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Classifying ecological types and evaluating site degradation

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Abstract

An analytical method for classifying ecological types was developed and tested for mountain meadows in central Nevada. Six ecological types were identified by plot sampling of vegetation and soil-site variables. Two-way indicator species analysis and canonical correspondence analysis were used to identify ecological types and to compare the discriminating abilities of different ecosystem components. Each ecological type was a characteristic combination of landform, soil, and vegetation. Changes in vegetation and soil conditions were assessed along a gradient of degradation within one ecological type—the dry graminoid/Cryoboroll/trough drainageway type. Direct gradient analysis was used to display changes in plant composition and indicators of site degradation. Plant and soil indicators of degradation were basal cover of vegetation, standing crop production of 3 key grass species, rates of infiltration, and soil compaction. Three states of range degradation were identified along the gradient. The grass-dominated state was the most desirable in terms of forage production, basal cover of vegetation and infiltration, while the grass/forb/shrub state represented the most degraded and least productive state.

Resumen

Un método analítico para la clasificación de tipos ecologicos fué desarrollado y evaluado para las áreas abiertas de bosques en la región central de Nevada. Se identificaron 6 tipos ecológicos mediante el muestreo de parcelas de vegetación y variables de suelo-sitio. Se utilizaron análisis de correspondencia canónica y de 2 entradas para las especies indicadoras con el fin de identificar los tipos ecológicos y para comparar las habilidades discriminatorias de los diferentes componentes de los ecosistemas. Cada tipo ecológico fué caracterizado mediante una combinación de forma del paisaje, suelo, y vegetación. Los cambios en la vegetación y las condiciones del suelo fueron evaluadas a lo largo de un gradiente de degradación dentro de un tipo ecológico—el graminoide seco/Cryoboroll/drenaje tipo cóncavo. El análisis de gradiente directo fue usado para mostrar cambios en la composición de plantas y en los indicadores de degradación de sitio. Los indicadores de degradación de plantas y suelo fueron cobertura basal de vegetación, producción de follaje de 3 especies claves de zacates, grados de infiltración, y compactación del suelo. Tres niveles de degradación de sitios fueron identificados a lo largo del gradiente. El área dominada por zacates fue la más deseable en términos de productividad de forraje, cobertura basal de vegetación e infiltración, mientras que el area con zacate/hierbas/arbustos represento la mayor degradación y menor productividad.

Key Words: canonical correspondence analysis, discriminant analysis, infiltration, range condition, range site, riparian

Classification of landtypes and condition of those landtypes has long been a topic in resource management (Dyksterhuis 1949, 1958, Joyce 1993). Classification of landtypes into ecological types is an attempt to understand spatial variation across the landscape (Pamo et a. 1991). Condition of a site attempts to measure temporal variation in 1 ecological type. Changes in range condition usually are assessed from measurements of the type and quantity of vegetation. However, according to Wilson and Tupper (1982), range condition should also be based on soil stability as soil degradation is the most serious manifestation of a decline in range condition. The relationship between site degradation and vegetation change needs study if range scientists are to understand and quantify ecosystem effects associated with range degradation.

Soil and vegetation indicators of degradation are likely to be site specific, and therefore apply to specific ecological types. For the purposes of this study, the term ecological type (USDA-FS 1991) is synonymous with ecological site and range site. It is important that a classification of ecological types be developed before range condition is assessed so that the productive capabilities of a site are known (West et al. 1994). Bosch and Kellner (1991) emphasized the importance of understanding the process of rangeland degradation before assessing the condition of any area.

Several authors (Laycock 1991, Tausch et al. 1993, Westoby et al. 1989) have proposed that rangeland dynamics be described by a set of discrete "states' of vegetation on a site and a set of "transitions" between states. Westoby et al. (1989) indicated that management criteria should be used in selecting and defining the

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states that occur in a given situation. Although management of rangelands and the assessment of condition has been ongoing for many years in central Nevada, few studies have been undertaken to assess changes in vegetation composition associated with site degradation of mountain meadows. The objectives of this study were to: 1) define a classification of ecological types for mountain meadows in central Nevada; 2) to identify indicators of community deterioration and the different degradation states within the dry graminoid/Cryoboroll/trough drainageway ecological type; and 3) outline possible states and transitions between states within the dry graminoid/Cryoboroll/trough drainageway ecological type.

