Classifying Grassland Vegetation with a Diversity Index

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Highlight: An objective method of classifying grassland vegetation is used to evaluate similarities of species composition between stands. The procedure used for the classification involved the calculation of a change in diversity that occurred when vegetation units, such as stands, were combined into larger units. Some species were noted to occur in several stands in such a way as to change diversity which was interpreted in terms of species importance.

In order to be effective, the rangeland manager must have a thorough knowledge of the ecological structure of plant and animal communities. He should also be able to identify the various communities that occur within the boundaries of his management unit. Anderson (1965) stated that some system for recognizing plant communities was essential as a preliminary step in studying vegetation. It then follows that such a system would also be useful in vegetation management. In fact, a major problem for the range resource manager is to identify units of vegetation which can be easily managed and can be interpreted ecologically. The objective of the present study was to use and evaluate hierarchical diversity analysis as a method for describing and classifying grassland vegetation.

Several authors have discussed the use of hierarchical procedures for vegetation classification and a detailed account of these is given by Brady (1971). Some effort has been made to use this approach as a relative measure of the degree of similarity between vegetation stands (Lance and Williams, 1967). In turn, such a measure of similarity should be useful in constructing a vegetation classification system. Many of these similarity measures are simple to interpret since no assumptions are necessary concerning the analytical properties of the vegetation similarity index. Therefore, no confidence limits of a statistical nature are necessary which will place the vegetation units into various vegetation classes. Other techniques using statistical criteria, such as discriminant analysis, are available for classifying vegetation into known groups after these groups have been defined (Bonham, 1972).

Comparisons between vegetation units can be based on a number of available similarity indices (Lance and Williams, 1967). The index of diversity proposed by McIntosh (1967) was chosen for this study. This index measures the change in

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Fig. 1. An example of four stands grouped by hierarchical diversity procedures.

species diversity that occurs between any two vegetation stands. A decrease in similarity between stands in a hierarchical structure can be reflected in graphical form by an increase in incremental height of the vertical lines connecting them. This concept is illustrated in Figure 1. That is, vegetation units A and B are more similar to each other than are units C and D. This kind of vegetation analysis for classification should enable a range resource manager to evaluate similarities and dissimilarities that may exist between vegetation types occurring within his area of management.

Literature Review

Pielou (1969) stated that a major problem in classification of vegetation is to determine whether or not classification is even appropriate for the problem at hand. However, Kendall and Stuart (1966), along with Pielou (1969), stated that classification may be appropriate simply as a matter of convenience in describing vegetation. Vegetative units can always be subdivided or classified according to criteria established by the interested individual, but this does not suggest that the vegetation represented by such units can be described as having well-defined boundaries.

Classification alone does not indicate whether the vegetation consists of a number of distinct communities, or whether it consists of overlapping communities (Pielou, 1969). Quite often, unnatural classifications are made which result in clusters or groups of stands exhibiting a high degree of similarity within these clusters or groups (Kendall and Stuart, 1966). In fact, distinct boundaries seldom exist between either

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natural or artifical groupings of vegetation (Whittaker, 1970).

Whittaker (1970) stated that vegetation diversity is dependent on two characteristics of the vegetation. One is the number of species present, identified as S, which indicates species richness. The other characteristic describes the distribution of the individuals in the population among the species, symbolized by N. McIntosh (1967) also used these characteristics to define maximum and minimum diversity in vegetation. Diversity is at a maximum when individuals in the population are evenly distributed among the species in the population. That is, the number of individuals per species is equal to N/S. A concentration of individuals into one or a few species, with the remaining species having low representation, results in a lowering of diversity. Diversity reaches a minimum when one species is represented by N-S+1 individuals and the remaining species are represented by only one individual (McIntosh, 1967). For a full discussion of various types of diversity, refer to Whittaker (1970).

