FINAL REPORT

Properties, Occurrence, and Management of Soils with Vesicular Surface Horizons

Effects of Disturbance by Natural and Simulated Cattle Trampling on Seedling Emergence from Different Soil Surface Types

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Four types of surface soils occur on study sites in the Humboldt Loess Belt of N. Nevada. These soils differ in microtopographic position, crust strength, structure of the A11 horizon, and organic matter content. Natural revegetation by native species on different surface soils and the effects of cattle trampling on revegetation on these soils was evaluated.

A study of hand-planted seed and simulated trampling showed that crested wheatgrass, squirreltail, and Thurber needlegrass can emerge through a moist surface crust in a wet year but not through a dry crust in a drought year. The soil beneath sagebrush was the most favorable location for emergence in the drought year. Most seedlings did not survive the summer or fall in either year of study.

A study of natural populations of native species showed that, in general, more seedlings emerged from cracks between crusted polygon surfaces than from the polygon surface itself. Different species emerged better from different microsites. Trampling increased the number of seedlings emerging from the polygons and decreased the number emerging from the cracks. Trampling had more effect on the location and number of seedlings on lower condition sites than on the higher condition site.

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SUMMARY

This report summarizes 2 year's work on the effects of a livestock trampling disturbance on seedling emergence from different soil surface types.

Four kinds of surface soil morphologies occur on certain Xerollic Argids in the Wyoming big sagebrush/grass vegetation type in the Humboldt Loess Belt of northern and central Nevada. These soils are: non-crusted Type I found on coppice dunes, non-crusted Type II found on coppice benches, crusted Type III found on intercoppice microplains, and crusted Type IV found on playettes. These surface soils are related to microtopographic position and exhibit differences in external polygon physiognomy and internal soil morphology. The surface cover of each soil varies among sites.

Type II and III surfaces are of particular interest in this study because of extent of cover and location in livestock traffic patterns. The Type II surface contains two distinct microsites: "pinnacles" which are polygons with convex tops, and "trenched cracks" which are the wide openings between pinnacles. Microsites of the Type III surface are "polygons" with a flat, crusted, vesicular A_{11} horizon, and "cracks" which are the narrow openings between polygons. These two surfaces and microsites have unique properties that can influence the response to grazing management systems. First, a crusted surface may be a mechanical barrier to seedling emergence when the surface is dry. Second, these soil surfaces have a unique "pinnacle/trench crack" or "polygon/crack" micro-surface morphology that may provide "safe sites" with suitable microenvironments for seed germination and seedling emergence, and establishment. Cattle trampling may destroy these "safe sites" and create more extensive crusts.

Simultaneously, however, trampling may plant seeds in an otherwise smooth, crusted polygon surface and thereby provide new microenvironments for seedling emergence. Before grazing systems can be properly designed, land managers need insight into the interactions among cattle trampling, crust properties, and seedling emergence and establishment. The objective of this study was to investigate natural revegetation on different soil surface morphological types and to determine the role of cattle trampling in the revegetation process.

Two research methods were used to evaluate seedling emergence. In the first study, seed was hand-planted in the fall of the year on plots representing each microsite on four soil surfaces. Simulated trampling was used to disturb the soil. In the other approach, natural populations (young plants in 1977 and seedlings in 1978) on microsites of the Type II and III surfaces were sampled on areas grazed and trampled and ungrazed and untrampled by cattle.

A drought in 1976-77 and unusually wet conditions in 1977-78 prevent conclusive statements about seedling emergence from hand-planted seed. In general, crested wheatgrass, squirreltail, and Thurber needlegrass emerged best on the Type I surface in a dry year. Emergence of crested wheatgrass and squirreltail was sufficient for stand regeneration only on the Type I surface in the dry year of 1976-77. In a wet year of 1977-78 moist crusts were not a barrier to seedling emergence, however, emergence of crested wheatgrass and squirreltail on Type II and III surfaces was sufficicnt to increase stand density only on two of five sites. Thurber needlegrass emergence was sufficient for stand regeneration only on one site.

Trampled Type II surface reforms after wetting and drying to resemble a Type III surface. Trench cracks become cracks and pinnacles flatten to form polygons. The Type III surface reforms with the original crack and polygon positions unaltered. Moss and lichen cover are destroyed by trampling on Type II or III surfaces but not on a Type I surface.

In natural populations, the kind of soil surface type did not influence the number of young plants of native species present in 1977. In 1978, more seedlings were found on the Type II surface. Species emergence was influenced by the kind of microsite present in both 1977 and 1978. The number of trench cracks and cracks and pinnacle and polygon surfaces at a site determines the species composition of emerged seedlings and theoretically the species composition of established plants. More sagebrush plants were found on the untrampled Type III polygon surface of low condition sites, while perennial grasses and perennial and annual forbs were found mostly in trench cracks of Type II surface regardless of tramping.

Trampling changes surface morhplolgy and results in different microenvironmental conditions for seedling emergence. Trampling increased emergence of seedlings from polygon surfaces probably by planting seed in the otherwise smooth, hard surface. At the same time, trampling reduced the suitability of the trench crack and crack microsites for emergence perhaps by covering the seed deeply with soil.

A trampling disturbance may result in permanent changes in soil-surface morphology and permanently alter the kind and amount of specific microenvironments available for seedling emergence. A decrease in the amount of trench crack of Type II surface and an increase in the amount of crusted Type III surface occurs with trampling. As a result, species that emerge best on the Type III polygon surface microsite would be expected to increase, for example, sagebrush. Those species that emerge best on the Type II trench crack microsite, such as perennial grasses, would be expected to decline in density as the amount of this surface is reduced. These responses are related to range condition and appear to influence trend in range condition.

INTRODUCTION

The soil on many grazing allotments in Nevada is characterized by high silt content, vesicular structure, and crusted surface. These soils are found in the Humboldt Loess Belt, a 20 million acre (8.1 million hectares) area of windblown silt and very fine sand deposition in the northern and central parts of the State (Fig. 1).

These kinds of soils have unique properties that can influence the response from grazing management systems. First, a crust may be a mechanical barrier to seedling emergence when the surface is dry. When the surface is saturated, reduced gas diffusion may also hinder seedling germination and emergence. As a result, germination and emergence of seedlings occur only over a limited soil moisture range. Secondly, crusted soil surfaces have a unique micro-surface morphology characterized by polygonally shaped units separated by cracks that may provide "safe sites" with suitable microenvironments for seedling germination, emergence, and establishment. Cattle trampling may destroy these "safe sites" and create more extensive crusts. Simultaneously, however, trampling may plant seeds in an otherwise smooth crusted polygon surface and thereby provide new microenvironments for seedling emergence. Before grazing management systems can be properly designed, insight is needed into the interactions among cattle trampling, crust properties, and seedling emergence and establishment.

OBJECTIVE

The objective of this study was to investigate natural revegetation on different soil-surface morphological types (surface type) and the role of cattle trampling in the revegetation process. Since changes in a plant community depend largely on successful reproduction of individual species, attention was focused on three questions related to seedling emergence and establishment.

1) What is the relation between different surface types and seedling emergence?

2) Does a trampling disturbance affect surface types and the number and species composition of emerged seedlings on different soil surfaces?

3) Do emerged seedlings become established?

SITE DESCRIPTION

Locations

Nine study sites were chosen in northern Nevada (Fig. 1 and Appendix I) over the 2-year study period. These sites are located as follows: Lower Coils Creek (LCC) about 31 airline miles (50 km) north west of Eureka; Paradise Valley (PV) about 40 miles (64 km) north of Winnemucca; Panther Canyon (PC) about 35 miles (56 km) south of Winnemucca; Dinner Station 1 (DS1), about 20 miles (32 km) north of Elko; Jiggs 1 about 30 miles (48 km) south of Elko on the Circle L Ranch; Jiggs 2 on Highway 46 about 1 mile (2 km) west of the Highway 51 junction; and two sites on Highway 11 north of Elko--Elko 1 (E1) about 2 miles (3 km) west of Highway 51, and Elko 2 (E2) about 7 miles (11 km) west of Highway 51. All sites are located broadly dissected alluvial fans.

Soils

Soils at the nine study sites were classified to the family level (Appendix I) on the basis of profile descriptions (Appendix 2), and laboratory characterizations (Appendices 5 and 6). Surface soil textures (A11 horizon) are sandy loams, loams, silt loams, and clay loams.[1] Very fine sand fractions are high and vary between 28.9% at Paradise Valley Type II and 14.1%

[1] Particle size distribution was estimated by the hydrometer method that included removal of organic matter by boiling with hydrogen peroxide and separation of sand fractions.

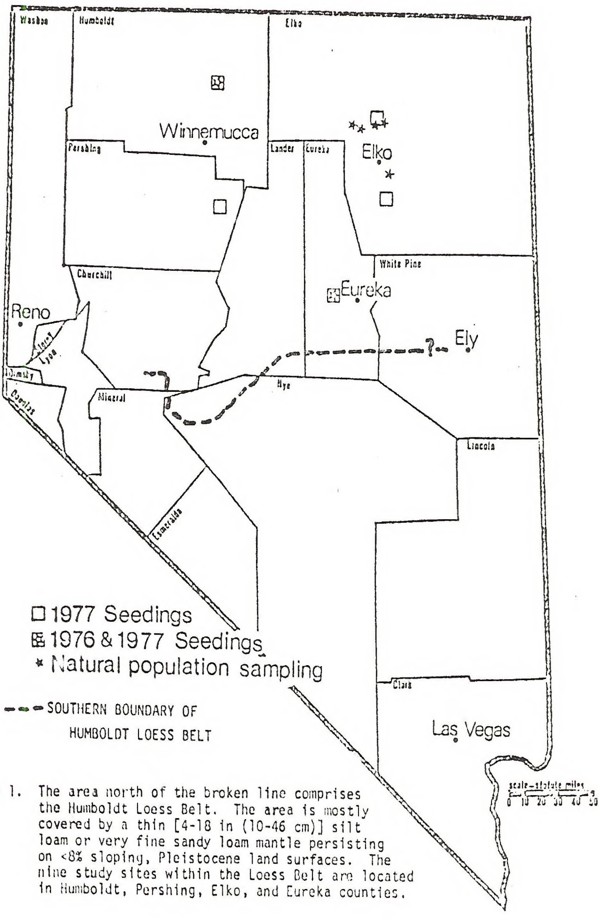

Figure 1. The area north of the broken line comprises the Humboldt Loess Belt. The area is mostly covered by a thin [4-18 in (10-46 cm)] silt loam or very fine sandy loam mantle persisting on <8% sloping, Pleistocene land surfaces. The nine study sites within the Loess Belt are located in Humboldt, Pershing, Elko, and Eureka counties.

at Elko I Type III. Sand content ranges from 58.3% at Lower Coils Creek Type 1 to 21.2% at Dinner Station 1 Type III. Silt content ranges from 55.0% at Jiggs 2 Type II to 28.1% at Lower Coils Creek Type I. Total clay percent ranges from 27.9% at Dinner Station 2 Type I to 6.1% at Paradise Valley Type IV.

Percent organic matter in the surface soil (A11 horizon) decreases from Type I to Type IV surface.[2] Organic matter content of Type I surface ranges from 7.3% at Dinner Station 1 and Jiggs 1 to 3.0% at Dinner Station 2. Organic matter content on Type II surface ranges from 6.4% at Paradise Valley to 2.8% at Dinner Station 2. On Type III surface, organic matter ramges from 3.5% at Panther Canyon to 1.6% at Lower Coils Creek, Jiggs 2, Elko 1, and Elko 2. Type IV surface at Lower Coils Creek and Paradise Valley has the lowest organic matter recorded: 1.1% and 0.5%, respectively.

Past field studies defined <u>four</u> possible surface types that occur in the Humboldt Loess Belt and these surfaces are also found on all study sites. These four types occur on different landforms, have different soil morphology, and occur in different proportions on various soils.

The four surface types are genetically related to their micro-landform, and thus can be identified in part by their microtopographic positions. The major types are listed in Table 1 by Roman numerals which serves as names for them. It is important to name these surface types by their Roman numeral rather than their microtopographic position since other surface types occur on the same microtopographic positions elsewhere. Schematic diagrams are given for microtopographic position, polygon shape, and surface morphology that have been defined for alluvial fan remnants within the Humboldt Loess Belt (Fig. 2).

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[2] Organic matter was determined by the Walkley-Black Method.

Table 1. Characteristics of soil surface morphological types.

