significant components of the annual community after the first year following disturbance. Apparently these species are unable to compete with the aggressive *Bromus tectorum* seedlings for moisture and seedling safe sites. *B. tectorum* continues to be present in the revegetated stands of the disturbed areas (Figure 8). Individual plants were often quite small in size resulting from increased competition for moisture and safe sites with the invading perennial species.

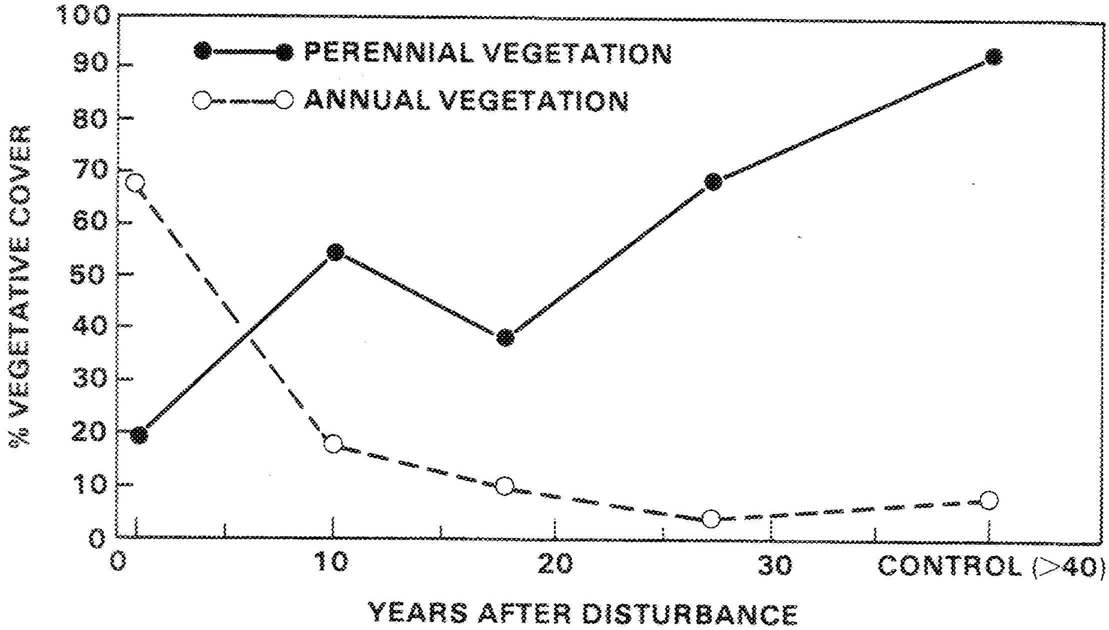

Figure 7. Percent of Annual and Perennial Vegetation Versus Years After Disturbance by Bulldozer.