Study Area and Methods

Study Area

This study was conducted in the Shoshone, Toiyabe, Toquima, and Monitor mountain ranges of the Toiyabe National Forest in central Nevada. Field work was conducted from about June 1 to September 15 each year from 1990 through 1993. The study area lies in the center of the Great Basin physiographic province. The elevation of the study sites ranged from 2,030 to 3,200 m. Stream courses in the study area are narrow and often incised. Important graminoid species in meadows were: Nebraska sedge (*Carex nebrascensis* Dewey), Aquatic sedge (*Carex aquatilis* Wahlenb.), tufted hairgrass (*Deschampsia cespitosa* [L.] Beauv.), Nevada bluegrass (*Poa secunda* ssp. *juncifolia* Scribner R. Soreng), Kentucky bluegrass (*Poa pratensis* ssp. *pratensis* L.), Douglas sedge (*Carex douglasii* Boott., slender wheatgrass (*Elymus trachycaulus* [Link] Malte.), mat muhly (*Muhlenbergia richardsonis* [Trin.] Rydb.), and baltic rush (*Juncus balticus* Willd.). Important shrub species were: basin big sagebrush (*Artemisia tridentata* ssp. *tridentata* Nutt.) and rabbitbrush (*Chrysothamnus* spp.). Plant nomenclature follows Hickman (1993). Riparian communities occurred on 4 dominant landform types: floodplains, springs, trough drainageways, and stream terraces.

The semi-arid climate is characterized by cold winters and warm summers with most precipitation occurring as winter snow. The average temperature ranges from –4°C in January to 20°C in July, with a yearly mean of 12°C. Average annual precipitation is 31 cm at the townsite of Austin, Nev. (Sakamoto, 1973).

Sampling Design

Ecological Type Classification: One-hundred ten plots were selected for study that represented a range of meadow plant communities, parent material, landforms, soil taxa, and elevations occurring within the study area. Vegetation, soil, and landform characteristics were homogeneous within plots. Due to the narrowness of riparian zones in the study area, sample plots were typically 10 to 20 m in width, and 20 to 50 m in length. Plots were sampled for canopy cover of plant species along 3 parallel 20-m transects. Direction of the initial transect and distance between transects were random within the boundaries of each plot. Canopy cover was estimated by cover classes in 6 (0.25m^2) quadrats systematically placed at 3-m intervals along each transect. This gave a total of 18 cover quadrats for the 3 transects which met a sampling objective where the standard error of the mean divided by the mean was less than 0.15 for more important (abundant) species. More abundant species was defined as the 3 species having the greatest foliar cover on a plot. Ten cover classes were used in estimating cover for individual species (Jensen et al. 1993). Canopy cover of individual species was estimated as a mean percentage by averaging over the 3 transects for each plot. Points on a quadrat frame were used to record basal cover of vegetation and soil cover on each of the 3 vegetation transects. Quadrat frames were placed at 1-m intervals along each transect and 10 points were recorded at each frame. A total of 200 points per transect were used for a total of 600 hundred points per plot. The number of points intersecting basal vegetation and soil were converted to a percentage by dividing the number of points intersecting each category by the total number of points.

At each plot, soils were described to at least 1 meter depth and classified to family level (Soil Survey Staff 1975, 1992). Soil texture and coarse fragment data were estimated in the field for each soil horizon to provide estimates of drainage and soil hydraulic conductivity. In addition, size and sorting of material was analyzed by plotting grain size distribution curves from sieve analysis of surface horizons. This allowed for a comparison of the similarity of soil texture and grain sizes among and within ecological types formed in fluvial deposits. Soil hydraulic conductivity varies with both grain size and sorting of soil material. Hazen (1911) developed a durable empirical equation to relate hydraulic conductivity to the D_{10} grain size (Bowles 1979, Freeze and Cherry 1979). The D_{10} grain size was determined from the grain size distribution curves for each plot. The D_{10} size is the particle size (microns) of the finest 10% of the earth material. Particular attention was paid to soil moisture status by depth, redoximorphic features, and temperature because these factors have been described as important in characterizing ecosystems (Jenny 1980, Vepraskas 1992). Sites sampled in the month of June were revisited in July so that soil temperature and moisture depths for those plots reflected mid-season readings.