Soil Surface Morphological Type	Microtopographic Position	Description of Microtopographic Position
I	Coppice	A semi-conical form, the highest microtopographic elevation.
II	Coppice bench	A flattish, or gently sloping area next highest to the coppice, and higher than any adjacent intercoppice microplain or playette, if the latter occur.
III	Intercoppice microplain	A gently sloping or nearly flattish area next lower than the coppice bench. (Absent in some situations).
IV	Playette	A slightly depressional area or flat area at the lowest microtopograhic elevation and surrounded by coppice benches, or intercoppice microplains. (Absent in some situations).

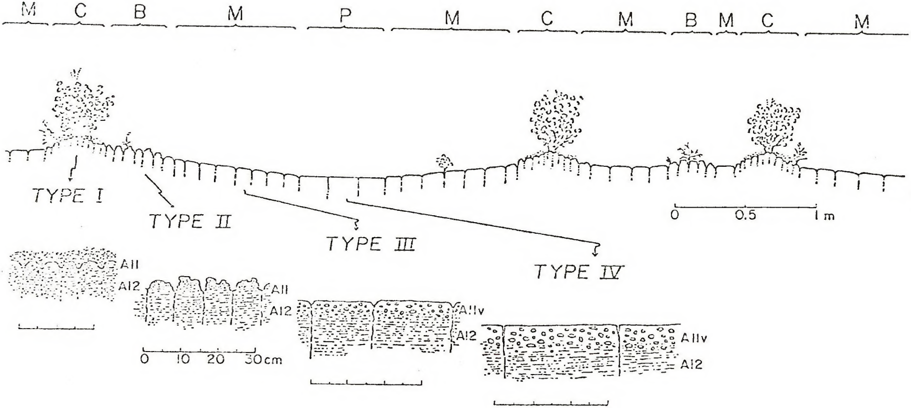

Figure 2.[1/] Schematic cross-sectional diagrams of the microtopographic positions and associated surface-soil morphological types with big sagebrush (Artemisia tridentata) plant communities. Microtopographic positions are: C = coppice, B = coppice bench, M = intercoppice microplains, P = playette. Vertical scale somewhat exaggerated; intercoppice microplains and playettes can be much wider than shown here; several coppices can be linked together. Vertical lines under soil surface indicate sides of crust polygons (A11v) which continue downward as sides of prisms in the compoundly weak prismatic and moderate platy A12 horizon. Type I is litter covered. Circles indicate vesicles in crust (A11v). Only types III and IV are significantly crusted.

1/ Diagram source: Dr. F.F. Peterson, Department of Plant, Soil and Water, University of Nevada Reno.

Differences in soil morphology among the four surface types consist of (1) external polygon physiognomy, and (2) internal soil morphology and thickness of the A11 horizon. The polygons are actually the massive tops of squat, very coarse prisms. These prisms extend down through the entire A horizon, and in some cases, on into the B horizon. They are attributed to recurrent soil shrinking and fracture along the same semi-vertical planes, or prism faces. These prism faces are clearly expressed in the A11 horizon of Types II, III, and IV, but become more difficult to distinguish with depth through the A12 horizon, and especially in any A2 horizon present. They are rather difficult to distinguish in a root-proliferated and litter covered Type 1 surface.

The different surface types can be described by their morphological characteristics and general vegetative conditions. The Type I surface morphology occurs on the coppice microtopographic position. The surficial A11 horizon is an aeolian deposit and is mostly litter, moss, or lichen covered. It is noncrusted, only very slightly hard, and is weak to moderate very fine subangular blocky structured. It is additionally structured into weak, 2-4 inch (5-10 cm) diameter, convex topped, squat prisms or polygons which are separated by trench-like, 0.4 inch (1 cm) wide by 0.4 inch (1 cm) deep cracks at their tops. These shallow trenches most commonly are filled with litter.

Type I surfaces regularly support big sagebrush; occasionally the shrub is dead but the coppice is still intact. Bunchgrass may or may not occur under or to the side of the shrubs, depending on the range condition. The interior of the coppice is commonly at least partially litter covered, otherwise mostly moss and lichen covered. Coppice margins commonly show bare soil and prominent pinnacling with Sandberg bluegrass on top of some pinnacles.

The Type II surface morphology occurs on the coppice bench microtopographic position, and appears to be the flattened, somewhat eroded remnant of a former Type I coppice. The surficial A11 horizon is only very weakly and very thinly <0.8 inch (<2 cm) crusted, and is either massive or massive in its upper part and very weakly platy with depth. The crust is quite fragile. This A11 horizon is additionally structured into barren or lichen covered, relatively small 2.8-5.9 inch (7-15 cm) diameter squat prisms or polygons with convex tops or more commonly with several 0.4-1.2 inch (1-3 cm) high by 0.8-1.2 inch (2-3 cm) diameter pinnacles. The polygons are round-shouldered and separated by prominent, trench-like cracks about 0.4 inch (1 cm) deep and 0.4 inch (1 cm) wide at their tops. This largely barren, predominantly trench-cracked and pinnacled surface is microtopographically below the Type I surface and above the Type III and IV surfaces. Its trench-cracks seem preferred sites for natural seed lodgement and seedling emergence.

The Type II surface generally is poorly vegetated. Sandberg bluegrass bunches are pedestalled (i.e., on a pinnacle) and occur near a polygon trenched crack, if not in it. Cheatgrass grows out of the trenched cracks and commonly covers the small polygons with litter. Seedling big sagebrush plants also occur in the trenched cracks, as do a few phlox plants. At some sites very well protected from trampling, lichen covers the entire Type II surface.

The Type III surface morphology occurs on the gently sloping to flattish intercoppice microplain microtopographic position. The surficial A11v horizon is a massive, moderately coarsely vesicular, durable crust about 0.6-1.6 inches (1.5-4 cm) thick and is separated into squat prisms, or polygons, roughly 5.1-14.2 inches (13-36 cm) in diameter. The ploygons have angular shoulders and narrow cracks between them. This surface is most commonly barren except for a very few plants of big sagebrush or phlox rooted in the cracks, but can be lichen covered where protected from trampling.

Some sites have a scattered pebble pavement; in other places pebbles lie in rings on top of the polygon cracks.

Type IV surface morphology occurs in the playette microtopographic position that is a slight depression below the intercoppice microplains where water collects and stands briefly after heavy rainstorms or during snowmelt. The A11v surficial horizon is a prominent, durable, massive, coarsely vesicular crust from 1.6-3.1 inches (4-8 cm) thick. It is relatively light-colored, quite barren, and irregularly broken into large, squat prisms or polygons of from 7.9-14.2 inches (20-36 cm) diameter. The polygon shoulders are angular and intervening cracks are narrow.

From site to site on different kinds of soil, the areal proportions of surface types and the degree of crust expression for the surface types---particularly Type III--- apparently varies with microtopographic position, kind of soil materials, range condition, and probably kind of profile and climate. We have substantial field evidence from which genetic mechanism and sequence can be postulated for the Humboldt Loess area where the seeding sites are located.

The Type I coppice surface is the apparent result of accumulation of windblown soil material at the base of a shrub that sprouted in a Type II or III surface. Concurrent incorporation of litter and root residues resulted in a higher humus content and formation of moderate very fine subangular blocky structure. Primary evidence for aeolian accumulation is continuity of the relatively light colored A11v subhorizon of contiguous Type III surfaces horizontally under the slightly higher, dark colored, semi-conical A11 horizon of the Type I surface. The A11 horizon of the Type I surface commonly is slightly sandier than an adjacent Type III A11 horizon, and than the buried, apparent lateral extension of adjacent A11v subhorizon.

Where buried under a coppice, this former soil surface horizon apparently acquires the prominent compound fine platy and very fine subangular blocky structure that is characteristic of the continuous A12 horizon under all four surface types. Thus, under a coppice, the A12 appears slightly thicker with a slighter lighter grey color in the upper 1.6-2.4 inches (4-6 cm) (i.e., the presumably buried former surficial horizon) than away from the coppice. Occurrence of big sagebrush seedlings in polygon cracks of Type II or III surfaces, without coppice dunes, somewhat larger shrubs with small coppice dunes, and large old shrubs with relatively high coppice dunes are accessory evidence of aeolian accumulation around shrubs initially started in Type II and III surfaces.

The margins of Type I are prominently pinnacles where not litter covered and some are barren and appear eroded as well as pinnacled. Where sagebrush have died recently, litter cover is absent and yet the semiconical coppice is strongly pinnacled, frequently most bare, and give the impression of being eroded. Where only a few trampled down, centripetally strewn fragments of a dead sagebrush occur on a Type II pinnacled surface, there is no longer a semiconical peak, or dune-coppice form at the site of the shrub crown. This apparent sequence suggests that some of the Type II surfaces are flattened and pinnacled remnants of former Type I coppice surfaces.

Massive vesicular crusting in Types III and IV surfaces results from recurrent saturation then dessication of readily slaked, silty soil material. For a particular soil site, surficial saturation depends on water infiltrating more rapidly than it percolates down and out of the surficial subhorizon. Microtopographic positions that receive runoff in addition to precipitation and pond, or or can only slowly dispose of surface runoff (i.e., playettes and intercoppice microplains) have the highest potential for surficial saturation. We find the thickest vesicular crusts on playettes, thinner ones on intercoppice microplains, and little or no such crusting on coppice bench or coppice microtopographic positions.

Given rapid enough water addition to pond or sheet-flood, soil hydraulic conductivity determines the rate and depth of soil saturation. Slaking very fine sandy loams and silt loams probably have low hydraulic conductivity, in addition to those capillary properties necessary for vesicle formation and perhaps platy structure formation.

Two other morphological features also may affect low hydraulic conductivity of the A horizon and cause surficial saturation. Water percolating by unsaturated flow is markedly slowed when it passes from a finely porous layer to a more coarsely porous layer. The prominent fine platy structure of the A12 subhorizons, in the soils studied, places coarse horizontal pores below the surficial A11 subhorizon and might result in sufficiently low water tension in the A11 horizon to cause slaking and development of vesicular pores.

Water penetration is also slowed by underlying, slowly pervious clayey argillic or natric horizons. During major storms and snowmelt, enough water is added to many Aridisols--particularly in the playette position--to fill the A horizon if it cannot percolate through the argillic or natric horizon. After storms on dry soils, some Type IV playette surfaces are temporarily and shallowlyponded and saturated down to, and a centimeter or so past, a shallow 4-6 inch (10-15 cm) abrupt textural boundary to an argillic or natric horizon. Adjacent Type III, II, and I surfaces with thicker A horizons are more deeply wetted and neither saturate nor pond.

The percent cover of the four surface types varied among study locations (Appendix I). The greatest cover of Type I surface is on trampled areas on Dinner Station 2 (39.0%) and Dinner Station 1 (38.5%). The least is at Elko 2, trampled (17.4%). More Type II surface is found at all untrampled sites than on the adjacent trampled sites. The greatest amount of Type II surface is found at Dinner Station 1, untrampled (53.4%) and the least at Lower Coils Creek trampled (13.4%). More cover of Type III surface is found on the trampled areas versus the adjacent untrampled areas. The relation between trampling and Type II and III surfaces suggests that the Type II surface is changed to a Type III surface with trampling. The greatest percent cover of Type III surface is at Elko 2, trampled (46.6%) and the least is at Dinner Station 1, untrampled (14.7%). The greatest cover of Type IV surface is found at Lower Coils Creek (8.5%) with no Type IV surface at Dinner Station 2 and Elko 2.

Precipitation

Precipitation from October, 1976 to August, 1977 was 4.3 inches (11.0 cm) at Lower Coils Creek and 6.3 inches (16.0 cm) at Paradise Valley. Precipitation from October, 1977 to July, 1978 is given in Table 2. Since gauges were not charged or read on the same days at all sites, exact differences in precipitation cannot be stated. Total precipitation was similar at all sites, however, differences in spring-summer precipitation are evident (Table 3). Panther Canyon had the most spring-summer precipitation 5.2 inches (13.1 cm) followed by Dinner Station 2 4.7 inches (12.0 cm) and Dinner Station 1 3.0 inches (7.6 cm). Jiggs 1 and Paradise Valley had the least spring-summer precipitation, 1.8 and 1.5 inches (4.6 and 3.8 cm), respectively.

Vegetation

A species list with scientific and common names and symbols is presented in Appendix 4. Total shrub crown cover is highest at Panther Canyon

Table 2. Total precipitation at the nine study sites between October, 1977 and July, 1978

Location[1]	Beginning Date	Ending Date	Precipitation-in.	(cm)
PV	10-8	7-16	10.2	(25.8)
LCC	10-29	7-18	8.0	(20.2)
PC	10-9	7-16	11.8	(29.9)
J1	10-7	7-17	7.7	(19.2)
J2	No data recorded			
DS1	10-7	7-18	10.0	(25.4)
DS2	11-1	7-18	9.9	(25.1)
E1	No data recorded			
E2	No data recorded			

Table 3. Summer precipitation at the nine study sites between April, 1978 and July, 1978.