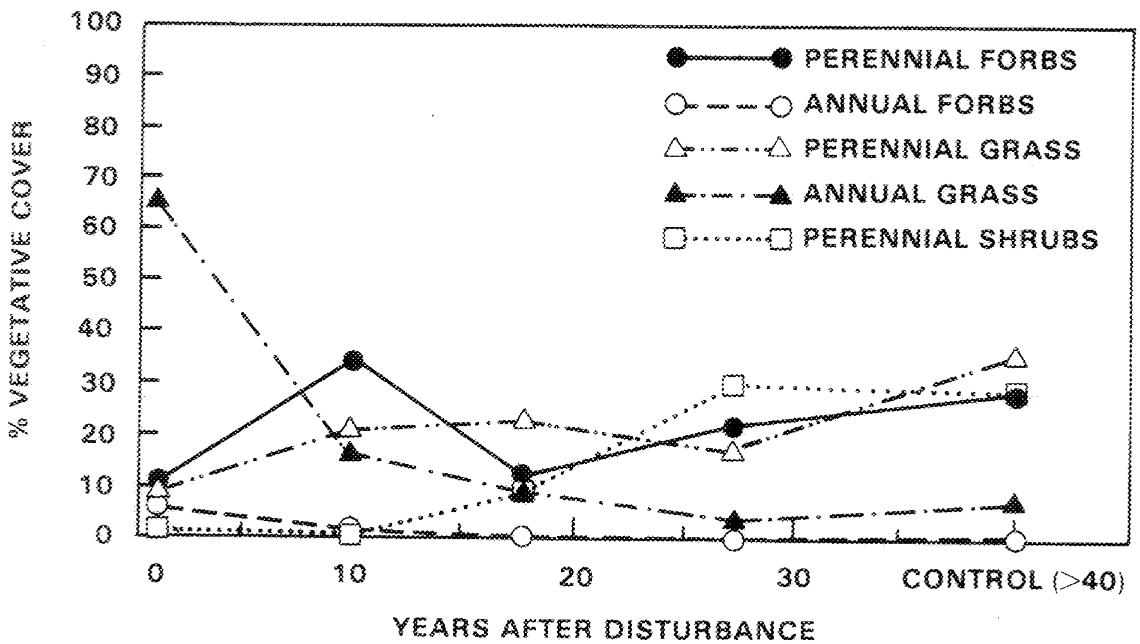

Figure 8. Percentage of all Vegetative Classes Versus Years After Disturbance by Bulldozer.

Annual forbs showed only a slight increase in abundance as a result of soil disturbance (Table 6). These species were mostly small in size and scattered on the disturbed sites. As was the case with the annual grasses, this competitive advantage was short lived. Annual forbs rapidly declined in importance and abundance in these disturbed communities (Figure 8). The lack of suitable seedling safe sites and competition for water were probably the major reasons for this decline.

Grasses make up about one half of the perennial species on the disturbed areas one year after disturbance (Table 6). The principal species is Poa sandbergii. This small perennial bunchgrass was least disturbed by bulldozing. Owing to the availability of seeds and the ability of this grass to invade disturbed areas, the abundance of P. sandbergii continuously increased (Figure 8). P. sandbergii is known to be one of the hardiest of the native perennial grasses and has shown the greatest adaptation to a number of environments, including disturbed areas (Daubenmire 1970). The morphologically larger grasses are greatly disturbed by blading and showed little indication of ability to reinvade the disturbed habitat. Agropyron spicatum in particular appeared to be very sensitive to even minimal disturbance and apparently cannot compete well on disturbed areas with other species either native or alien.

Oryzopsis hymenoides (indian ricegrass), Sitanion hystrix (bottlebrush squirreltail) and Stipa thurberiana (Thurber's needlegrass) show some small increase in representation on the disturbed areas and appear to be less sensitive to disturbance than A. spicatum. However, these species are not dominant in sagebrush bunchgrass communities.

Perennial forbs make up about one-half of the vegetation present on the disturbed areas after the first year (Figure 8). The deep-rooted forbs

Lupinus sulphureous (sulphur lupine), Lupinus luecophyllus (velvet lupine), and Crepis atrabarba (hawksbeard) proved to be very resilient to blading. These plants sprouted vigorously from rootstock the first spring after disturbance. C. atrabarba particularly appeared to be enhanced. This is probably the result of decreased competition for soil water caused by the removal of other competing perennials. This relationship was very evident on site 3. This site was deeply bladed, in some areas several inches. C. atrabarba and B. tectorum were the major species found in this area. The data indicated that Crepis atrabarba declined in abundance, while the other major perennial forbs increased in abundance to pre-disturbance concentrations.

The majority of the increase in perennial vegetation that occurs 15 to 20 years post disturbance is the result of the invasion and establishment of the shrub Artemisia tridentata (Figure 8). With the exception of a very few small plants, A. tridentata is virtually eliminated on areas disturbed by bulldozing. This species does not have the ability to sprout from buried rootstock after disturbance and must therefore enter an area by seeds. Years of above-average precipitation are favorable to establishment of A. tridentata seedlings over competing annuals. Upon establishment, seedlings would show relatively rapid and steady growth as suggested by the data.

The plant community resulting from shallow disturbance by blading on an Artemisia/Agropyron community had the following structure. The community had a much reduced layer of cryptogam crust while supporting an increased contingent of annual grasses. Bromus tectorum was the principal annual grass species but was depauperate. The perennial species present were chiefly the grass Poa sandbergii and the shrub, Artemisia tridentata. Some other perennial grasses were represented but in small amounts. Perennial forb cover was variable but appears to occur in the same relative amounts as the native community. Species diversity in self-revegetated communities is less than in native stands and represents a less complex vegetative structure than that of undisturbed habitat.