Site Degradation: Twenty-two sites from the 110 plots were selected for study that were within the dry graminoid/Cryoboroll/trough drainageway ecological type. Sites with different grazing histories were sampled–ranging from sites that had received heavy, season long grazing, to sites which had a history of light, short duration grazing. One site, which had a history of light to moderate use by livestock, was selected as a reference site. This site, which was considered to be relatively nondegraded, provided a point of reference during the analysis phase of the study. All plots were on slopes of 1 to 6%. Plots were sampled for canopy cover of plant species and basal cover of vegetation as described above. At each plot, soils were described to at least 1 meter depth and classified to family level (Soil Survey Staff 1975, 1992). Depth and abundance of roots was recorded (Soil Survey Staff 1975). Weaver (1919) emphasized the importance of rooting depth in the assessment of condition. Branson et al. (1981) reported on the relationship of condition to kinds of roots (tap-root vs. fibrous roots) and infiltration. Particular attention was paid to the size (very fine, fine, medium, and coarse) and abundance classes (few, common, and many) of roots by depth. In addition, the shape and grade of soil structure was recorded by depth (Soil Survey Staff 1975). Soil structure has 5 shapes: platy, prismatic, columnar, blocky, and granular and 3 grades: weak, moderate, and strong. The grade of platy soil structure was recorded in one of 3 classes; 1 = weak, 2 = moderate; and 3 = strong.

Vegetation was clipped at the height of standing crop on sites that had not been grazed that year to determine standing crop accumulation. Clipping was done between 4 and 21 July 1994. Vegetation was clipped to a height of 1 cm in 10 randomly placed 0.25 m^2 quadrats on each plot. Samples were dried and standing crop production (kg/ha) was calculated for each plot by key forage species (Nevada bluegrass, slender wheatgrass, and mat muhly) and by total standing crop biomass (graminoids, forbs, and shrubs).

Three double cylinder infiltration tests (Cook and Stubbendieck 1986) were run on each plot. Infiltration is influenced by soil hydraulic conductivity and water content (Pullan 1990, Reynolds and Elrick 1990). Hydraulic conductivity varies by both size and sorting of material as well as the continuity of soil macro and micro pores. Edwards et al. (1992) reported that flow paths within the soil were related to infiltration while bulk density was not. To attain uniform antecedent soil water content, all plots were prewet with 5 liters of water and drained overnight. Tests consisted of 5 refill readings at 5 minute intervals over 30 minutes in order to attain a steady state infiltration measurement. In Nevada rangeland plant communities, Blackburn (1975) obtained steady state values within 30 minutes with a ponded test.

Statistical Analysis

Site Classification: Two-way indicator species analysis (TWINSPAN) (Hill 1979) was used to classify the 110 study plots into discrete plant community groups. This analysis was based on the presence or absence of plant species on a plot. Because TWINSPAN classification is based on ordination, it produces a vegetation classification that reflects dominant gradients in the data. In the case of riparian vegetation, this is often a gradient that reflects soil moisture. Recent studies have indicated that the order in which stands are input into the analysis can affect classification results (Tausch et al. 1995). Thus, stand order was rerandomized for each of 5 separate TWINSPAN runs to determine plant community groups consistently present through all analyses.

Multivariate discriminant analysis was then used on the groups derived from TWINSPAN classification to determine which groups were different in soil and landform characteristics (Greig-Smith 1983, Ludwig and Reynolds 1988). At each division in the classification, a minimal set of soil and landform variables that best explained the classification was identified using the option of forward selection of variables in the discriminant tests. Groups that were not different in soil and landform features were aggregated into ecological types. This approach is similar to that described by Fincher and Smith (1993) for classifying ecological types of hardwood stands in Vermont. Soil-site variables used in this analysis were: parent material, elevation, slope, aspect, landform type, soil taxon, grain size, depth to saturation, depth to mottles, depth to coarse fragments (> 20% gravel and/or cobble), and soil temperature. Prior to analysis, the environmental variables were checked for normality and found to have Poisson distributions. These variables were normalized using a square root transformation.