Location[1]	Beginning Date	Ending Date	Precipitation-in.	(cm)
PV	4-24	7-16	1.5	(3.8)
LCC	4-23	7-18	2.3	(5.8)
PC	4-24	7-16	5.2	(13.1)
J1	4-1	7-17	1.8	(4.6)
J2	No data recorded			
DS1	4-1	7-18	3.0	(7.6)
DS2	4-1	7-18	4.7	(12.0)
E1	No data recorded			
E2	No data recorded			

[1] See Appendix 1 for key to location symbols.

(37.5%) and lowest at Elko 2, grazed (13.4%) (Appendix 3). Wyoming big sagebrush has the greatest crown cover at Lower Coils Creek (29.0%) followed closely by Dinner Station 1, ungrazed (28.9%). The lowest crown cover of Wyoming big sagebrush (5.6%) is at Jiggs 2 due mainly to large number of dead sagebrush, perhaps due to insect damage. Perennial grass cover is greatest at Jiggs 2 (4.9%) and least at Lower Coils Creek (0.9%) and Paradise Valley, grazed (1.0%).

Grazing Histories

The Dinner Station 1 exclosure site has not been grazed for 40 years; the area outside the exclosure is grazed season-long each year. Elko 1 and Elko 2 have both been divided by a highway right-of-way fence for approximately 11 years. Grazing outside the fence has been light, if any. The area inside the fence is grazed season-long each year. Elko 1 has somewhat more cattle use than Elko 2 because of a water trough inside the fence.

The Jiggs 1 exclosure is 15 years old; outside the exclosure is the Cord crested wheatgrass seeding. Jiggs 2 has been divided by a highway right-of-way fence for approximately 14 years. The Brush Field crested wheatgrass seeding is directly south of Jiggs 2 and, as a result, the study site is invaded by crested wheatgrass.

The exclosure at Paradise Valley is 3 years old. The area outside the exclosure is grazed season-long each year. The Panther Canyon site was grazed season-long until 1973, then in a 3-pasture rest-rotation system until 1977 when the exclosure was built.

METHODS

Seeding Trials

An evaluation of grass seedling emergence and establishment in relation to surface type and simulated trampling was begun in the fall of 1976. Permanent plots 1 ft^2 (0.09 m^2), in area were randomly located at Lower Coils Creek and Paradise Valley on Types I, II, III and, when available, Type IV surfaces. In order to follow changes in the soil surface type and emergence and establishment of seedlings, each plot was diagrammed with respect to trench cracks, pinnacles, cracks, and polygons (Fig. 3). Squirreltail, Thurber needlegrass and crested wheatgrass seeds were handplanted 0.4 in (1 cm) apart in trench cracks, cracks, or on polygon surfaces. The seeding was followed by the trampling treatments described in Table 4. Each treatment had ten replications.

Emergence of seedlings was determined in the spring of 1977 and is expressed as a percent based on number of live seed planted. Plots were rechecked in the spring of 1978 for emergence of new seedlings and for survival of seedlings that emerged in 1977. All plots were examined at various times during the two years after initial trampling treatments for changes in surface types and for reformation of surface microtopography.

Permanent plots were also established at Jiggs 1, Panther Canyon, and Dinner Station in the summer of 1977. New plots were established at Lower Coils Creek and Paradise Valley. The seeding rate was increased to 100 seeds of each species per plot or about one seed/0.03 in^2 (0.2 cm^2) on the polygon surface or one seed/0.24-0.32 in (0.6-0.8 cm) of crack or trench crack. The trampling treatments remained the same as in Table 4 with two exceptions:

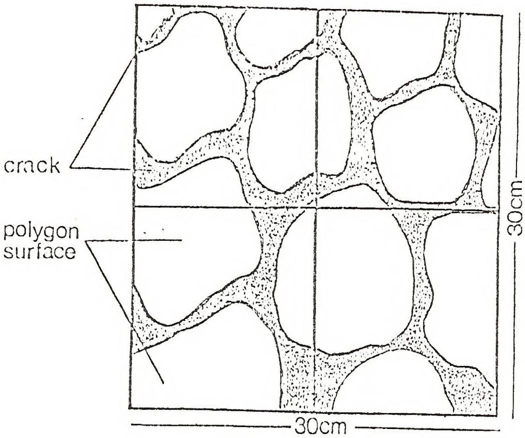

Figure 3. Plot diagram for seeding study on a Type III surface.

Table 4. Trampling treatments for seeding trials in fall, 1976 and summer, 1977.

The treatments for the four surface types were as follows:

A. Seed placed in cracks or trench cracks. In fall, 1976 seeds were placed 1 cm apart. In summer, 1977, 100 seeds were sprinkled in the length of the cracks or about 1 seed every 0.24-0.32 in (0.6-0.8 cm).

B. Seed placed in cracks or trench cracks as in A and trampled to a depth of approximately 1 in (2.5 cm) with a post studded with nails protruding 1.2 in (3 cm).

C. Center of polygon surface or coppice trampled to a depth of 1 in (2.5 cm) and seeds placed in the powdered surface at a depth of 0.4 in (1 cm). Seeds placed 0.4 in (1 cm apart in 1976 with about 1 seed/0.03 in^2 (0.2cm^2) in 1977.

D. Seed (100) of each species broadcast over one quadrant of a Type III plot [0.22 ft^2 (0.02 m^2)] and trampled. This treatment was used only in 1977 at Paradise Valley and Panther Canyon because an unusually wet summer caused the cracks of the Type III surface to close.

Each surface type was treated depending on the individual morphological characteristics.

Surface Type	Treatment
I	C
II	B (A in 1976)
III	A;B;C;D (1977 only)
IV	A,B,C

1. Seeds were not placed in untrampled trench cracks of the Type II surface (Treatment A) because they appeared to roll or be washed down the slope of the coppice bench and emerge outside the permanent plot area.
2. At Paradise Valley and Panther Canyon, seeds were broadcast over the entire Type III surface within a plot and trampled. This change was made because the cracks were closed due to an unusually wet summer season.

All plots were examined in the spring of 1978 for emergence of seedlings. Data obtained from the seeded plots were analyzed by means of a two-way analysis of variance (treatment vs. species). Individual comparisons with equal sample sizes were made with Duncan's multiple range test. Individual comparisons with unequal sample sizes were made with Scheffe's test.

Natural Population Sampling

The location of naturally occurring plants in 1977 and 1978 was determined under actual cattle grazing and trampling conditions. In 1977, a sample of 100, 2.7 ft^2 ($0.25m^2$) temporary plots randomly spaced on grazed and ungrazed Type II and Type III surfaces was used to sample at Dinner Station 1, Elko 1, and Elko 2. Due to drought conditions and poor seedling emergence, the number of young plants of grasses, forbs, and shrubs in trench cracks or on pinnacles of the Type II surface or in cracks and on polygons of the Type III surface were recorded. Young plants are defined as those individuals that had not disrupted the soil morphology at their bases, deposited litter, or collected aeolian deposits as to obscure surface type at the point of emergence.

After the wet winter of 1977-78, natural populations of seedlings could be sampled in the spring of 1978 on grazed and ungrazed areas at Elko 1, Dinner Station 2, and Jiggs 2. The methods were the same as those used in 1977 except that plot size was reduced to 1 ft^2 (0.09 m^2) due to very high seedling emergence.

Chi square tests of independence were used to indicate significant differences in the total number of individuals of a certain species on untrampled and trampled areas.

RESULTS AND DISCUSSION

1977 Seeding Trials

Drought conditions in 1976-1977 [4.3 in (11.0 cm) precipitation at Lower Coils Creek and 6.3 in (16.0 cm) at Paradise Valley] prevent conclusive statements about the emergence of seedlings from hand-planted seed in artificially trampled plots. Less than 1% of planted seed emerged at Lower Coils Creek. A rain in the spring of 1977 at Paradise Valley, however, resulted in enough seedling to suggest the effects of trampling treatments on the emergence of squirreltail, crested wheatgrass, and Thurber needlegrass seedlings(Table 5). Emergence of all species was very low on Types II, III, and IV regardless of trampling treatment. Crested wheatgrass and squirreltail emergence was greater than that of Thurber needlegrass especially on the Type I surface. Emergence of squirreltail and crested wheatgrass seedling was much higher on Type I surface than on the other surfaces. The Type I or coppice is probably the most suitable environment for seedling emergence during a drought year because sagebrush overstory and mulch cover reduce soil temperatures and soil moisture loss by evaporation. Type II, III, and IV surfaces are less desirable for seedling emergence because of high temperatures and high rates of evaporative moisture loss from the cracks and barren soil surfaces. Crested wheatgrass that emerged through the Type II and III surfaces produced more vigorous plants than did squirreltail or Thurber needlegrass.

Trampled Type II surface examined the spring following treatment had reformed to resemble the Type III surface. Trench cracks had become

Table 5. Percent seedling emergence in spring, 1977 and simulated trampling treatments at Paradise Valley. Treatments were made in fall, 1976.

	Surface Type							
	I	II	II	III	III	III	IV	IV
	Trampling Treatment[1]							
Species	C	A	B	A	B	C	A	B
AGDE[2]	32.05	0.01	0.07	0.08	0.06	0.05	0.04	0.01
SIHY	32.30	0.02	0.05	0.01	0.16	0.12	0.08	0.01
STTH	0.06	0.0	0.0	0.01	0.0	0.0	0.0	0.0

[1] Trampling treatments: A - seeds placed in trench cracks or cracks.
B - seeds placed in trench cracks or cracks and trampled.
C - center of polygon surface or coppice trampled and seeds placed in the powdered surface.

[2] See Appendix 4 for key to species symbols.

cracks typical of the Type III surface and pinnacles were flattened to form polygons. The Type III surface reformed with the original crack positions unaltered by the trampling treatment. Moss and lichen cover was destroyed by trampling on Type II and Type III surfaces but was not destroyed on the Type I surface.

1978 Seeding Trials

The percent seedling emergence at all five sites seeded in the summer of 1977 and sampled in spring of 1978 was highly variable. At the Paradise Valley, Panther Canyon, and Dinner Station 1 sites no significant differences were detected among species seeded, surface type, or trampling treatments (Table 6). Results from Jiggs 1, however, indicated a significantly higher percentage of emerged Thurber needlegrass seedlings (13.3%) than crested wheatgrass (1.2%) or squirreltail (3.0%) planted in cracks of Type III surface and trampled (Table 7). Thurber needlegrass seed planted this way also produced more seedlings than when planted by the other four methods.

At Paradise Valley and Panther Canyon, emergence was significantly higher on the polygons than in associated cracks of the Type III surface for all three species when seed had been broadcast over the entire plot and trampled (Table 8). The large difference in emergence from the polygon and crack microsites may be influenced by the method of seeding. Since no cracks were present at time of seeding and the entire surface was trampled. Seed was not placed directly in cracks and any small cracks present were filled with powdered soil. Therefore, these data do not fully represent a normal crack response.

High emergence on the polygon surfaces themselves is probably related to the unusually high precipitation at both these study sites from fall,

Table 6. Percent seedling emergence in spring, 1978 from hand-planted seed and simulated trampling treatment at Paradise Valley (PV) and Panther Canyon (PC). Treatments were made in summer, 1977.

Surface Type and Trampling Treatments[2]	Species					
	SIHY[1]		AGDE		STTH	
	Location					
	PV	PC	PV	PC	PV	PC
Type I - C	22.2	10.1	12.3	12.9	6.9	11.8
Type II - B	17.7	12.4	16.0	13.1	5.4	17.4
Type III - D	24.5	17.3	15.6	17.6	4.4	12.6

[1] See Appendix 4 for key to species symbols.

[2] Treatments:

B - Seeds placed in cracks and trampled.

C - Center of polygon surface or coppice, trampled and seed placed within the powdered surface.

D - Seed broadcast over entire plot and trampled.

Table 7. Percent seedling emergence in spring, 1978 from hand-planted seed and simulated trampling treatment at Jiggs 1 (J1), Lower Coils Creek (LCC), and Dinner Station (DS1). Treatments were made in summer, 1977.