McIntosh (1967) proposed a measure of diversity in terms of a geometrical distance. That is, the relative distance between two communities is the square root of the sum of the squared differences between the measures of each species. This index is calculated as

$$D_{jk} = \sqrt{\sum_{i=1}^{S} (X_{ij} - X_{ik})^2}$$
(1)

where X is the measure of the i^{th} species in stands j and k, and D is the diversity value. The summation extends over the number of species, S. McIntosh (1967) further proposed that a stand of vegetation be compared to a reference level of bare ground which has zero individuals, and gives a diversity value for an individual single stand as

$$D_{j} = \sqrt{\sum_{i=1}^{S} n_{i}^{2}}$$
 (2)

where *n* represents the number of individuals in a given species for stand *j*. The index, D_j , given in equation (2) then represents the complement of diversity. Furthermore, this index is also directly related to diversity by the equation

$$D_{j} = N - \sqrt{\sum_{i=1}^{S} n_{i}^{2}}$$
 (3)

where N is the total number of individuals in the population sampled.

McIntosh (1967) further noted that equation (3) is a measure of diversity since its value depends upon the number of individuals in the sample and their distribution among the species. This index is similar to the information statistics proposed by Shannon and Weaver (1949) and Brillouin (1962) as diversity measures. McIntosh's index, in contrast to other diversity measures, is sensitive to N, the total number of individuals occurring within a community. Equation (3) was used in this study to calculate diversity for an individual stand by replacing n_i with the relative cover value for species *i* and Nwith the total relative cover for stand *j*.

Methods

The study area was located at the Research Ranch,

| Fable 1. | An | example | of | species | cover | data | for | two | stand s | and | two |
|----------|-------|------------|------|----------|---------|--------|-------|-------|---------|-------|------|
| species | used | l to calcu | late | a chang | ge in d | iversi | ty a | nd th | ie prop | ortio | n of |
| the cov | er va | lues cont | ribu | ted by i | he spe | cies w | vithi | n eac | h stand | • | |

| | | Speci | | | | | |
|--------|------------|------------|------------|------------|------------|--------------|--|
| | | 1 | | 2 | Total | | |
| Stands | Cover % | Proportion | Cover % | Proportion | Cover % | Proportion | |
| 1 2 | 20 35 | .33 .70 | 40 15 | .67 .30 | 60 50 | 1.00 1.00 | |
| Total | 55 | 1.03 | 55 | .97 | 110 | 2.00 | |

approximately 60 miles south of Tucson, near Elgin, Ariz., in Township 21S, Range 18E. The area has not been grazed by domestic livestock since late 1967. The study site contained 1000 acres with vegetation conditions ranging from densely sodded to sparsely covered grassland. The general area, which ranges in elevation from 4800 to 5200 ft, is surrounded by the Huachuca Mountains on the southeast, Canelo Hills on the south and southwest, and the Mustang Mountains on the northeast. Average annual precipitation is 18 inches, 60% of which occurs during summer months.

The vegetation of the site is now primarily a shortgrass type which Weaver and Clements (1938) recognized most nearly resembles the shortgrass region of the Great Plains. In fact, they indicated that this type cannot be distinguished from the latter when overgrazed. This is verified in that the dominants are made up almost exclusively of *Bouteloua* (grama grasses) and *Aristida* (three-awn grasses) species.

Field data on each species in the area were collected during the summer of 1969. A 40cm \times 40cm plot was placed at random in stands of vegetation which were 10m \times 10m. Ten of the smaller sample plots were used within each stand to estimate ground cover of foliage to the nearest 5% for each species. Twenty-five of these stands were sampled within the grassland area. Data on all vascular plants occurring within the plots were retained in the analysis.

Average cover values for species in each stand were summed, and this sum was divided into the individual cover value for each species. Therefore, each species value was proportional to the species importance in the stand. In this case, the sum of the relative cover values for all species equaled 100% for each stand. These relative cover values by species were used to calculate a similarity index for any two stands based on the measure of change in diversity as expressed in equation (4)

$$\Delta D = D_{i+k} - (D_i + D_k)$$
(4)

where ΔD is the change in diversity as two stands are combined. D_{j+k} is the diversity calculated using equation (3) after the species cover values have been pooled from the two stands, *j* and *k*. The value obtained from equation (4) will equal zero when the two stands are identical.