In classifying ecological types, it is useful to subject the soil and landscape data to ordination analysis to determine the dominant environmental gradients in the data. We did this by performing canonical correspondence analysis (CCA) (ter Braak 1987a). The CCA is a direct gradient analysis program which relates species data directly to a set of environmental data (ter Braak 1987b). The CCA scores for the first 3 axes for each plot were used as input to cluster analysis. Multiple discriminant analysis then was used on the groups derived from cluster analysis to determine which groups were different in soil and landscape characteristics. By performing both TWINSPAN and CCA analyses on the data, important environmental variables having the most influence on vegetation patterns were determined.

Site Degradation: Direct gradient analysis in the form of canonical correspondence analysis (CCA) (ter Braak 1987a) was used to determine a gradient of degradation within the dry graminoid/Cryoboroll ecological type. Environmental features used as indicators of degradation were: 1) standing crop production of 3 key grass species (Nevada bluegrass, slender wheatgrass, and mat muhly); 2) percent basal cover of all vegetation; 3) rate of infiltration (ml/5 min); and 4) the degree of compaction as indicated by the occurrence and grade of platy soil structure. The CCA allows major elements in the distribution patterns of different locations to be compared and related to environmental information (Jongman et al 1987, Palmer 1993). This approach does not assume a climax condition, but produces classes and orders of locations that define a gradient according to known site factors, plant species composition, and soil conditions (Beeskow et al. 1995). The CCA produces a plot of both sites and environmental factors in the same ordination space. In this way, the relationship of individual plots to the environmental variables was shown. The position of the reference plot along the gradient served as a check to determine if the reference site was actually in a relatively nondegraded condition as shown by the measured plant and environmental variables.

Three classes of sites, or states, were derived from the CCA ordination of sites within the dry graminoid/Cryoboroll/trough drainageway ecological type. Analysis of variance and Fisher's L.S.D. were used to determine significant differences in the environmental variables among states. The Student's "t" test was used to determine differences in rooting depths and D_{10} grain sizes among states.

Results and Discussion

Ecological Type Classification

TWINSPAN classification of the 110 riparian meadow sites followed by discriminant analysis using soil-site characteristics delineated 6 basic clusters (site types) (Fig. 1) depicted as a dendrogram. At each division in the dendrogram, a minimal set of variables that best explained the classification is shown. The names of each of the 6 ecological types represent the dominant vegetation on the site at the nondegraded state, followed by the dominant soil suborder, and finally the dominant landform of the type. These results were compared with the groups obtained from clustering of canonical correspondence analysis (CCA) scores followed by discriminant analysis of site characteristics. Eight plots were classified differently using the CCA technique. The plots which were classified differently belonged to 3 site types; types 1, 2, and 3. This was probably due to the fact that these types shared some common species and were separated by subtle soil moisture characteristcs. Yet, these types also displayed significant differences in plant species composition and soil moisture (Table 1).

Examination of depths to soil mottling and depths to soil satu-

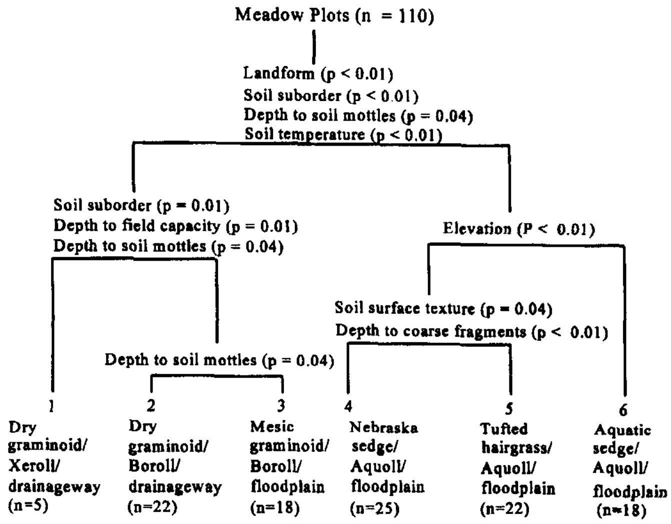


Fig. 1 Classification of 110 meadow plots into 6 ecological types based on discriminating soil and landform characteristics.

ration in Table 1 shows a clear moisture gradient from the drier ecological types (1, 2, and 3) to the wetter types (4, 5, and 6). Douglas sedge, Nevada bluegrass, and mat muhly were associated with deeper depths to soil saturation and soil mottling (Table 1). Nebraska sedge, tufted hairgrass, and aquatic sedge were associated with shallower depths to soil saturation and mottling.