Surface Type and Trampling Treatment[2]	SIHY[1] J1	SIHY LCC	SIHY DS1	AGDE J1	AGDE LCC	AGDE DS1	STTH J1	STTH LCC	STTH DS1
Type I - C	1.7a[3]	1.4a	4.4a	2.8a	1.6a	8.3a	4.8a	2.6a	5.3a
Type II - B	1.5a	1.2a	8.6a	0.8a	1.6a	6.7a	2.6a	5.5a	14.4a
Type III - A	0.6a	1.6a	5.9a	0.6a	0.8a	5.9a	3.3a	4.4a	6.7a
Type III - B	3.0a	0.9a	4.6a	1.2a	1.6a	7.5a	13.3b	4.2a	11.5a
Type III - C	1.6a	0.4a	1.2a	1.0a	0.6a	2.4a	4.8a	1.5a	4.4a

[1] See Appendix 4 for key to species symbols.

[2] Trampling treatments:

A - Seed placed on trench cracks or cracks.

B - Seed placed in trench cracks or cracks and trampled.

C - Center of polygon surface or coppice trampled and seed placed within the powdered surface.

[3] A different letter indicates a significant difference at the 95% level of confidence between treatments within species and site or between species within a site.

Table 8. Percent seedling emergence in spring, 1978 from crack or polygon microsites of Type III surface broadcast seeded and artificially trampled at Paradise Valley (PV) and Panther Canyon (PC). Treatments were made in summer, 1977.

	Species					
	SIHY[1]		AGDE		STTH	
	Location					
Microsite	PV	PC	PV	PC	PV	PC
Polygon	24.0*[2]	16.3*	17.3*	16.6*	15.9*	10.7*
Crack	0.5	1.0	0.5	1.0	0.4	1.8

[1] See Appendix 4 for key to species symbols.

[2] Asterisk indicates a significant difference at the 95% level of confidence between the number of seedlings on the polygon versus in the crack at each location.

1977 to summer, 1978 [Paradise Valley 10.3 in (25.8 cm) and Panther Canyon 12.0 in (29.9 cm)]. These data show that moist crusts are not barriers to seedling emergence. In addition, the high moisture content in the soil surface may have enhanced germination. Another factor that may have contributed to high emergence on the polygon surfaces was the large number of seeds planted in each plot [1/0.03 in^2 (0.2 cm^2)]. At this high density, the force exerted by many seedlings may be sufficient to break through the surface crust.

1977 Natural Population Sampling

In the spring of 1977 the location of young plants was sampled at Dinner Station 1, Elko 1 and Elko 2 on adjacent areas that had been either grazed by cattle or protected for a number of years prior to the study. The mean number of young plants on the trampled and untrampled surfaces is given in Table 9. The trampled surfaces at Elko 1 and Elko 2 had fewer young plants than did the adjacent untrampled surfaces. This indicates a detrimental effect of trampling on seedling emergence and establishment. At Dinner Station 1, however, a greater number of young plants occurred on the trampled than untrampled surface [24.4 vs. 20.9/2.7 ft^2 (0.25 m^2)]. The exclosure at Dinner Station 1 used for the untrampled sample had not been grazed for 40 years. A larger number of young plants on the trampled surface, in opposition with Elko 1 and Elko 2 results, suggests the vegetation stand inside the exclosure may represent a closed community with poor seedling establishment due to competitive effects not trampling effects.

No significant difference was detected in the density of young plants between Type II or Type III surfaces at the three sites regardless of trampling (Table 10). Trampling did not appear to affect the density of young plants on the Type II surface at Dinner Station 1. At the Elko 1 and

Table 9. Mean density [number/2.7 ft^2 (0.25 m^2)] of young plants at Dinner Station 1 (DS1), Elko 1 (EI), and Elko 2 (E2) in relation to a trampling treatment.

Site	Trampling Treatment	
	Untrampled	Trampled
EI	12.8*[1]	5.2
E2	11.4*	9.1
DS1	20.9*	24.4

[1] Asterisk indicates a significant difference between trampling treatments at the 95% probability level as determined by Student's t-test.

Table 10. Mean density [number 2.7 ft^2 (0.25 m^2)] of young plants at Elko 1 (E1), Elko 2 (E2), and Dinner Station 1 (DS1) in 1977 on Type II and Type III surfaces with and without cattle trampling.

Site and Trampling Treatment	Surface Type II	Surface Type III
E1		
Untrampled	8.4a[1]	8.5a
Trampled	3.4b	3.5b
E2		
Untrampled	6.9ac	6.0b
Trampled	4.9cd	4.7d
DS1		
Untrampled	8.5bc	7.4c
Trampled	9.2ab	12.0a

[1] Means within location followed by the same letter are not significantly different at the 95% probability level as determined by Student's t-test.

Elko 2 sites, however, significantly more young plants occurred on the untrampled Type II surface than on the adjacent trampled Type II surface.

Trampling had a significant effect on the density of young plants on the Type III surface at all sites. At the Elko 1 and Elko 2 sites trampling caused a decline in the density of young plants (Table 10). At Dinner Station 1, however, the trampling treatment had an opposite effect with more young plants on trampled Type III surface than on the adjacent untrampled surface. Again, this conflicting result may be due to the use of a 40-year-old exclosure for the untrampled comparison area at this site.

At all locations, except the trampled Type II surface at Elko 1 and the trampled Type III surface at Elko 1 and Elko 2, more young plants were found in the trench cracks of the Type II surface and cracks of the Type III surface than on adjacent pinnacle and polygon microsites of these surfaces (Table 11).

Trampling generally decreased emergence and establishment from trenched cracks of the Type II surface. Fewer young plants were found in the trampled trench cracks at Elko 1 and Elko 2 (2.6 and 3.5/2.7 ft^2 (0.25m^2, respectively) than in the adjacent untrampled trench cracks [7.2 and 6.6/2.7 ft^2 (0.25m^2), respectively] (Table 11). No significant difference was found at Dinner Station 1. Trampling slightly increased plant density on pinnacles of Type II surface at Elko 2 and Dinner Station 1 and slightly decreased density at Elko 1.

The location of young plants showed a similar pattern between untrampled and trampled Type III surface (Table 11). At Elko 1 and Elko 2, trampling caused a significant decline in the number of young plants in the cracks. At Elko 1, the mean number of young plants in the untrampled cracks was 7.4/2.7 ft^2 (0.25 m^2) and in the trampled cracks, 0.7/2.7 ft^2 (0.25m^2). At the Elko 2 site, the mean number of young individuals in the

Table 11. Mean density [number/2.7 ft^2 (0.25 m^2)] of young plants found in trench cracks and on pinnacles of the Type II surface or in cracks and on polygons of the Type III surface at Elko 1 (E1), Elko 2 (E2), and Dinner Station 1 (DS1) in 1977.

	Trampling Treatment			
	Untrampled		Trampled	
	Surface Type		Surface Type	
Site and Microsite	II	III	II	III
E1				
Trench crack/crack	7.2a[1]	7.4a	2.6b	0.7c
Pinnacle/polygon	1.7d	1.0d	0.6c	2.9b
E2				
Trench crack/crack	6.6a	5.7a	3.5b	2.1c
Pinnacle/polygon	0.1e	0.3e	0.8d	2.1c
DS1				
Trench crack/crack	8.2c	7.7bc	7.5ac	9.0ab
Pinnacle/polygon	0.4f	0.2f	1.5e	3.1d

[1] Means within location followed by the same letter are not significantly different at the 95% probability level as determined by Student's *t*-test.

untrampled cracks was 5.8/2.7 ft^2 (0.25 m^2) and in the trampled cracks 2.1/ 2.7 ft^2 (0.25 m^2)). This indicates that a trampling disturbance makes the crack microsite less desirable for seedling emergence. At Dinner Station 1 trampling had no affect on plant density on the crack microsite, but increased density on the polygon microsite.

These data suggest that the untrampled trench crack and crack microsites provide the more favorable environment for seed germination and for seedling emergence and establishment than does the trampled microsite. Trampling apparently reduces the suitability of the trench crack and crack microsites for seedling emergence probably by covering the seed with 2-3 cm of powdered soil that seals the seed inside the cracks after the soil is saturated and dries. Conversely, trampling increases plant density on the polygons, probably by planting seed into an otherwise smooth, hard surface.

Changes in the density of young plants was related to increases and decreases of individual species (Table 12). Density of all species was lower on the trampled area at Elko 1. This decline may be due to the presence of a water trough and heavier grazing than at Elko 2 and Dinner Station 1 sites. At Elko 2 all species declined under trampling except Wyoming big sagebrush, which remained constant, and forbs which increased from 39 to 57/269 ft^2 (25 m^2). Desert phlox showed a large decline, however, the change was not statistically significant. The trampled Dinner Station 1 site showed an increase in young big sagebrush from 4 to 14/269 ft^2 (25 m^2), squirreltail from 405 to 558/269 ft^2 (25 m^2), and desert phlox from 1232 to 1420/269 ft^2 (25 m^2). Sandberg bluegrass density decreased from 153 to 102/269 ft^2 (25 m^2).

Several factors should be kept in mind when interpreting these results. First, grazing and trampling intensity the year prior to sampling was not evaluated and may not have been equivalent at all three sites.

Table 12. Mean density [number/269 ft^2 ($25m^2$)] of young plants at Elko 1 (E1), Elko 2 (E2), and Dinner Station (DS1) on untrampled (untr) and trampled (tr) surfaces in 1977.

	Site					
	E1		E2		DS1	
	Trampling Treatment					
Species[1]	untr	tr	untr	tr	untr	tr
ARTRWY	24*[2]	10	21	23	4*	14
CHVI	-	1	-	-	1	3
SIHY	383*	172	104*	75	405*	558
ELCI	-	-	-	-	17*	0
STTH	-	-	106*	79	2	-
POSA	64*	39	77	71	153*	102
ORHY	-	-	2	13	-	-
PHAU	3	-	765	607	1232*	1420
LOMAT	578*	188	-	-	152	148
Forbs	40*	13	39*	57	85	77

[1] See Appendix 4 for key to species symbols.

[2] Asterisk indicates a significant difference at the 95% probability level between trampling treatments within a species and within a site as determined by the Chi square test of independence.

Second, use of a closed community for comparison at Dinner Station 1 may have caused results that conflict with the other two sites. Third, the low density of seedlings and clumped distribution of young plants that resulted from the drought year of 1976-1977 made adequate sampling of the individual species difficult. Also, it is impossible to compare results of a sample of young plants in 1977 with results of a sample of seedlings in 1978.

1978 Natural Population Sampling

Higher precipitation in the winter and spring of 1977-1978 resulted in a high density of seedlings on the study areas. Therefore, only seedlings of perennial plants and annual forbs were sampled at Dinner Station 2, Jiggs 2, and Elko 1.

Field observations made when the study sites were selected suggested that seedling populations varied with kind and amount of grasses, forbs, and shrubs present, and with the surface type present. Therefore, data from natural seedling populations were interpreted in relation to differences in range condition.

In order to separate data from these sites in text and tables, each was given an arbitrary range condition rank based on basal cover of perennial grass and presence and abundance of desirable and undesirable species. Dinner Station 2 was rated in the best condition of the three because of high grass cover and the presence of two desirable perennial forbs, tapertip hawksbeard, and biscuitroot. Jiggs 2 also has a high grass cover but was rated below Dinner Station 2 because of the large amount of rabbitbrush, and weedy annual forbs. Elko 1 was rated in the lowest condition because of low grass cover, some rabbitbrush, and weedy annual forbs. In the text and tables, Dinner Station 2 is called "good condition," Jiggs 2, "fair condition," and Elko1, "poor condition." "Condition" used in this context is not necessarily the same as "condition used by the Soil Conservation Service's range site and condition guides.

The mean number of seedlings on the untrampled and trampled areas at the good condition site (DS2) was similar (Table 13). As conditions declined, however, more seedlings were found on the trampled surface than on the untrampled surface and most of these were seedlings of Wyoming big sagebrush. The number of seedlings on the Type II and Type III surfaces at the good condition site was similar regardless of trampling, but more seedlings were present on the trampled surfaces at the lower condition sites (Table 14).

On the untrampled areas at Dinner Station 2 and Jiggs 2, the good and fair condition sites, more seedlings were found in the trench cracks of the Type II surface and cracks of the Type III surface than on adjacent pinnacle and polygon microsites (Table 15.) Also, more seedlings were found in trench cracks of Type II surface at both locations than in the cracks of the Type III surface. Seedling density on polygons and pinnacles was similar at Dinner Station 2 but was higher on the pinnacles at Jiggs 2. At Elko 1, the poor condition site, most of the seedlings emerged from the pinnacle and polygon microsites with more seedlings on the pinnacles. Seedling density was higher in the trench cracks of Type II surface than in the cracks of Type III surface.