Intermediate steps in the calculations included computer storage of the change in diversity values, ΔD , for all possible combinations of vegetation stands (Brady, 1971). The amount of change in diversity of a stand when compared to itself was equal to zero and all other values were greater than zero.

Each change of diversity values for any two stands was used to start the construction of hierarchies for the vegetation stands. The process began with the selection of the smallest change in diversity value for any two stands. These two stands were then combined to form a vegetation group which expressed the average diversity characteristic for the two stands. Following this, the two stands represented by the next smallest value were combined into a group if neither of the stands had been previously combined. This procedure was

| | Group A | | Group B | | Group C | | Group D | | Group E | |
|--------------------------|-------------------|------------------|-------------------|------------------|----------------------|------------------|-------------------|------------------|-------------------|------------------|
| Species | % Stands occurred | Avg cover (%) | % Stands occurred | Avg cover (%) | % Stands occurred | Avg cover (%) | % Stands occurred | Avg cover (%) | % Stands occurred | Avg cover (%) |
| Andropogon barbinodis | 43 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 2 |
| Aristida barbata | 86 | 2 | 67 | 1 | 100 | 5 | 100 | 15 | 100 | 3 |
| Aristida ternipes | 0 | 0 | 0 | 0 | 40 | 1 | 0 | 0 | 0 | õ |
| Bouteloua chondrosioides | 100 | 8 | 100 | 4 | 80 | 4 | 100 | 15 | 100 | 2 |
| Bouteloua curtipendula | 43 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 9 |
| Bouteloua gracilis | 29 | * | 67 | 2 | 100 | 13 | 100 | 2 | 0 | Ō |
| Bouteloua hirsuta | 100 | 8 | 83 | 4 | 40 | 1 | 50 | 3 | 100 | 4 |
| Desmanthus cooleyi | 43 | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Dychoriste decumbens | 29 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | * |
| Eragrostis intermedia | 43 | * | 33 | * | 0 | 0 | 50 | * | 100 | 3 |
| Evolvulus arizonicus | 0 | 0 | 33 | * | 0 | 0 | 0 | 0 | 100 | * |
| Hilaria belangeri | 71 | 3 | 100 | 11 | 40 | 1 | 50 | * | 50 | 1 |
| Lycurus phleoides | 86 | 1 | 67 | 3 | 60 | 1 | 50 | * | 100 | * |
| Mimosa dysocarpa | 29 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sida procumbens | 29 | * | 0 | 0 | 0 | 0 | 0 | 0 | 0 | Ō |

Table 2. Summary of species cover of grassland stands and groups formed from hierarchical analyses.

*Indicates a cover value of < 1.0 percent.

repeated for all of the stands represented in the ΔD matrix until all of the stands had been assigned to a group. The process at this point was initiated again and new groups were formed from the combined stands as in the first iteration. Iterations were continued until all of the groups were combined in such a way that only one group remained which included all 25 vegetation stands.

Data in Table 1 will be used here to illustrate the application of equations (3) and (4). The subscripts of D (diversity) represent stands 1 and 2, respectively. The use of relative cover values will always make N of equation (3) equal to unity for all stands which may be convenient. Therefore,

$$D_{1} = 1.00 - \sqrt{(.33)^{2} + (.67)^{2}}$$

$$= 1.00 - \sqrt{.5578}$$

$$= 0.253$$

$$D_{2} = 1.00 - \sqrt{(.70)^{2} + (.30)^{2}}$$

$$= 1.00 - \sqrt{.5800}$$

$$= 0.238$$

$$D_{1+2} = 2.00 - \sqrt{(1.03)^{2} + (.97)^{2}}$$

$$= 2.00 - \sqrt{2.0018}$$

$$= 0.585$$

$$\Delta D = 0.585 - (0.253 + 0.238)$$

$$= 0.094$$

The value of the calculated change in diversity was used to determine the height of vertical connecting lines between the corresponding groups. Thus, a hierarchical classification for the various groups was derived. The last step in the classification procedure was the actual formation of the hierarchy in the form of a diagram, which was constructed manually by using the change in diversity values. Interpretations of stand groupings with respect to species occurrences were then made.

