

Using multivariate techniques to quantitatively estimate ecological stages in a mixed grass prairie

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Abstract

Cluster analysis followed by stepwise discriminant analysis was used to delineate ecological stages on a mixed grass prairie in western South Dakota. Forty-seven variables were analyzed for 48 sites ranging from potential vegetation to early seral stages. A cover-frequency index for western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), and buffalograss (*Buchloe dactyloides*) was the most valuable in identifying 4 different ($P < 0.0001$) ecological stages. Ecological stage classification was estimated to be 95% accurate. The methods presented are quantitative, precise, easy, time-efficient, and meet the goals of resource managers with a minimum of bias.

Key Words: discriminant analysis, ISODATA, mixed grass prairie, range, classification

To meet the increasing demand for intensive management of public rangelands, improved and efficient methodologies for assessing range ecological stages are needed. Range condition classification has been a major tool in rangeland management (Dyksterhuis 1949), and over the years several theories and recommendations for basing range condition classification on vegetation classification have been developed (Smith 1979, Wilson and Tupper 1982, Daubenmire 1984, Hoffman 1984, Meeker and Merkel 1984, Dyksterhuis 1985, Hall 1985, Mason 1985, Ross 1985). Bjugstad and Whitman (1970) noted a need for more accurate and reliable measurements when determining range condition; however, little attention has been given to improving methodologies.

Current methods used by the Forest Service (USDA-USFS 1968) and Soil Conservation Service (USDA-SCS 1976) are not sensitive enough to determine changes in ecological stages (succession) unless major vegetation changes have occurred. One problem is that each method relies on subjective evaluation. The use of ordination procedures (Mueller-Dombois and Ellenberg 1974, Whittaker 1967, Foran 1986) mitigates this problem. Other multivariate statistical techniques have also been useful in refining and improving vegetation classification (del Moral 1975, MacCracken et al. 1983, McLendon and Dahl 1983, Mosely et al. 1986) and in identifying key vegetation variables to be measured.

The objectives of this study were to (1) identify the most useful variables (species) in a western wheatgrass-bluegrama-buffalograss vegetation type, or combination of variables, for discriminating among ecological stages; (2) test the accuracy of multivariate analyses in determining and predicting ecological stages; and (3) establish a resource value rating of ecological stages as related to management of livestock and wildlife.

Study Area and Methods

The study was conducted in Conata Basin and Badlands National Park, approximately 29 km south of Wall, S. Dak. The semiarid-continental climate is characterized by cold winters and warm summers. The temperature ranges from -5° C in January to 26° C in July, with a mean of 10° C. Average annual precipitation

is 40 cm, based on 20 years of climatological data from Cedar Pass Visitor Center in the Badlands National Park, 21 km from the study area. Most precipitation occurs as rain during the growing season (April–September). Precipitation (October 1 to September 30) for plant growth during this study was 46 cm.

The study area is within the wheatgrass-grama-buffalograss (*Agropyron-Bouteloua-Buchloe*) vegetation type (Kuchler 1975). Dominant grasses on the study area are western wheatgrass (*Agropyron smithii* Rydb.), blue grama (*Bouteloua gracilis* (H.B.K.) Lag.) buffalograss (*Buchloe dactyloides* (Nutt.)), and needleleaf sedge (*Carex eleocharis* Bailey). Dominant forbs are scarlet globemallow (*Sphaeralcea coccinea* (Pursh) Rydb.), prostrate verbain (*Verbena bracteata* Lag. & Rodr.), Patagonian plantain (*Plantago patagonica* var. *spinulosa* (Dene.) A. Gray), and dogweed (*Dyssodia papposa* Vent.). Plant nomenclature follows McGregor et al. (1986). Soil textures of the study sites in the Badlands National Park and Conata Basin are clayey, and range sites included dense clay, silty clay, and shallow clay (SCS, unpublished Pennington Co. Soil Survey, in prep. Wall, S. Dak.).