Variables associated with landscape position and substrate—soil suborder, depth to soil mottling, elevation and depth to coarse fragments—were the most highly correlated factors with both species and sample distribution. Each ecological type was a characteristic combination of ecosystem components (physiography, landform, vegetation, and soil).

The results from the ecological classification of sites increases our understanding of how these sites relate to landscape position and substrate. Soils occurring on drainageways with deeper depths to soil mottles typical of Types 1, 2, and 3 occur in the drier meadows. The affinity of dry graminoid species for these sites indicates that these soils are not saturated within the rooting zone during the growing season. Soils occurring on floodplains (Types 4, 5) and at springs along faultlines (Type 6) have shallower depths to soil mottles and saturation. The affinity of sedges for these sites indicates soils that are saturated for at least a part of the growing season. Results of the soil sieve analysis indicated that Types 4 and 5 differed significantly (t-test, P=0.04) in D_{10} grain size, and therefore in soil permeability, and texture (Table 1).

A number of studies have been developed that use multivariate analysis to identify patterns in species distributions and associations among soil, vegetation, and physiographic variables (Pregitzer and Barnes 1982, Barnes et al. 1982). Other studies (Daubenmire 1976, Jimerson 1990, Pfister and Arno 1980) have used vegetation as a key integrative component in site evaluation that can be used to qualify response to climatic, physiographic, and soil factors. Smith (1993, 1995) used TWINSPAN classification and CCA for determining ecological types in northern hardwood stands in central Vermont. In that study, only undisturbed stands were used in the analysis process. That approach is useful because the classification is not complicated by analyzing seral gradients concurrently with ecological type classification. An important part of any landtype classification is further testing of the classification to determine the integrity and robustness of the ecological classes. In our study, we are in the process of collecting additional data and conducting analyses on the independent data set as a means of verifying the classification system.

Table 1. Summary of selected physiographic, soil, vegetation variables (mean±SD) for the 6 riparian ecological types.

Soil-site and vegetation characteristics	Ecological types[1]					
	1 n=5	2 n=22	3 n=18	4 n=25	5 n=22	6 n=18
Depth to saturation, cm	>100	>100	94±28	28±21	41±31	15±13
Soil temperature at 50cm[2]	11±3	10±3	10±2	7±4	8±4	7±3
Depth to mottles, cm	90±17	80±29	57±33	36±34	35±33	34±22
Slope, degrees	4±3	6±6	6±4	6±4	8±5	6±3
Aspect	All	All	All	All	All	All
Elevation, meters	2360±144	2560±389	2507±312	2416±190	2743±321	3091±180
Depth to 20% coarse fragments, cm	85±26	73±32	86±28	67±33	22±26	51±37
Soil texture (D_{10} size)[3]	41±12	49±28	43±19	42±12	65±30	66±16
Landform	Drainageway	Drainageway	Floodplain	Floodplain	Floodplain	Spring
Soil Suborder	Xeroll	Boroll	Boroll	Aquoll	Aquoll	Aquoll
Constancy, percent						
Douglas sedge	100	68	55	16	9	20
Nevada bluegrass	38	86	61	29	13	0
Mat muhly	36	54	38	12	13	0
Nebraska sedge	0	0	55	75	36	6
Kentucky bluegrass	1	22	72	70	59	20
Baltic rush	8	81	88	79	34	66
Tufted hairgrass	0	0	5	45	63	53
Aquatic sedge	0	0	0	2	0	93

[1] 1=Dry graminoid/Xeroll/trough drainway; 2=Dry graminoid/Cryoboroll/trough drainway; 3=Mesic graminoid/Boroll/floodplain; 4=Nebraska sedge/Aquoll/floodplain; 5=Tufted hairgrass/Aquoll/floodplain; 6=Aquatic sedge/Cryaquoll/floodplain.
[2] Degrees Celsius
[3] microns