The number of seedlings on microsites at the good condition site was not significantly increased by trampling (Table 15). At the fair condition site, Jiggs 2, trampling had no effect on the number of seedlings in cracks of the Type III surface but decreased seedling density in the trench cracks of the Type II surface. The pinnacle and polygon microsites, however, had significantly more seedlings after trampling. At the poor condition site most of the seedlings were found on the pinnacle and polygon microsites. Trampling had

Table 13. Mean density [number/1 ft^2 (0.09 m^2)] of seedlings at Dinner Station 2 (DS2), Jiggs 2 (J2), and Elko 1 (E1) in 1978 in relation to cattle trampling.

		Trampling Treatment	
Site	Condition	Untrampled	Trampled
DS2	Good	26.6	27.7
J2	Fair	24.1*[1]	42.1
E1	Poor	59.4*	81.0

[1] Asterisk indicates a significant difference between trampling treatments at the 95% probability level as determined by Student's t-test. Comparisons are made within site.

Table 14. Mean density [number/1 ft^2 (0.09)] of seedlings at Dinner Station 2 (DS2), Jiggs 2 (J2), and Elko 1 (E1) in 1978 on Type II and Type III surfaces in relation to cattle trampling

Site and Trampling Treatment	Surface Type II	Surface Type III
DS2 (Good Condition)		
Untrampled	14.1bc[1]	12.7c
Trampled	15.0ab	12.5bc
J2 (Fair Condition)		
Untrampled	14.5c	9.7d
Trampled	24.9a	17.7b
E1 (Poor Condition)		
Untrampled	36.9ab	22.6c
Trampled	45.9a	33.9b

[1] Means within location followed by the same letter are not significantly different at the 95% probability level as determined by Student's t-test.

Table 15. Mean density [number/1 ft^2 (0.09 m^2)] of seedlings in trench crack and on pinnacles of Type II surface or in cracks and on polygons of the Type III surface at Dinner Station 2 (DS2), Jiggs 2 (J2), and Elko 1 (E1) in 1978.

	Trampling Treatment			
	Untrampled		Trampled	
Site, Range Condition,	Surface Type		Surface Type	
and Microsite	II	III	II	III
DS2 (Good Condition)				
Trench crack/crack	11.8a[1]	8.6b	11.9a	6.5bc
Pinnacle/polygon	1.9d	3.9cd	3.1d	6.3bc
J2 (Fair Condition)				
Trench crack/crack	11.6c	7.3d	10.3a	6.4d
Pinnacle/polygon	2.9e	2.5f	14.8a	12.5b
E1 (Poor Condition)				
Trench crack/crack	8.9d	6.7e	7.2d	5.2f
Pinnacle/polygon	27.9a	15.9c	38.9a	28.0b

[1] Means within location followed by the same letter are not significantly different at the 95% probability level as determined by Student's t-test. Comparisons are made within a surface type and between grazing treatments within a surface type and microsite.

no significant effect on the seedling density on either microsite of the Type II surface, but increased seedling density on both microsites of the Type III surface.

These results show that seedling emergence varies with the kind of microsite and the presence of a trampling disturbance. Trampling evidently makes the pinnacle and polygon microsite much more suitable for seedling emergence on the fair and poor condition sites, but has little or no effect on the suitability of trench cracks of Type II surface or cracks of Type III surface at any site.

Changes in seedling density due to trampling were related to increases and decreases in individual species (Table 16). At Dinner Station 2, the good condition site, squirreltail, Sandberg bluegrass, and desert phlox seedlings increased with trampling, while sagebrush, Nevada onion, biscuitroot, and tapertip hawksbeard declined. Generally, the small annual forbs decreased in number after trampling, but gilia increased significantly.

At the fair condition site, big sagebrush seedlings increased from 787 to 1804/96.8 ft^2 (9 m^2) and basin wildrye declined from 600 to 459 individuals. Squirreltail and Sandberg bluegrass were present only in very low numbers. In general, the small annual forbs, except groundsmoke, increased on the trampled area (Table 16).

At Elko 1, the poor condition site, big sagebrush seedlings increased drastically from 4814/96.8 ft^2 (9 m^2) on the untrampled area to 7114/96.8 ft^2 (9 m^2) on trampled surface (Table 16). Desert phlox, Sandberg bluegrass and Nevada onion decreased with trampling and squirreltail was unchanged. The annual species groundsmoke and tansy mustard increased while gilia and cryptantha decreased with trampling.

Results show that the density of sagebrush seedlings increased as range condition declined, regardless of trampling treatment. There are four possi-

Table 16. Species showing an increase, decrease, or no change in seedling density [number/96.8 ft^2 (9m^2)] at Dinner Station (DS2), Jiggs 2 (J2), and Elkol (E1) on untrampled (untr) and trampled (tr) surfaces in 1978.

Site and Range Condition	Increasing Species[1]	untr	tr	Decreasing Species	untr	tr	No Change	untr	tr
DS2 (Good)	SIHY	70*[2]	177	ARTRWY	117*	96	-	-	-
	POSA	56*	302	ALNE	173*	65	-	-	-
	PHAU	221*	579	COPA	1012*	808	-	-	-
	GITR	18*	202	MICRO[4]	587*	261	-	-	-
				LOMAT	119*	61	-	-	-
				CRAC	108*	48	-	-	-
J2 (Fair Condition)	ARTRWY	787*	1804	ELCI	600*	459	-	-	-
	CRGR	137*	256	GARA	243*	55	-	-	-
	DERI	197*	589	-	-	-	-	-	-
	COPA	129*	162	-	-	-	-	-	-
	RATE	48*	632	-	-	-	-	-	-
E1 (Poor Condition)	ARTRWY	4814*	7114	POSA	87*	50	SIHY	60	72
	GARA	117*	142	PHAU	221*	114	-	-	-
	DERI	36*	68	ALNE	85*	22	-	-	-
				GITR	274*	185	-	-	-
				CRGR	93*	45	-	-	-

[1] See Appendix 4 for key to species symbols.

[2] Asterisk indicated a significant difference at the 95% probability level between the number of seedlings on untrampled and trampled surfaces as determined by the Chi square test of independence.

ble explanations for this large density at the poorer condition sites. First, there is an abundance of sagebrush seed and a relatively small amount of perennial grass seed present at the poor condition sites. A second reason may be that certain species emerge better under specific microenvironmental conditions provided by different microsites. Third, trampling may alter these microsites making them a more favorable location for emergence and establishment of some species and less favorable for other species. These favorable microenvironments are most likely based on several factors including seed size, moisture and temperature requirements, crust hardness, and emergence forces of seedlings. Fourth, sagebrush seedlings may be able to germinate more successfully under reduced competition on a poor condition site than under intense competition of a closed community represented by a higher condition site. For example, at the good condition site, more big sagebrush seedlings occur on Type III surface rather than on the Type II surface regardless of trampling (Table 17). This may be a result of competition from the perennial grasses on the Type II surface of a good condition site compared with reduced competition on the less well vegetated Type III surface. As condition declines, fewer perennial grasses are present, competition on the Type II surface is reduced, and there is more opportunity for germination, emergence, and establishment of other species. For instance, at Jiggs 2 (Table 18) and Elko 1 (Table 19), the fair and poor condition sites, more young sagebrush plants occurred on the Type II than on the Type III surface in both untrampled and trampled areas. This suggests that the Type II surface is more suitable microenvironment for sagebrush emergence on fair and poor condition sites. In addition, trampling seems to enhance the suitability of these microsites for sagebrush emergence. On the Type II surface

Table 17. Mean seedling density [number/96.8 ft^2 (9 m^2)] of species in 1978 on untrampled and trampled Type II and III surface types at Dinner Station 2 (good condition).

Species[1] and Surface Type		Trampling Treatment	
		Untrampled	Trampled
ARTRWY	II	32a[2]	31a
	III	85*[3]	65
SIHY	II	54a*	11a
	III	16*	66
POSA	II	37a*	114
	III	19	188
PHAU	II	96a*	359a
	III	125*	220
ALNE	II	73a*	30
	III	100*	35
GITR	II	11*	100
	III	7*	102
COPA	II	669*	481
	III	343	327
MICRO[4]	II	228a*	131
	III	359	130
LOMAT	II	53*	27
	III	66*	34

1 See Appendix 4 for key to species symbols.

2 The letter "a" indicates a significant difference at the 95% probability level between surface type as determined by the Chi square test of independence.

3 Asterisk indicates significant difference at the 95% probability level between trampling treatments as determined by Student's t-test.

Table 18. Mean seedling density [number/96.8 ft^2 ($9m^2$)] of species in 1978 on untrampled and trampled Type II and III surface types at Jiggs 2 (fair condition).

Species[1] and Surface Type		Trampling Treatment	
		Untrampled	Trampled
ARTRWY	II	483a[2]	1190a
	III	304*[3]	614
ELCI	II	269a*	239
	III	331*	220
GARA	II	174a*	37a
	III	69*	18
CRGR	II	60*	149
	III	77*	107
DERI	II	143a*	369
	III	54*	220
COPA	II	85*	103
	III	44*	59
RATE	II	20*	218
	III	28*	414

[1] See Appendix 4 for key to species symbols.

[2] The letter "a" indicates a significant difference at the 95% probability level between surface type as determined by the Chi square test of independence.

[3] Asterisk indicates significant difference at the 95% probability level between trampling treatments as determined by Student's t-test.

Table 19. Mean seedling density [number/96.8 ft^2 ($9m^2$)] of species in 1978 on untrampled and trampled Type II and III surface types at Elko 1 (poor condition).

Species[1] and Surface Type		Trampling Treatment	
		Untrampled	Trampled
ARTRWY	II	3000a[2]	4076a
	III	1814*[3]	3038
SIHY	II	42a	50a
	III	16	22
POSA	II	65a*	31a
	III	22	19
ALNE	II	39*	6
	III	45*	16
PHAU	II	96a*	56a
	III	125*	6
GITR	II	224a*	135a
	III	50	50
CRGR	II	67*	23
	III	26	22
DERI	II	28a	51a
	III	8	17
GARA	II	96a	91a
	III	21*	51

1 See Appendix 4 for key to species symbols.

2 The letter "a" indicates a significant difference at the 95% probability level between surface type as determined by the Chi square test of independence.

3 Asterisk indicates significant difference at the 95% probability level between trampling treatments as determined by Student's t-test.

at both the fair and poor condition sites, more individuals emerged on the trampled surface [J2, 1190; E1, 4076/96.8 ft^2 (9 m^2)] than the untrampled surface (J2 3000; E1 483). The Type III surface showedthe same response.

Seedling of native species varied with microsites (trench cracks, cracks, or pinnacles, and polygon surfaces). At the good condition site, most sagebrush seedlings emerged from the untrampled trench cracks (Table 20). With trampling the number of sagebrush seedlings was similar on Type II microsites, but significantly more seedlings grew on the polygons than in the cracks of Type III surface.

The untrampled, fair condition site had more sagebrush seedlings in the trench cracks of Type II surface and similar seedling density in the cracks of Type III when compared with the pinnacle and polygon microsites (Table 21). Trampling of the Type II and Type III surfaces on fair condition site significantly increased the number of young individuals on the pinnacle and polygon microsites compared with the trench cracks and cracks. The moss and lichen cover on untrampled Type II pinnacle surfaces may have prevented contact of sagebrush seed with mineral soil and reduced germination. Trampling may also increase emergence of sagebrush seedlings on crusted surfaces by planting seed in soil. The position of the seed is stabilized and the chance to rolloff or be washed off the surface into adjacent cracks is reduced.

At the poor condition site, Elko 1, significantly more sagebrush seedlings occurred on both the pinnacle and polygon surfaces regardless of trampling treatments (Table 22). Perhaps, at this site even the untrampled Type II and Type III surfaces are bare and lack competitive vegetation and provide a suitable microclimate for seedling emergence and establishment.

Table 20. Mean seedling density [number/96.8 ft^2 ($9m^2$)] of species found in 1978 in trench crack and on pinnacle microsites of Type II surface and in crack and on polygon microsites of Type III surface in relation to trampling treatments at Dinner Station 2 (good condition).