Forty-eight sites were selected for study, ranging from climax or near climax (potential) to a low seral stage. Vegetation condition of these sites selected ranged from potential or near-potential on the Badlands National Park to early seral stages based on SCS standards, where sites had been disturbed by cattle and prairie dog grazing and by past farming practices. Climax vegetation occurred on the 3 range sites defined by SCS standards in the study area. Because all 48 sites were similar in climatic environment, differences in vegetation composition were believed to be a result of past grazing by herbivores.

Each site was selected at random within perceived seral stages. Sites were sampled for canopy cover and frequency of occurrence by plant species over a 2-year period. Three parallel 50-m transects were systematically established 30.5 m apart at each site. Direction of plots were established at random. Canopy cover was estimated in 50 (2×5 dm) plots systematically spaced at 1-m intervals along each transect (Daubenmire 1959). Canopy cover and frequency of occurrence of individual species were estimated as mean percentage by averaging over the 3 transects for each site. Mean percent canopy cover was multiplied by frequency of occurrence to produce a cover-frequency index (maximum = 10,000) for each species at each site. Both canopy cover and frequency of occurrence were evaluated independently, but statistical evaluation of seral stages were less reliable.

Preliminary analyses led to the selection of 47 variables (comprising 45 common plant species, litter, and total canopy cover). Minor, uncommon species, which showed exceedingly high variation, were excluded because they yielded no interpretable results. For data reduction and identification of important variables, the 48 sites were assigned to 1 of 4 ecological stages (potential to low seral stage), based on perceived seral stage and relative proportions of potential species as determined by SCS methods (USDA-SCS 1976). Stepwise discriminant analysis (Dixon 1983) for reduction of variables was then used to identify the important variables (7 species) whose occurrence was highly correlated with the initial ecological stages; these 7 plant species were then selected from this

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analysis ($P \leq 0.05$ to enter) for further analyses. This procedure was used for data reduction in obtaining the number of variables relevant to the classification of seral stages and not an evaluation of perceived seral stages.

In most cases it is useful to reduce the number of variables of large data sets in some way before applying any particular clustering technique. A simple way to do this, and one which has been used in several studies, is to perform a principal components analysis on the data (Everitt et al. 1971). The first few principal component scores for each variable are used as input to the cluster analysis employed. In this study the same 7 variables were obtained in both discriminant analyses of the perceived seral stages and principal components analyses. Principal component analysis eliminates the need for perceived seral stages. However, the author recommends the use of perceived seral stages with discriminant analyses for data reduction because it is easier to interpret and understand. This procedure is also helpful for field selection of sites and sampling.

Data for the 7 species on each of the sites were subjected to a nonhierarchical cluster analysis (ISODATA) to group the sites into ecological stages (Ball and Hall 1967). Stepwise discriminant analysis was used again to estimate compactness of clusters, identify the key variables that accounted for their differences, and to develop Fisher classification coefficients (Dixon 1983, del Moral 1975). Error rates for misclassification were estimated by jackknife procedures (Lachenbruch and Mickey 1968). This procedure drops out 1 site at a time and tests the classification based on 47 sites.

Total aboveground biomass was estimated at peak growth under 5 wire cages (1.2×2.4 m) randomly established on each of 26 sites. Vegetation was harvested at ground level from 2 randomly located quadrats (31×61 cm) under each cage. Plant species were oven-dried at 60°C for 48 hours to a constant weight and weighted to the nearest 0.1 gram. Weights were expressed as kilograms per hectare by site. These data were subjected to discriminant analysis to determine accuracy of seral stages as defined by SCS standards.

Results

Cluster analysis separated the 48 sites into 4 separate groups representing specific ecological stages. Discriminant analysis indicated a significant separation ($P < 0.0001$) among these 4 stages. Only 3 plant species were required to estimate 3 canonical discriminant functions that accounted for 98% of total variation (Table 1). Western wheatgrass was the most important variable in

Table 1. Relative importance of plants for classifying ecological stages of rangeland in western South Dakota using standardized discriminant function coefficients.

Plant ¹	Discriminant function coefficients			Total variation explained %
	Function 1	Function 2	Function 3	
Western wheatgrass	0.89	0.24	0.44	81
Blue grama	-0.49	-0.36	0.83	94
Buffalograss	-0.33	0.89	0.38	98

¹Plants species are listed in order of entrance into the discriminant analysis. Magnitude of the coefficients indicate the importance of the species in each function.

function 1, buffalograss in function 2, and blue grama in function 3.