Site Degradation

The canonical corresponence analysis (CCA) ordination of sites within the dry graminoid/Cryoboroll/trough drainageway ecological type is shown in Fig. 2. Axis 1 represents the relative position of the samples along a gradient of community composition and environmental features. Axis 1 was primarily a gradient of basal cover of vegetation, standing crop biomass production of 3 key grasses, and soil compaction as indicated by the distinctness of soil plate structure. The ordination of sites along the y-axis separated sites differing mainly in the rate of infiltration. For the environmental variables, the arrows point in the direction of increasing value (ter Braak 1987b). From the plot, the relationship of the variables to each other becomes apparent. For example, the amount of basal cover of vegetation points in the opposite direction from soil compaction, and therefore these 2 variables are negatively correlated. The length of an arrow is a measure of how much the species distributions differ along that environmental variable. Important environmental variables have longer arrows than less important environmental variables (ter Braak 1987b). Autocorrelation among variables was checked using the Variance Inflation Factor (VIF) in the statistical package CANOCO (ter Braak 1987b).

The reference site position along the degradation gradient is shown in Fig. 2. This site was considered to be relatively nondegraded and was characterized by graminoid dominance, a high basal cover of vegetation, low soil cover, high standing crop biomass, and relatively high rates of infiltration (Table 2). Sites in the same portion of the gradient were considered to be relatively nondegraded (State I) (Table 2). Changes in composition and abundance of forage species were observed along the main gradient, apparently reflecting vegetation response to a gradient of degradation. With an increase in degradation, a decrease of perennial grasses and an increase in forb species occurred. The 3 dominant species in the grass meadows, the cool-season bunchgrasses, Nevada bluegrass and slender wheatgrass, classified as highly palatable, and the rhizomatous species mat muhly, considered palatable, were considered decreasers under light to moderate degradation. These grass species accounted for most of the standing crop production and a majority of the forage production (Table 2). On more degraded sites, forbs such as iris (*Iris missouriensis* Nutt.) and yarrow (*Achillea millefolium* L.) were more abundant (State II) (Table 2). At this stage, scattered shrubs were evident. Basin big sagebrush, a dominant shrub in low areas along drainageways in fine textured soils occurs on these sites at State III. Rabbitbrush, an aggressive colonizer of disturbed sites, also occurs at State III. The low palatability of these shrubs probably has been important in the establishment of these shrubs.

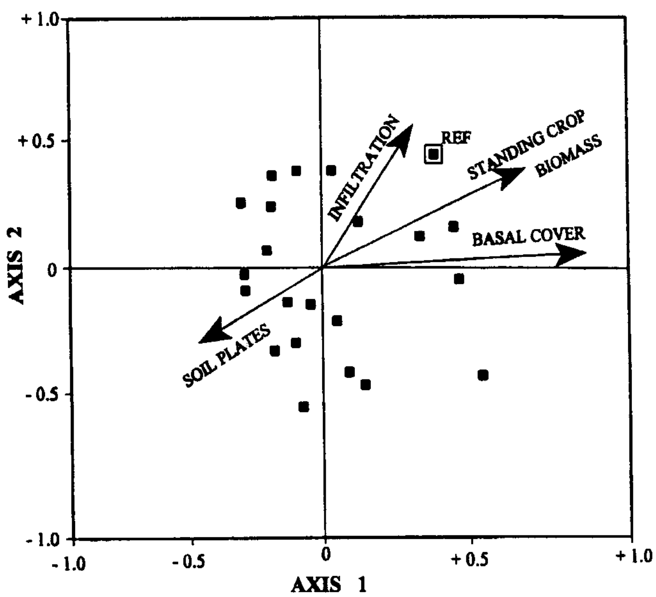


Fig. 2. Canonical correspondence analysis of sites within the dry graminoid ecological type. The 4 indicator variables for site degradation are shown by arrows. Each arrow points in the direction of increasing value for a variable. Axis 1 was primarily a gradient of standing crop biomass of 3 key grass species and basal cover of vegetation with these variables increasing in value to the right side of the diagram. The distinctness of soil plate structure increased to the left on axis 1. Axis 2 was primarily a gradient of infiltration rate. The reference site (REF) was an example of a nondegraded site.