		Trampling Treatment			
		Untrampled		Trampled	
		Surface Type			
Species[1]	Microsite	II	III	II	III
ARTRWY	- Trench crack/crack	25a[2]	56a*[3]	15	4a
	Pinnacle/polygon	7*	29*	16	61
SIHY	- Trench crack/crack	52a*	12a*	85a	38a
	Pinnacle/polygon	2*	4*	26	28
POSA	- Trench crack/crack	35a*	17a*	90a	57a
	Pinnacle/polygon	2*	2*	24	131
PHAU	- Trench crack/crack	89a*	120a*	342a	196a
	Pinnacle/polygon	7	5	13	24
ALNE	- Trench crack/crack	59a*	51a*	12	15
	Pinnacle/polygon	14	49*	18	20
COPA	- Trench crack/crack	584a*	245a*	342a	163
	Pinnacle/polygon	80*	98*	139	164
MICRO[4]	- Trench crack/crack	182a*	200a*	103a	61
	Pinnacle/polygon	46*	159*	28	69
LOMAT	- Trench crack/crack	47a*	52a*	26a	25a
	Pinnacle/polygon	6	14	7	9
CRAC	- Trench crack/crack	38a*	56a*	21a	13a
	Pinnacle/polygon	2	12	7	7
GITR	- Trench crack/crack	2*	4*	81a	30a
	Pinnacle/polygon	9*	3*	19	72

[1] See Appendix 4 for key to species symbols.

[2] The letter "a" indicates a significant difference between trench/crack and pinnacle/polygon microsites within a grazing treatment and species at the 95% probability level as determined by the Chi square test of independence.

[3] Asterisk indicates a significant difference between grazing treatments within a microsite and a species at the 95% probability level as determined by the Chi square test of independence.

Table 21. Mean seedling density [number/96.8 ft^2 ($9m^2$)] of species found in 1978 in trench crack and on pinnacle microsites of Type II surface in relation to trampling treatments at Jiggs 2 (fair condition).

		Trampling Treatment			
		Untrampled		Trampled	
		Surface Type			
Species[1]	Microsite	II	III	II	III
ARTRWY	- Trench crack/crack	327a*	152*	243a	57a
	Pinnacle/polygon	156*	152*	947	557
ELCI	- Trench crack/crack	256a*	302a*	212a	178a
	Pinnacle/polygon	13*	24*	27	42
GARA	- Trench crack/crack	139a*	46*	3a	9
	Pinnacle/polygon	35	23*	34	9
CRGR	- Trench crack/crack	48a*	59*	122a	61a
	Pinnacle/polygon	12*	18*	27	46
DERI	- Trench crack/crack	127a*	45a*	160a	178a
	Pinnacle/polygon	16*	9*	209	42
COPA	- Trench crack/crack	80a	41a	66a	39a
	Pinnacle/polygon	5*	3*	37	20
RATE	- Trench crack/crack	15a*	23a*	105	101a
	Pinnacle/polygon	5*	5*	113	313

1 See Appendix 4 for key to species symbols

2 The letter "a" indicates a significant difference between trench/crack and pinnacle/polygon microsites within a grazing treatment and species at the 95% probability level as determined by the Chi square test of independence.

3 Asterisk indicates a significant difference between grazing treatments within a microsite and a species at the 95% probability level as determined by the Chi square test of independence.

Table 22. Mean seedling density [number/96.8 ft^2 (9m^2)] of species found in 1978 in trench crack and on pinnacle microsites of Type II surface and in crack and on polygon microsites of Type III surface in relation to trampling treatments at Elko 1 (poor condition).

		Trampling Treatment			
		Untrampled		Trampled	
		Surface Type			
Species[1]	Microsite	II	III	II	III
ARTRWY	- Trench crack/crack	479a[2*3]	341a	399a	356a
	Pinnacle/polygon	2651*	1473*	3677	2862
SIHY	- Trench crack/crack	83a	13a	33a	15a
	Pinnacle/polygon	9	3	17	7
POSA	- Trench crack/crack	59a*	18a	25a	11
	Pinnacle/polygon	6	4	6	8
ALNE	- Trench crack/crack	20*	12a	4	7
	Pinnacle/polygon	19*	34*	2	9
GARA	- Trench crack/crack	31a	11	30a	18a
	Pinnacle/polygon	65	10*	61	33
PHAU	- Trench crack/crack	90a*	106a*	49a	53a
	Pinnacle/polygon	6	19*	9	3
GITR	- Trench crack/crack	177a*	28	72	28a
	Pinnacle/polygon	47	22*	63	2
CRGR	- Trench crack/crack	35*	17a*	12	5a
	Pinnacle/polygon	32*	9	11	17
DERI	- Trench crack/crack	21a	5a	27	4a
	Pinnacle/polygon	7*	19	24	13

1 See Appendix 4 for key to species symbols.

2 The letter "a" indicates a significant difference between trench/crack and pinnacle/polygon microsites within a grazing treatment and species at the 95% probability level as determined by the Chi square test of independence.

3 Asterisk indicates a significant difference between grazing treatments within a microsite and a species at the 95% probability level as determined by the Chi square test of independence.

Sagebrush seed apparently requires a very moist winter and spring for successful germination and emergence. This requirement is evidenced by the low number of sagebrush seedlings [1.4/10.8 ft^2 (1 m^2)] at Elko 1 in 1977, a drought year compared to 1325/10.8 ft^2 (1 m^2) in 1978, a wet year. The relation between the trampling response on polygon surfaces and precipitation is an important consideration. Although trampling of polygon surfaces may plant seed in an otherwise hard, smooth surface, emergence will be very poor unless the crust is kept moist by spring precipitation.

Emergence of perennial grass seedlings also varied with trampling treatment and microsite. More squirreltail seedlings emerged from the untrampled than the trampled Type II surface at Dinner Station 2 (Table 17). Without trampling, seedling density was higher on the Type II surface than on the Type III surface. With trampling, more seedlings emerged on the Type III surface. Sandberg bluegrass showed the same trend except that the difference in seedling density between trampled and untrampled surface types was not significant. Regardless of trampling treatment or surface type, density of squirreltail seedlings was always greater in the trench cracks and cracks compared with pinnacle or polygon surfaces (Table 20). Density of Sandberg bluegrass seedlings was also greater in the trench cracks and cracks of the untrampled Type II and III surfaces and trampled Type II than on the pinnacles and polygons, but the trampled Type III polygon surface supported the highest seedling density of this species.

At Jiggs 2, the density of basin wildrye seedlings and tillers on the untrampled Type II and III surfaces was similar. More plants were found on the untrampled trenched crack and crack microsites, but on the trampled area more plants were found on the pinnacle and polygon microsites. More basin wildrye seedlings and tillers emerged from the trench cracks and cracks than from the pinnacles and polygon microsites regardless of trampling treatment (Table 21).

Elko 1, the poor condition site, had higher emergence of both squirreltail and Sandberg bluegrass seedlings on Type II surface regardless of trampling (Table 19). Also emergence of these species was greater in the trench cracks and cracks than on the pinnacle and polygon surfaces regardless of trampling (Table 22).

Desert phlox is the major perennial forb at Elko 1 and Dinner Station 2. At these sites more seedlings of this species were found on the untrampled Type III surface than on the untrampled Type II surface while the reverse was true on trampled areas (Tables 17 and 19). However, more seedlings were found on trampled areas of both surfaces at the good condition site, while most of the seedlings on the poor condition site were found on the untrampled condition. Emergence of phlox was also greater in the trench cracks and cracks than on the pinnacle and polygon microsites at both these locations regardless of trampling Tables 20 and 22).

A general trend for annual forbs was evident at all three sites. More seedlings emerged in the Type II than Type III surfaces (Tables 17, 18, and 19), and most species emerged best in the environment provided by the trench cracks and cracks than by the pinnacle or polygon surfaces (Tables 20, 21, and 22). Three exceptions were noted. Nutty ranunculus grew best on trampled Type III polygon surface. *Microsteris* spp. grew best in the trench cracks and cracks of untrampled Type II and Type III surfaces. Tansy mustard followed the general trend except more individuals grew on the pinnacles than in the trench cracks of the trampled Type II surface.

Establishment of seedlings from the simulated trampling treatment appears to be largely dependent on available moisture the summer after emergence. Seedlings that emerged in 1977, the drought year, died early in the spring. Most seedlings emerging in the spring of 1978, a wet year, survived until the middle of summer, and a few survived until the fall. There was no apparent relationship between survival and microsite of emergence.

Measurements of natural population of seedlings and young plants again indicated that establishment is dependent on available moisture the summer after emergence. Most seedlings had died as early as June in 1977. Many young plants, however, were observed in June-July of 1978 but most had died by August. Despite the very high emergence of sagebrush at the Elko 1 site in 1978, very few (if any) seedlings survived through August. Spring emergence and establishment during the summer and fall probably is not the mechanism for plant recruitment except in very unusual years. In a related study, emergence occurred in the fall in response to a precipitation event. Establishment of the plants during the fall when competing vegetation is dormant may be a mechanism for plant recruitment.

CONCLUSIONS

Many factors are involved in the successful reproduction and establishment of plant species. These factors include: 1) site condition which determines the species present, their abundance, and the degree of competition from established vegetation; 2) the characteristics and extent of microsites that provide environments suitable for the germination, emergence, and establishment of different species; 3) the impact of an environmental disturbance such as cattle trampling that destroys existing microenvironments and creates new microenvironments; and 4) the amount and time of precipitation. These factors and others (temperature, available nutrients, the presence of seed-eating rodents, etc.) play interacting parts in natural revegetation.

This study investigated the influence of surface soil types, microsite differences, range conditions, and trampling effects on natural revegetation. Results obtained lead to the following conclusions:

1. Crusted soil surfaces do not restrict seedling emergence if moisture tension is low. If crusted surfaces are saturated or

dry, emergence is greatly reduced. Results after 2 years showed that emergence of native species from crusted surface ranged from 4 to 14% in the dry year of 1977, and from 70 to 85% in the wet year of 1978.

2. Species emergence varied on different surface types. Results of the hand-planted seed and simulated trampling study showed that emergence of crested wheatgrass and squirreltail was sufficient for stand regeneration only on the Type I surface in the dry year of 1977. In the wet year of 1978, emergence of the two species was sufficient to increase stand density on two of five sites. Emergence of Thurber needlegrass was sufficient for stand regeneration only at one site in 1978.
3. In natural populations, the kind of surface type did not influence the number of young plants of native species present in 1977. In 1978, the number of seedlings of native species was influenced by surface type with more seedlings on the Type II surface.
4. Species emergence was influenced by the kind of microsite present. The number of trench cracks and cracks and pinnacle and polygon surfaces at a site determines the species composition of emerged seedlings and theoretically the species composition of established plants. More sagebrush plants were found on the untrampled Type III polygon surface of low condition sites, while perennial grasses and perennial and annual forbs were found mostly in trench cracks of Type II surface regardless of trampling.
5. Trampling changes surface morphology and results in different microenvironmental conditions for seedling emergence. It may, in combination with grazing, destroy lichen, moss, and perennial grass

cover and make new microenvironments more suitable for other species. Trampling also increases emergence of seedlings from polygon surfaces probably by planting seed in the otherwise smooth, hard surface. At the same time, trampling reduced the suitability of the trench crack and crack microsites for emergence of sagebrush perhaps by covering the seed deeply with soil. These responses are related to range condition and appear to influence trend in range condition.

6. A trampling disturbance may result in permanent changes in soil-surface morphology and permanently alter the kind and amount of specific microenvironments available for seedling emergence. A decrease in the amount of trench crack of Type II surface and an increase in the amount of crusted Type III surface occurs with trampling. As a result, species that emerge best on the Type III polygon surface microsite would be expected to increase, for example, sagebrush. Those species that emerge best in the Type II trench crack microsite, such as perennial grasses, would be expected to decline in density as the amount of Type II surface is reduced.

FIELD APPLICATION

Implications for range management as a result of this study apply only to the Wyoming big sagebrush/grass vegetation type with vesicular-structured, polygonal crusted soils and managed by a grazing plan that includes cattle grazing to shatter and plant seed.

1. Minimize heavy trampling of soils that have a tendency to slake when wet and to form crusts when dry.

2. Implement management first on sites with a minimum amount of Type III and IV surfaces.
3. Implement management first on areas with remnants of desirable perennial grasses and forbs.
4. Trampling low condition sites will lead only to an increase in Wyoming big sagebrush.
5. Supplying seed of adapted native species on poor condition ranges may be a method of increasing the density of desirable species.
6. Graze after seed drop to cover seed in cracks. Trampling too early will fill cracks and reduce the amount of favorable microsites.
7. In predicting a response to management, expect better results on surfaces with trench crack and crack microsites than on smooth polygon surfaces.
8. Select study plots to represent all surface types and microsites in order to fully evaluate results of grazing treatments.
9. Recruitment of desirable perennial plants on crusting soils through natural revegetation or with supplemental seeding will be a very slow process except in very wet years.

Appendix 1. Site description of the nine study areas including site name and symbol, location, approximate elevation, soil classification and, percent cover of soil-surface types.