Western wheatgrass, blue grama, and buffalograss, which were present in all 4 stages, were the most useful variables in discriminating among ecological stages (Table 2). Because many other species did not occur in all 4 ecological stages, they were not useful for estimating stages. In addition, their extremely high variability (SD,

Table 2. Means (\pm SE) of indices obtained by multiplying frequency of occurrence (%) with canopy cover (%) of individual variables by ecological stage.

Grasses ¹	Range condition class			
	A Potential ²	B	C	D Early seral
Western wheatgrass	4212 \pm 353	113 \pm 54	629 \pm 214	611 \pm 161
Blue grama	1213 \pm 554	4892 \pm 312	945 \pm 298	1205 \pm 260
Buffalograss	81 \pm 58	1669 \pm 586	4975 \pm 483	494 \pm 166

¹Plant species used for discriminating among range condition classes.

²Potential vegetation (Kuchler 1975).

2 to 3 times greater than mean) would make adequate sampling prohibitive for these species within and among stages. Many of the other plant species and litter differed so little between/among the 4 stages that they also were not good variables for discriminating among stages.

The 3 major plant species were used to estimate Fisher classification coefficients to predict ecological stages (Table 3). The classification function for class A had a greater weighting for western

Table 3. Fisher classification coefficients of ecological stages for mixed grass prairie in western South Dakota.

Grasses ¹	Range condition class			
	A Potential ¹	B	C	D Early seral
Western wheatgrass	0.00837	-0.00058	0.00156	0.00105
Blue grama	0.00013	0.00403	0.00116	0.00089
Buffalograss	0.00057	0.00163	0.00341	0.00051
Constant	-19.12531	-12.56381	-10.90578	-2.36823

¹Potential vegetation as described by Kuchler (1975).

wheatgrass, class B for blue grama, and class C for buffalograss; ecological stage D had approximately the same weighting for all 3 grasses, but had low values. Based on jackknifing procedures in program BMDP7M (Lachenbruch and Mickey 1968, Dixon 1983), ecological stage of vegetation in the field could be classified with an estimated 95% accuracy.

Estimated total peak plant production was greatest (\pm 80% CI) for ecological stage B, followed by stage D, stage C, and stage A (Table 4). Western wheatgrass production was greatest in stage A (1,021 kg/ha), blue grama in stage B (576 kg/ha), and buffalograss in stage B (1,168 kg/ha). Stage B had the greatest grass and grasslike production (2,018 kg/ha) of the 4 ecological stages. Total forb production was greatest in stage D.

Estimated cattle forage production (plants consumed by cattle, kg/ha) for the 4 ecological stages was greatest for class B (2,180 \pm 489; 80% CI). Class A, C, and D were 1,364 \pm 293, 1,719 \pm 180, respectively. Forage species were determined using cattle diets from the Conata Basin (Uresk 1986). Additional forage provided in stage D was made up of forbs, whereas livestock forage production on stage A sites was mainly grass.

Discussion

Cluster analysis and discriminant analysis, which were used in this study to define ecological stages (cover-frequency index), examined all plant species collectively and associated variances between/among species. ISODATA (Ball and Hall 1967) clustered the data from individual sites into groups (classes) that are internally homogenous with a minimum variance within groups (del Moral 1975). Cluster analysis examined response patterns in vege-

Table 4. Estimated peak plant production (kg/ha ± 80% CI) by ecological stages for mixed grass prairie in western South Dakota (n = 26 sites).