Table 2. Average values (±SD) for important soil and vegetation variables in each of the 3 states identified in the dry graminoid/Cryoboroll/trough drainageway ecological type in central Nevada. Data for States I, II, and III represent the right, center, and left portions of the x-axis of Fig. 2, respectively.

Soil and vegetation characteristics	State I Grass n=4	State II Grass/forb n=8	State III Grass/forb/shrub n=10
Key species biomass[1]	2694±944[a]	1472±306[a]	1111±361[b]
Total standing crop[2]	2829±1216[a]	1678±553[b]	1564±313[b]
Basal area cover (%)	34±5[a]	15±4[b]	9±5[b]
Soil cover (%)	7±2[a]	12±7[b]	16±8[b]
Infiltration rate[3]	1219±373[a]	721±527[ab]	465±214[b]
Frequency of plates (%)[4]	0	45	73
Mean foliar cover, percent			
Nevada bluegrass	39	10	7
Slender wheatgrass	2	19	4
Mat Muhly	17	11	6
Iris	0	12	27
Yarrow	1	3	6
Basin Big Sagebrush	0	1	6
Rabbitbrush	0	1	4

Means in the same row followed by the same lowercase superscripts (a,b) are not significantly different at P<0.05, Fisher's L.S.D. test

[1]Standing crop biomasss of 3 key grass species (kg/ha): Nevada bluegrass, slender wheatgrass, and mat muhly

[2]Standing crop biomass of all species combined (kg/ha)

[3]Infiltration rate (ml/5 min)

[4]Frequency of occurrence of moderate to strong plate structure

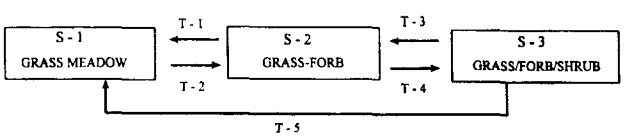
Average rooting depths were not different between States I (45 cm) and II (46 cm) (t-test, P=0.89). Rooting depths were shallower in State III (22 cm) as compared with State II, however, this difference was not significant (t-test, P=0.07). The shallow rooting depths in State III may be due to soil compaction. Rooting depths in State III generally occurred at the depth at which moderate plate structure was observed. The depths of subsoil plates in our study generally agree with depths reported elsewhere for soil compaction in grazed area (Lull 1959) as well as soil mechanics theory (Terzaghi 1943, Bowles 1979, Das 1994).

Tongway and Hindley (1995) have developed a method for assessing soil condition in Australia. Their methods are for use on arid shrublands and tropical grasslands. Important indicators used in their study were vegetation basal cover, soil cover, litter cover, cryptogram cover, and erosion features. Tongway and Hindley (1995) state that a soil in good condition is able to absorb and store rainfall, store and cycle nutrients, provide appropriate habitat for growth of plants, and resist erosion.

Beeskow et al. (1995) used gradient analysis to study soil degradation for grasslands of Patagonia, Argentina. They reported on changes in the vegetation and soil surface along a grazing intensity gradient and documented 3 stages of range deterioration from a grass steppe to shrub steppe. Blackburn (1975) studied the relationship of soil infiltration and erosion as measured by sediment production on 28 different sagebrush plant communities in central and eastern Nevada. He reported that for sagebrush sites, higher erosion was associated with lowered rates of infiltration and poor soil aggregate structure. We did not measure erosion in our study, however, there were significant differences in rates of infiltration between States I, II, and III (Table 2). These differences occurred without significant differences in soil textures among states. Sieve analyses of soils indicated that grain size distributions were similar among States I, II, and III, therefore, hydraulic conductivity and rates of infiltration should be similar among these groups. However, in States II and III, soil compaction was associated with lower rates of infiltration apparently reflecting changes in infiltration along a gradient of site degradation. Spaeth et al. (1996) reported that the use of plant species biomass improved infiltration prediction. In our study, rates of infiltration increased as biomass on the site increased (Table 2).