Site Name	Symbol	Location	Approximate Elevation - feet (meters)	Soil Classification	Percent Cover of Soil Surface Types I	II	III	IV
Paradise Valley	PV	NE¼ of Sec. 3	4494 (1370)					
Untrampled		T40N R39E		fine, montmorillonitic, mesic, Xerollic Nadurargid	22.1	41.2	30.3	6.4
Trampled					25.4	28.8	41.7	4.5
Lower Coils Creek	LCC	SW¼ of Sec. 21	6396 (1950)	fine, montmorillonitic, mesic, Xerollic Duragrid				
Trampled		T11N R49E			33.0	13.4	45.1	8.5
Panther Canyon	PC	SE¼ of Sec. 14	5510 (1680)	fine-loamy, montmonrillonitic, mesic, Xerollic Durorthid				
Trampled		T31N R39E			36.2	23.6	40.2	0.0
Jiggs 1	J1							
Untrampled		T33N R56E	5117 (1560)	fine-loamy, montmorillonitic, mesic, Xerollic Duragrid	45.6	29.6	33.0	1.7
Jiggs 2	J2							
Untrampled		T29N R55E	5576 (1700)	fine-loamy, montmorillonitic, mesic, shallow Xerollic Durothid	33.7	28.7	37.6	0.0
Trampled					29.8	22.6	39.9	7.7
Dinner Station 1	DS1							
Untrampled		T37N R54E	5904 (1800)	fine, montmorillonitic, mesic, Durixerollic Haplargid	32.9	53.4	14.7	0.1
Trampled					38.5	28.9	32.3	0.5
Dinner Station 2	DS2							
Untrampled		T37N R45E	5904 (1800)	fine, montmorillonitic, mesic, Durixerollic Haplargid[1]	35.4	43.4	21.2	0.0
Trampled					39.0	34.9	26.1	0.0
Elko 1	E1							
Untrampled		T38N R54E	5904 (1800)	fine, montmorillonitic, mesic, Xerollic Haplargid	27.2	41.0	28.3	3.5
Trampled					28.9	37.3	32.7	1.9
Elko 2	E2							
Untrampled		T38N R43E	5904 (1800)	coarse-loamy, montmorillonitic, mesic, Xerollic Duragrid	24.9	50.2	25.0	0.0
Trampled					17.4	35.0	46.6	0.0

[1] Similar to DS1 by inference.

Appendix 2. Illustrative pedon of the fine, montmorillonitic, mesic, Xerollic Nadurargid at the Paradise Valley Site.[1,2]

Physiograph Position: dissected alluvial fan

Horizon	Depth cm	Color		Texture	Structure	Consistence			1:5 pH	$CaCO_3$	Roots	Boundary	Coarse Fragments % vol.
		Dry	Moist			Dry	Moist	Wet					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
A11v[3]	0-6	2.5Y 6/2	2.5Y 4/2	sil	m	sh	fr	so/ps[4]	8.6	eo	1	aw	<3
A12	6-17	2.5Y 7/2	2.5Y 5/2	sil	3fpl	sh	fr	so/ps[4]	8.6	eo	1	as	<2
A2	17-25	2.5Y 7/2	2.5Y 5/2	sil	1csbk	sh	fr	so/ps[4]	8.7	eo	1	as	<2
B21t	25-49	10YR 6/3	10YR 4/3	cl+	1mpr & 3msbk	h	fi	vs/p	9.0	eo	2	cw	8
B22tca	49-78	10YR 6/3	10YR 5/4	c	3mpr & 3msbk	h	fi	vs/vp	9.3	e	1	as	10
B3ca	78-88	10YR 7/3	10YR 5/4	cl+	2m-fsbk	sh	fr	vs/p	9.1	es	0	as	15
C1sicam	88-102+	2.5Y 8/2 & 2.5Y 6/3	...	...	1cpl	cw	...	...	8.9	ev	0	...	20

[1] A trampled Type III surface.
[2] See key to morphological abbreviations at the end of this appendix.
[3] The upper 2-3 cm of the A11v horizon is massive and nonvesicular due to trampling. The remainder 0.5-1 mm vesicular pores.
[4] Exhibits pronounced dilatency when saturated.

Appendix 2. Illustrative pedon of the fine, montmorillonitic, mesic, Xerollic Durargid at the Lower Coil's Creek Site.[1,2]
Physiographic Position: alluvial fan remnant

Horizon	Depth cm	Color Dry	Color Moist	Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	1:5 pH	$CaCO_3$	Roots	Boundary	Coarse Fragments % vol.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
A11v[3]	0-4	2.5Y 6/2	2.5Y 4/2	l	m	vsh	fr	so/ps	7.7	eo	0	as	<5
A12	4-16	10YR 6/3	10YR 4/3	l	1vfpl & 2vfsbk	sh	fr	ss/p	7.8	eo	1	as	<5
A2	16-32	10YR 6/4	10YR 4/3	l+	1cpr & 1fsbk	sh	fr	s/p	8.2	eo	1	vaw	<5
B21t	32-54	7.5YR 6/4	7.5YR 4/6	c	2mcpr & 3fabk	h	fi	vs/vp	8.4	eo	1	cw	<5
B22t	54-71	10YR 6/5	10YR 5/4	c	2fabk	h	fi	vs/vp	8.6	e	1	cw	10
B23tca	71-81	10YR 6/5	10YR 5/4	cl	1fabk	h	fi	vs/vp	8.9	e	1	vai	30
C1sicam	81-91+	10YR 8/4	10YR 6/4	...	m	cs	...	...	9.1	ev	-[4]	...	50

[1] Type III soil surface.
[2] See key to morphological abbreviations at end of this appendix.
[3] Has many about 0.5-1mm vesicular pores.
[4] Root mat on top of duripan.

Appendix 2. Illustrative pedon of fine-loamy, montmorillonitic, mesic, Xerollic Durorthid at the Panther Canyon site.[1,2]

Physiographic Position: dissected alluvial fan

Horizon (1)	Depth cm (2)	Color: Dry (3)	Color: Moist (4)	Texture (5)	Structure (6)	Consistence: Dry (7)	Consistence: Moist (8)	Consistence: Wet (9)	pH (10)	$CaCO_3$ (11)	Roots (12)	Boundary (13)	Coarse Fragments % vol (14)
A11v	0-5	2.5Y 7/2	10YR 3/3	sil	2vcpl	sh	vfr	ss ps	7.5	eo	1vf, 1f	as	< 1%
A12	5-17	10YR 7/2	10YR 4/3	sil	2csbk	so	vfr	ss p	7.8	eo	2vf,2f	gs	< 1%
B21	17-32	10YR 7/3	10YR 5/3	sil	2csbk	so	vfr	ss p	8.0	eo	2f,2m,1co	gs	< 3%
B22	32-70	10YR 7/3	10YR 5/3	l	2msbk	h	fi	so ps	8.2	es	2f,2m, 1co	cw	5%
C1cam	70-82+	...	...	...	duripan	vh	vfi	so po	8.2	ev	1f,1m	...	5%

1 An untrampled Type III surface

2 See key to morphological abbreviations at the end of this appendix.

Appendix 2. Illustrative pedon of the fine, loamy, montmorillontic, mesic, Xerollic Durargid at the Jiggs 1 site.[1,2]

Physiographic Position: broadly dissected alluvial fan

Horizon (1)	Depth cm (2)	Color Dry (3)	Color Moist (4)	Texture (5)	Structure (6)	Consistence Dry (7)	Consistence Moist (8)	Consistence Wet (9)	pH (10)	$CaCO_3$ (11)	Roots (12)	Boundary (13)	Coarse Fragments % vol (14)
A11v	0-5	2.5Y 2/2	10YR 5/3	sl	2cpl	sh	vfr	ss ps	7.4	eo	1vf	as	< 1%
A12	5-10	10YR 7/2	10YR 4/3	sil	3vcpl&2vfpl	so	vfr	ss po	7.5	eo	2vf,2f	as	<1%
B21	10-23	10YR 7/3	10YR 5/3	l	2csbk	sh	fr	ss ps	7.8	eo	2f,1co	cw	<1%
B22	23-33	10YR 7/3	10YR 4/4	l	2msbk	so	vfr	ss ps	8.0	eo	2f, 2m	as	< 1%
B3t	33-43	10YR8/4	10YR 5/4	scl	2cpr	vh	fi	ss ps	8.0	ev	2f,2m	gs	3%
C1cam	43-63	10YR 8/2	10YR 8/4	duripan	2mabk	vh	vfi	... ...	8.1	ev	1m	gw	...

1 An untramped Type III surface.
2 See key to morphological abbreviations at the end of this appendix.

Appendix 2. Illustrative pedon of fine, loamy, montmorillonitic, mesic, shallow Xerollic Durorthid at the Jiggs 2 site.[1,2]

Physiographic Position: sideslope of dissected alluvial fan remnant

Horizon (1)	Depth cm (2)	Color Dry (3)	Color Moist (4)	Texture (5)	Structure (6)	Consistence Dry (7)	Consistence Moist (8)	Consistence Wet (9)	pH (10)	$CaCO_3$ (11)	Roots (12)	Boundary (13)	Coarse Fragments % vol (14)
A11v	0-5	10YR 6/3	10YR 5/3	sil	m&2mv	sh	fr	ss sp	7.2	eo		as	10%
A11	5-8	10YR 6/4	10YR 4/4	sil	1mpl	so	vfr	ss sp	7.5	eo		as	< 5%
B2	8-20	10YR 5/4	10YR 3/4	cl	1fsbk	sh	fi	s p	7.8	eo		aw	10%
Csi	20+	10YR 7/3	10YR 4/3	...	...	h	vh	... ...	8.0	es		...	...

1 An untrampled Type III surface.
2 See key to morphological abbreviations at the end of this appendix.

Appendix 2. Illustrative pedon of fine, montmorillonitic, mesic, Durixerollic Haplargid at the Dinner Station 1 ungrazed site.[1,2]

Physiographic Position: top of a broadly dissected alluvial fan remnant

Horizon (1)	Depth cm (2)	Color Dry (3)	Color Moist (4)	Texture (5)	Structure (6)	Consistence Dry (7)	Consistence Moist (8)	Consistence Wet (9)	pH (10)	$CaCO_3$ (11)	Roots (12)	Boundary (13)	Coarse Fragments % vol (14)
A11v	0-7	10YR 6/2	10YR 4/2	sil	2fpl	sh	fr	ss ps	7.0	eo	f,vf	vas	
A12	7-12	10YR 7/2	10YR 4/3	sil	1fsbk	sh	fr	ss ps	7.2	eo	c,vp, c,m	aw	
A3	12-15	10YR 7/3	10YR 3/3	sil	2msbk	sh-h	fr	ss ps	7.4	eo	f,vf	aw	
B21t	15-28	10YR 4/3	10YR 4/3	scl	2mcpr& 2mabk	h	fi	s p	8.2	eo	c,vf	sw	
B22tca	28-38	10YR 4/3	10YR 3/3	scl	2msbk	sh-h	fi	ss p	8.8	es	c,vf	cw	
C1ca	38-69	10YR 7/3	10YR 6/3	l	1csbk	sh	fr	vs ps	...	ev	f,vf	cw	
C2sicam	69-83	10YR 8/2	10YR 6/4	vfsl	1fabk	h	fi	so po	...	ev	f,vf	cw	
IIB2tca	83-105+	10YR 4/4& 8/1	10YR 5/4& 8/1	scl	1fabk	l..	l	s p	...	es	f,vf	...	