Grasses ¹	Range condition class			
	A Potential ¹	B	C	D Early seral
Grass and grasslikes				
Western				
wheatgrass	1021 ± 454	36 ± 22	99 ± 48	592 ± 311
Blue grama	218 ± 150	576 ± 294	284 ± 152	120 ± 72
Buffalograss	26 ± 44	1168 ± 535	855 ± 297	97 ± 38
Needleleaf				
sedge	<1 ± <1	15 ± 7	39 ± 15	35 ± 24
Other				
graminoids	137	223	267	474
Total	1402 ± 448	2018 ± 570	1544 ± 296	1318 ± 334
Forbs				
Scarlet				
globemallow	44 ± 31	47 ± 15	45 ± 22	91 ± 45
Total forbs	153 ± 123	468 ± 397	458 ± 206	858 ± 395
Shrubs				
Total shrubs	37 ± 22	6 ± 9	1 ± 1	115 ± 145
Total production	1592 ± 387	2492 ± 459	2003 ± 240	2291 ± 255

¹Potential vegetation as described by Kuchler (1975).

tation data and separated the data into ecological stages that are more easily interpreted because of group homogeneity with minimum variances. Discriminant analysis allowed for an examination of the importance of variables (species) collectively, including determining which variables served best to separate classes (del Moral 1975).

Selection of variables to estimate ecological stages requires minimal variances within stages to meet statistical criteria for estimations in addition to biological importance. The basic data for a cluster analysis is a set of n variables or objects on which measurements have been recorded. This initial choice of measurements used to describe each variable, constitutes a frame of reference to establish clusters and the choice reflects, to some extent, the investigator's biological judgement of relevance for the purpose of clustering. Some attention needs to be given, therefore, to asking whether variables chosen are relevant to the type of classification being sought (Everitt 1977). For example, if a classification of the mentally ill is sought for the purpose of investigating the effect of different treatments on different types of patients, it is in general, not sensible to include such variables as height, weight, and other 'vital' statistics, since on the basis of these variables, the most likely classification is into males and females. This would be a 'useful' classification in other respects, but almost certainly not for classification of the mentally ill. In our study, the key variables were perennial plants that range from climax to a low seral stage with minimum variances within ecological stages. These plants were reliable for classification of seral stages. Minor species and annuals were too variable between and among stages and within years to provide a reliable ecological classification of seral stages.

Other methods, for example Soil Conservation Service (USDA-SCS 1976) and Forest Service range analysis (USDA-FS 1968), do not consider variances, only averages. In those methods, plant species are considered individually for evaluation and collectively only for subjective evaluations; generally those other methods do not consider canopy cover and frequency data. Production estimates are usually too highly variable to be used for defining ecological stages (Table 4); in addition, it is difficult to manipulate large tables of numerical data for interpretation without appropriate statistical evaluation. Percent plant composition can be misleading if based on average production estimates without considering variances. Composition data show relative changes, which are

less accurate for estimating ecological stages, whereas actual plant species data with associated variances provide accurate and precise information. The combination of ISODATA clustering technique and discriminant analysis to define ecological stages provides an effective procedure for separating stages using key plant species.

Production estimates are less accurate (31% error rate using some procedures defined in this study) in estimating ecological stages based on SCS standards because of greater variability in the data when compared with the cover-frequency index (Tables 2,4). Production estimates also are more time-consuming because they require actual field collection of plants. However, production estimates are necessary to estimate livestock stocking rates and provide an estimate of plant and range vigor.

Discriminant analysis indicated information on only 3 plant species (western wheatgrass, blue grama, buffalograss) was required to account for most of the variation among 4 ecological stages identified in this study. All variables (including minor species) were subjected to statistical analyses, plotting, and field evaluation. Minor plant species, total canopy cover, and litter did not show trends or prove useful for evaluating and describing ecological stages. Two factors limited the usefulness of these parameters: (1) variability was extremely high for individual parameters, and discriminant analysis selected those variables with a minimum of variance within an ecological stage; and (2) statistical differences between and among ecological stages for vegetation parameters were minimal because of the high variance or no change in the range of data for a variable (i.e., total canopy cover). Sampling the entire range of data from low to high estimates for a variable across stages (potential to early seral) is needed for this type of analysis. Perennial plants generally meet these criteria, whereas annual and minor species are highly variable to predict changes in stages, statistically and biologically. Other parameters such as plant vigor might provide additional information for evaluation of ecological stages (Bjurgstad and Whitman 1970, Rickard et al. 1975, Uresk et al. 1980, Wilson and Tupper 1982).