States and Transitions

Cover data were categorized into 3 groups (Fig. 3), using the results from canonical correspondence analysis (CCA) (Table 2). Each group represented a plant physiognomy that was identifiable in the field. These physiognomic classifications may be viewed as stable states of the state and transition concept of Westoby et al. (1989) (Fig. 3). Transitions between states can occur following changes in soil moisture due to changes in water table or to management practices. Since soil moisture and water table levels were approximately the same for all sites within this ecological type, these factors were considered not as important as management practices in causing the vegetation and site degradation we



DOMINANT PLANT SPECIES

Nevada bluegrass	Slender wheatgrass	Nevada bluegrass
Slender wheatgrass	Iris	Iris
Mat muhly	Yarrow	Basin big sagebrush

DOMINANT VEGETATION AND SOIL CONDITIONS

High basal cover	Moderate basal cover	Low basal cover
High forage production	Moderate production	Low production
High infiltration	Moderate to low infiltration	Moderate to low infiltration

Transitions

T - 1: Reduced grazing pressure. Improved soil conditions.
T - 2: Reduced herbaceous vigor by heavy grazing and/or lowered water table. Soil degradation.
T - 3: Fire or other shrub control technique. Improved soil conditions.
T - 4: Continued heavy grazing pressure and/or drop in water table. Soil degradation.
T - 5: Fire or other shrub control technique. Improvement in hydrologic conditions.

Fig. 3. State (S) and transition (T) diagram for the dry graminoid/Cryoboroll/trough drainway ecological type.

observed. Classifying ecological types, as was done in this study, allows for the environment and productive capabilities to be held relatively constant while studying changes in condition.

Site degradation, in the form of increased soil cover and an increase in the frequency of soil compaction, reduces perennial herbaceous vigor, reduces rates of infiltration, and appears to be a precursor for an increase in forb and shrub abundance in these graminoid meadows (transition 1). The 2 endpoints of the gradient were characterized by grasses with no shrub cover (State I) or a mixture of grasses, forbs, and shrubs (State III). The intermediate state represents a transition state with a mix of graminoids and forbs.

Some mountain big sagebrush and rabbitbrush seedlings were found in bare areas in State II. In contrast, no young plants were found in the graminoid-dominated sites. The increase in soil cover (Table 2) could explain the difference in shrub establishment between States I and II, and may be a principle factor in transition 3 (Fig. 3). Shrub control techniques as well as changes in livestock grazing might be used to encourage transition 5, the change from the grass/forb/shrub state (III) to the grass-dominated state (I). Currently it is not known what management options including grazing strategies would promote transition 2, the change from the grass/forb to the grass-dominated meadow state Although the different states (Fig. 3) might represent a successional pathway with grass-dominated meadows being the climax condition, it is not known whether the grass/forb/shrub state will change to a grass-dominated state following a decrease in the stocking rate or grazing exclusion. Management options such as brush control, reseeding, and other reclamation practices may be necessary if a rapid return to graminoid dominance is desired.

Conclusions

We were able to classify 6 meadow ecological types using a combination of classification by TWINSPAN analysis followed by discriminant analysis tests using site information. Ordination of plots using canonical correspondence analysis (CCA) of soil and landform data gave similar results. The 2 methods revealed distinct relationships between vegetation, landform, and soil factors in the study area. Variables associated with landscape position and substrate were the most highly correlated factors with both species distribution and sample distribution.

Direct gradient analysis in the form of CCA was used to determine a gradient of degradation within the dry graminoid/Cryoboroll/trough drainageway ecological type in central Nevada. Basal area cover of vegetation, production of 3 key grass species, and rates of infiltration were used as quantitative measures of the extent of ecosystem degradation. In this type, the main vegetation change associated with a gradient of degradation was the transformation of a grass-dominated into a grass/forb/shrub state. The grass/forb state represented a transition state represented a transition state between these 2 extremes. The invasion of forbs with low forage value into the graminoid meadow systems has decreased forage production. The invasion of shrubs, primarily basin big sagebrush and rabbitbrush, also has decreased forage production. Grass-dominated communities represented the most desirable state in terms of forage production, basal cover of vegetation and infiltration, while the grass/forb/shrub communities represented the least productive and most degraded state.

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