1 An untrampled Type III surface. The soil taxonomic unit for Dinner Station 2 is the same by inference.

2 See key to morphological abbreviations at the end of this appendix.

Appendix 2. Illustrative pedon of the fine, montmorillonitic, mesic, Xerollic Haplargid at the Elko 1 ungrazed site.[1,2]

Physiographic Position: inset alluvial fan remnant

Horizon (1)	Depth cm (2)	Color Dry (3)	Color Moist (4)	Texture (5)	Structure (6)	Consistence Dry (7)	Consistence Moist (8)	Consistence Wet (9)	pH (10)	$CaCO_3$ (11)	Roots (12)	Boundary (13)	Coarse Fragments % vol (14)
A11v	0-7	10YR 6/3	10YR 3/1	sil	2mpl&2fpl	sh	fr	ss sp	7.0	eo	...	as	10
A12	7-31	10YR 5/3	10YR 3/3	sil	1cpr&1fsbk	sh	vfr	ss sp	7.2	eo	...	as	10
B21t	31-48	10YR 5/3	10YR 4/3	cl	3msbk	h	fi	s p	2.4	eo	...	aw	20
B22t	48-67	10YR 6/4	10YR 4/4	c	3mcp& 3fsbk	h	vfr	vs vp	7.7	eo	...	aw	15
B3	67-100+	10YR 7/4	10YR 5/4	sc	lo	vh	efi	ss p	7.8	eo	...	...	60

1 An untrampled Type III surface.
2 See key to morphological abbreviations at the end of this appendix.

Appendix 2. Illustrative pedon of coarse-loamy, montmorillonitic, mesic, Xerollic Durargid at the Elko 2 ungrazed site.[1,2]
Physiographic Position: alluvial fan remnant

Horizon (1)	Depth cm (2)	Color Dry (3)	Color Moist (4)	Texture (5)	Structure (6)	Consistence Dry (7)	Consistence Moist (8)	Consistence Wet (9)	pH (10)	CaCo (11)	Roots (12)	Boundary (13)	Coarse Fragments % vol (14)
A11v	0-6	10YR 6/3	10YR 3/3	sil	m&2fpl	sh	fr	ss sp	7.0	eo	...	as	<5
A12	6-19	10YR 53	10YR 3/3	sil	2csbk&2msbk	sh	vfr	ss sp	7.2	eo	...	as	5-10
B21t	19-45	10YR 6/3	10YR 3/4	cl	3msbk	h	fi	s p	7.2	eo	...	cw	5-10
B22si	45-53	10YR 6/3	10YR 3/6	vgc	2msbk	h	fr	vs vp	7.6	eo	...	aw	50
B3	53-83	10YR 7/6	10YR 4/4	sac	m	s	fr	vs vp	7.6	eo	...	as	60
		f2d10YR 8/4	f10YR 8/4										
Clsicam	83+				cpl								

1 An untrampled Type III surface

2 See key to morphological abbreviations at the end of this appendix.

Appendix 2. KEY TO ABBREVIATIONS OF MORPHOLOGICAL TERMS FOR PEDON DESCRIPTIONS

1. Horizon Notation Suffixes

ca - pedogenic calcium carbonate
m - cemented or indurated
si - pedogenic silica
t - pedogenic clay accumulation

2. Color - Munsell color notation used

3. Soil Texture

st	- stony	l	- loam
k	- cobbly	sl	- sandy loam
g	- gravelly	sil	- silt loam
vcos	- very coarse sand	scl	- sandy clay loam
cos	- coarse sand	sicl	- silty clay loam
s	- sand	cl	- clay loam
fs	- fine sand	sc	- sandy clay
vfs	- very fine sand	sic	- silty clay
ls	- loamy sand	c	- clay
(+)	- rel. high clay for class	(-)	- rel. low clay for class

4. Structure

Grade

m - massive (structureless)
sg - single grain (structureless)
1 - weak
2 - moderate
3 - strong

Size

vf - very fine
f - fine
m - medium
c - coarse
vc - very coarse

Type

gr - granular
cr - crumb
pl - platy
pr - prismatic
cpr - columnar
abk - angular blocky
sbk - subangular blocky

5. Consistence

Dry		*Moist*	
lo	- loose	lo	- loose
so	- soft	vfr	- very friable
sh	- slightly hard	fr	- friable
h	- hard	fi	- firm
vh	- very hard	vfi	- very firm
eh	- extremely hard	efi	- extremely firm

Wet stickiness		*Wet plasticity*	
so	- nonsticky	po	- nonplastic
ss	- slightly sticky	ps	- slightly plastic
s	- sticky	p	- plastic
vs	- very sticky	vp	- very plastic

Cementation

cw - weakly cemented
cw - strongly cemented
ci - indurated

6. Soil pH

5.1 - 5.5 strongly acid
5.6 - 6.0 medium acid
6.1 - 6.5 slightly acid
6.6 - 7.3 neutral
7.4 - 7.8 mildly alkaline
7.9 - 8.4 moderately alkaline
8.5 - 9.0 strongly alkaline
above 9.0 very strongly alkaline

7. $CaCO_3$ test with 10% HCl

eo - non effervescent
ve - very slightly effervescent
e - slightly effervescent
es - strongly effervescent
ev - violently effervescent

8. Roots

Detailed description

Diameter classes		*Abundance clas*	
mi	- micro, less than 0.75 mm	vl	- very fe
vf	- very fine, 0.075 to 1 mm	1	- few
f	- fine, 1 to 2 mm	2	- plentifu
m	- medium, 2 to 5 mm	3	- abundan
co	- coarse, greater than 5 mm		

Gross description of Abundance

3 - numerous (undifferentiated diameter classes)
2 - many
1 - few
0 - none

9. Horizon Boundaries

Distinctness

va - very abrupt - transition less than 5 mm
a - abrupt - transition less than 1 in
c - clear - transition 1 to 2½ inches
g - gradual - transition 2½ to 5 inches
d - diffuse - transition greater than 5 inches

Topography

s - smooth
w - wavy
i - irregular
b - broken

10. Coarse Fragments (dominant size class)

g - gravel
k - cobbles
st - stones

Appendix 3. Percent live and dead crown cover of shrub species and percent basal area of perennial grasses.

Location[1] and Treatment	ARTRWY[2]	CHVI	Other shrub spp.	Total shrub crown cover	Dead shrub crown cover	Perennial grass cover
PV ungrazed	17.3	0	0	17.3	0	1.6
grazed	20.3	0	0	20.3	0	1.0
LCC grazed	29.0	0.1	0	29.1	0	0.9
PC grazed	25.3	10.8	1.4	37.5	1.1	1.8
J1 ungrazed	26.6	0	0	26.6	0	1.5
J2 ungrazed	5.6	12.6	0	18.1	16.4	4.9
grazed	6.1	7.9	0	14.0	10.3	4.9
DS1 ungrazed	28.9	0.8	0	29.7	0	4.1
grazed	19.7	1.4	0	21.1	0	4.7
DS2 ungrazed[3]						
grazed						
E1 ungrazed	22.2	0.1	0	22.3	0	2.6
grazed	24.3	0	0	24.3	0	2.5
E2 ungrazed	18.2	0	0	18.2	0	4.1
grazed	13.4	0	0	13.4	0	2.0

1 For key to location symbols see Appendix 1.

2 For key to species symbols see Appendix 4.

3 Percent cover at DS2 similar to DS1 by inference.

Appendix 4. List of species with scientific name, common name, and symbol.

Scientific Name	Common Name	Symbol
Artemisia arbuscula	low sagebrush	ARAR[8]
Artemisia tridentata wyomingensis	Wyoming big sagebrush	ARTRWY
Artemisia spinescens	bud sage	ARSP
Chrysothamnus visidiflorus	rabbitbrush	CHVI
Grayia spinosa	spiny hopsage	GRSP
Tetradymia canescens	horsebrush	TECA
Agropyron desertorum	crested wheatgrass	AGDE
Bromus tectorum	cheatgrass	BRTE
Elymus cinereus	basin wildrye	ELCI
Festuca idahoensis	Idaho fescue	FEID
Oryzopsis hymenoides	Indian ricegrass	ORHY
Oryzopsis webberi	Webber ricegrass	ORWE
Poa nevadensis	Nevada bluegrass	PONE
Poa sandbergii	Sandberg bluegrass	POSA
Sitanion hystrix	squirreltail	SIHY
Stipa thurberiana	Thurber needlegrass	STTH
Allium nevadense	Nevada onion	ALNE
Arabis pulchra	rockcress	ARPU
Astragalus lentiginosus	specklepod locoweed	ASLE
Castilleja chromosa	Indian paintbrush	CACH
Chaenactis spp.	false yarrow	CHAEN
Collinsia parviflora	blue-eyed Mary	COPA
Crepis accuminata	tapertip hawksbeard	CRAC
Cryptantha gracilis	cryptantha	CRGR
Delphinium andersonii	larkspur	DEAN
Descurania richardsonii	tansy mustard	DERI
Gayophytum ramosissimum	groundsmoke	GARA
Gilia transmontana	gilia	GITR
Halogeton glomeratus	halogeton	HAGL
Lepidium perfoliatum	shield-cress	LEPE
Lomatium spp.	biscuitroot	LOMAT
Lupinus caudatus	lupine	LUCA
Mertensia longiflora	bluebells	MELO
Microsteris spp.	microsteris	MICRO[4]
Opuntia basilaris	beavertail cactus	OPBA
Orobanche fasiculata	broomrape	ORFA
Penstemon speciosus	beardtongue penstemon	PESP
Phlox austromontana	desert phlox	PHAU
Ranunculus testicaulatis	nutty ranunculus	RATE
Salsola kali	Russian thistle	SAKA
Wyethis mollis	mules ears	WYMO
Zigadenus paniculatus	foothill death camas	ZIPA

Appendix 5. Sand fractions; total sand, silt, and clay; and textural classes of the various surface types from the study locations.

Location[1] and Soil Surface Type	Sand Fractions, %					Total %			Textural Class
	vcos	cos	ms	fs	vfs	Sand	Silt	Clay	
LCC I	11.5	8.5	4.5	11.6	22.2	58.3	28.1	13.6	sandy loam
LCC II	10.5	7.7	4.0	10.7	21.7	54.6	35.2	10.2	sandy loam
LCC III	8.6	5.6	3.0	8.5	19.8	45.5	41.9	12.6	loam
LCC	7.1	4.0	2.4	8.9	23.4	45.8	44.0	10.2	loam
PV I	2.1	2.2	1.3	7.9	24.1	37.6	50.1	12.3	silt loam
PV II	2.3	2.5	1.4	12.9	28.9	48.0	41.1	10.9	loam
PV III	1.7	1.9	1.3	10.2	27.9	43.0	48.6	8.4	loam
PV IV	1.8	1.8	1.1	11.0	26.7	42.4	51.5	6.1	silt loam
PC I	1.6	1.8	1.2	3.9	20.6	29.1	49.5	21.4	loam-silt loam
PC II	2.3	2.5	1.3	4.5	22.0	32.6	50.2	17.2	silt loam
PC III	1.7	1.8	1.1	4.3	14.5	30.7	52.2	17.1	silt loam
DS1 I	2.4	2.3	1.4	4.5	14.5	25.1	50.0	24.9	loam-silt loam
DS1 II	2.1	2.4	1.4	4.1	13.9	23.9	49.7	26.4	loam-silt loam
DS1 III	1.9	1.7	1.0	3.0	13.6	21.2	52.8	26.0	silt loam
DS2 I	2.3	2.5	1.8	5.9	15.5	28.0	44.1	27.9	clay loam-loam
DS2 II	1.9	2.1	1.5	5.2	14.2	24.9	48.0	27 1	clay loam-loam
DS2 III	1.7	1.8	1.3	4.7	15.3	24.8	48.4	26.8	clay loam-loam
J1 I	3.5	3.4	2.5	7.0	18.9	35.3	42.2	22.5	loam
J1 II	4.2	4.6	3.2	7.9	22.6	42.5	45.1	12.4	loam
J1 III	3.8	3.1	2.2	6.3	20.2	35.6	48.6	15.8	loam-silt loam
J2 I	12.3	7.3	4.1	11.0	17.7	52.3	36.8	10.9	loam-sandy loam
J2 II	4.2	3.9	1.9	5.7	16.4	32.1	55.0	12.9	silt loam
J2 III	13.0	7.2	3.0	6.9	16.1	46.2	42.4	11.4	loam
E1 I	3.5	4.0	2.6	8.6	18.8	37.5	45.0	17.0	loam
E1 II	4.9	3.2	2.0	7.6	22.0	39.7	44.7	15.6	loam
E1 III	4.2	3.7	11.9	14.9	14.1	36.9	47.2	15.9	loam

[1] See Appendix 1 for key to location symbols.

Appendix 6. Percent organic matter of the various surface types from the study locations.

Location[1] and Soil Surface Type	Organic Matter (%)	Location[1] and Soil Surface Type	Organic Matter (%)
LCC I	7.2	DS2 I	3.0
LCC II	4.1	DS2 II	2.8
LCC III	1.6	DS2 III	3.0
LCC IV	1.1		
PV I	6.9	J1 I	7.3
PV II	6.4	J1 II	6.1
PV III	3.1	J1 III	1.7
PV IV	0.5		
PC I	6.1	J2 I	4.3
PC II	3.8	J2 II	3.5
PC III	3.5	J2 III	1.6
DS1 I	7.3	E1 I	5.2
DS1 II	4.1	E1 II	2.9
DS1 III	2.6	E1 III	1.6
		E2 I	5.9
		E2 II	2.9
		E2 III	1.6

[1] See Appendix 1 for key to location symbols.