CONCLUSIONS

The data indicate that the following trends occurred in the *Artemisia-Agropyron* habitat-type after blading by bulldozer.

1. Scraping the upper few centimeters of the soil by bulldozing does not significantly alter the microclimate in terms of precipitation and soil temperature.
2. Blading and removal of the cryptogam crust did not significantly increase the amount of soil erosion. Wind erosion was significantly higher until the first heavy rains which produced a durable rain crust on these soils.
3. Blading increased the number of safe sites for seeds of annuals while destroying the native perennials. Formation of a soil crust appeared to inhibit the success of annuals.
4. Rain crusts or cryptogam crust, and the availability of sources of deep soil moisture appeared to be the factors favorable to the reinvasion of at least some native perennial species. After 27 years, the community had not returned to its expected predisturbance conditions in terms of the cryptogam crust or species composition of the vascular plants.

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APPENDICES

APPENDIX TABLE 1. Average Monthly Temperature (°C) for all Treatment Plots of Site 1 and 2.

Treatment	Range	MONTH O	N	D	J	F	M	A	M	J	J
Control	Maximum	20.6	12.4	5.8	6.7	9.2	16.4	23.2	32.3	39.1	41.1
Bladed	Maximum	21.7	14.4	7.7	8.2	10.1	17.5	23.3	31.5	37.3	40.1
Burned	Maximum	21.7	14.8	5.6	8.8	10.5	17.3	23.6	32.2	39.0	40.9
Control	Minimum	1.7	-1.7	-3.4	-3.9	-6.1	-1.3	-0.1	4.8	11.2	10.8
Bladed	Minimum	3.4	0.1	-2.5	-2.8	-5.3	-0.2	0.8	5.3	12.1	12.1
Burned	Minimum	3.6	0.2	-2.0	-2.9	-5.1	-0.1	1.2	5.4	12.4	12.1

APPENDIX TABLE 2. Percent Soil Water Content for Treatment Plots of Sites 1 and 2. Figures are Averaged Mid-month Values. Permanent Wilting Percentage was Estimated to be 5.5% Using a Water Retention Curve for Ritzville Silt Loam Soil.

Treatment	Depth(cm)	MONTH O	N	D	J	F	M	A	M	J	J	A
Control	0-10	11.4	11.3	14.3	18.6	4.6	17.5	17.4	8.2	3.4	7.5	3.4
	10-20	3.2	4.3	12.2	17.7	5.1	17.2	16.5	9.9	7.6	6.8	3.7
	20-30	3.3	3.7	3.9	16.7	14.6	16.6	15.6	10.7	6.9	6.5	5.2
	30-50	4.7	5.1	4.7	4.9	15.8	16.2	15.6	11.5	7.7	6.9	5.7
	50-100	4.4	4.7	4.5	4.4	5.6	11.3	12.8	12.4	8.8	6.9	5.5
Bladed	0-10	10.9	14.6	14.4	17.9	4.6	15.6	16.8	9.5	4.3	10.3	3.4
	10-20	3.8	4.7	10.2	16.4	6.4	16.1	15.9	11.3	7.9	11.6	5.5
	20-30	4.3	4.8	4.6	14.7	12.7	15.6	14.9	12.2	8.6	7.6	6.2
	30-50	5.4	6.0	5.2	5.8	13.5	14.2	13.7	11.1	9.6	8.2	6.7
	50-100	5.8	6.0	5.6	5.6	9.0	9.8	9.6	9.5	7.4	7.4	6.9
Burned	0-10	11.5	11.1	15.1	19.0	5.0	16.7	17.9	7.8	3.6	9.7	3.6
	10-20	3.3	4.0	9.3	16.1	5.9	16.3	15.3	9.1	5.8	7.8	4.5
	20-30	3.9	4.8	4.2	12.7	14.9	16.0	15.1	11.2	6.1	6.4	5.7
	30-50	4.8	5.0	4.6	4.6	5.4	12.7	13.0	10.8	6.0	5.9	5.4
	50-100	5.5	6.0	5.2	5.1	5.2	5.7	6.3	6.1	6.4	6.2	5.9