These classification functions are significant when applied within the western wheatgrass-bluegrama-buffalogramma vegetation type in western South Dakota. They may not be accurate over extremely large areas with different environments because precipitation, soil characteristics, and topography influence vegetation potential. New classification coefficients should be developed for other vegetation types, and other variables than those presented here may be important. Ecological stages derived using cluster analysis and discriminant analysis may, however, be used to estimate the degree of confidence that should be placed on ecological stage classification. The estimated error rates based on variables measured provide a level of confidence in separation of ecological stages.

Ecological stages were quantitatively identified with an estimated 95% reliability, based solely on cover-frequency estimates for western wheatgrass, blue grama, and buffalograss. Variation in these 3 species can be used by management as indicators of ecological stages and range condition. This method for assessing ecological stages is easily applied in the field. Once Fisher classification coefficients have been derived from discriminant, the method used to classify a site involves estimating the cover-frequency index for the 3 plant species and for each of the 3 species, multiplying its index by the appropriate coefficient for each ecological stage (Table 3). These values are summed for each stage and the highest score indicates the assigned ecological stage. For example, if scores are a -14, -10, -5, and -1, for classes A, B, C, and D respectively, the site would be classified in ecological stage D (-1 is the highest score); minor differences in scores indicate indecision. This procedure can be used to follow trends in ecological stages through time. The method, once developed, provides a manager with a tool in

Table 5. Estimated peak forage production (kg/ha \pm 80% CI) by ecological stage class for mixed grass prairie in western South Dakota. Forage species were determined from cattle diets in Conata Basin (Uresk submitted).

Ecological Stage	Forage Production
A Potential	1364 \pm 310
B Late	2180 \pm 489
C Mid	1550 \pm 293
D Early	1719 \pm 180

which a data set can be applied to obtain replicable results. With other methods, a data set can be interpreted by several managers and yield different results because of subjectivity.

The cover-frequency index combines estimates of 2 important vegetation characteristics. Frequency relates to the number of times a species occurs in a given number of small sample plots and is a measure related to density (Mueller-Dombois and Ellenberg 1974). Canopy cover, the vertical projection of the shoot area of plants, is of greater ecological significance than density in the measurement of plant distribution (Mueller-Dombois and Ellenberg 1974) and gives a better indirect measure of plant biomass than the number of individuals. Cover values may change due to year differences, but multiplied with frequency to form an index, changes in an ecological stage are less likely when a change may not exist; frequency values are less likely to change abruptly on a yearly basis. However, if high frequency paired with low cover is equivalent to low frequency paired with high cover for a species, then the index is flawed. The likelihood of both situations occurring in the vegetation type for these 3 species is highly unlikely, but it cannot be precluded for other plant species in other vegetation types. Individual variables, i.e., total grass, forbs, and shrubs were not good for estimating stages, because data did not show enough change from high to low among the stages. A disadvantage of using major categories is that the values may remain the same, but major changes could occur with individual plant species. Species of plants are better indicators to estimate changes in and between ecological seral stages.

The concept of ecological stages has been widely accepted as a measurement of community. Ecological stages provide a unit of measurement useful to managers in meeting objectives such as livestock or wildlife production (Smith 1978, Dyksterhuis 1985). Ecological stages can also provide information useful in evaluating effects of management. Descriptions of potential or near-potential vegetation and departures from potential have been used to measure ecological stages. However, management of rangelands for potential vegetation does not usually meet all management objectives and goals. In this study, ecological stage B is optimum for livestock production because highest forage yields are available; but for management of nongame animals on this area, an earlier stage, such as C and/or D, is more beneficial because of increased heterogeneity (Agnew et al. 1986).

Multivariate analyses provides a precise method for assessing range ecological stages and the degree of departure from potential communities. However, development of classification coefficients for ecological stages requires a large sample size representing the variety of stages caused by past grazing to assure data are adequate for effective analysis. The coefficients derived in this study would be applicable for clayey soils. Vegetation sampled must include samples from the entire area, ranging from potential to early seral stages. Furthermore, managers should recognize that management for potential vegetation may not meet their objectives in all cases. In this study, class A sites did not provide for either maximum livestock or nongame wildlife production.

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