Results and Discussion

The hierarchical classification of the 25 stands of grassland vegetation is presented in Figure 2. The assignment of stands

to form a vegetation group was arbitrary in that no criteria was used to determine when a significant change occurred in diversity. However, from a practical viewpoint, levels of ΔD may be chosen such that species composition is relatively uniform within the group of stands. The grassland data of this study indicated that three very distinct groups (A, B, and C) of vegetation stands were formed by the analysis. These groups of stands were the result of discontinuities which existed in the distribution of individual species in the study area. The two smaller groups, D and E, also differed from the three larger groups. Individual stands such as 20, 21, and 23, which were not linked to a larger group until the ninth or tenth iteration, had considerable variation in species composition and cover. These three stands had only small amounts of cover for the major species, and each stand had a different dominant species.

Interpretation of these groups can lead to an understanding of how species are associated with one another as measured by their individual contributions to ground cover. Table 2 describes the most important species cover characteristics with respect to groups of stands formed by the diversity analysis. These species are important in that they account for the change in diversity necessary to separate stands which are more dissimilar. Only a few species are noted as common to all



Fig. 2. Hierarchical grouping of 25 grassland stands using change in diversity procedures.

groups.

The largest single factor contributing to a species importance for a change in diversity within a group is the extent of its occurrence among that particular group of stands. That is, variation in species cover is more important in its contribution to change in diversity than the consistent occurrence of its cover values within a group of stands. Therefore, groups of stands are linked together as a particular species or group of species contributes to change in diversity. Stands become increasingly dissimilar with respect to each other as species contributions become increasingly variable within stands or within a group of stands.

The influence of individual species in forming groups can be seen by comparing stands 5 and 9 in Group A (Fig. 2). These two stands have havard three-awn (Aristida barbata), sprucetop grama (Bouteloua chondrosioides), hairy grama (Bouteloua hirsuta), and curly mesquite (Hilaria belangeri) in common. Another pair of stands which had a similar change in diversity, yet was very dissimilar to stands 5 and 9, was stands 11 and 12 in Group B. These two stands had lower cover values for havard three-awn than did stands 5 and 9. The other three species mentioned above had more variation in cover values within stands 11 and 12. Stand groupings A and B differ in several respects. Group A had 13 species occurring with cover values greater than zero, while in Group B only eight species occurred (Table 2). Therefore, the dissimilarity between the two groups could be established on the basis of different species numbers, as well as cover values of common species. As pairs of stands are combined into larger groups, linkage of these stands changed with regard to species. For example, stands 7 and 13 along with 11 and 12 had spruce-top grama and curly mesquite occurring in common. In comparison to this linkage, stands 3 and 15 were linked with the overall group by the occurrence of spruce-top grama. In the latter linkage, hairy grama and curly mesquite dropped out as common species and havard three-awn occurred as a minor species.

The linkage of all 25 stands and subsequently the five sub-groups was due to the cover of spruce-top grama and havard three-awn occurring in all groups (Table 2). Other species which were also important in linking the overall groups together included hairy grama, curly mesquite, and wolftail (*Lycurus phleoides*). In contrast, blue grama (*Bouteloua gracilis*) was responsible for providing a linkage between Groups C and D, but did not occur widely enough to influence further groupings (Table 2). Many other species occurred in minor amounts and had an influence on the change in diversity of various pairs of stands as the hierarchical structure was built.

The importance of individual species in linking vegetation groups together is obvious. That is, the individual species provides a method of constructing classification systems and influences the outcome of the classification. Usually only a few species are of major consequence for typing vegetation into units. In fact, vegetation types are usually constructed based on dominant species which occur within the type. However, vegetation typing based on this criterion is not always immediately obvious in a grassland such as the study area. This kind of vegetation pattern often appears to have the same few species occurring as dominants throughout, yet the hierarchical diversity analysis revealed important differences in vegetation structure of stand groupings.

In conclusion, the method of classifying vegetation by hierarchical analysis using change in diversity has provided a key for interpreting vegetation characteristics. Hierarchical analysis provided for a description of species and their influences in forming clusters of stands which were similar in species cover composition. The influence of minor species with small cover values occurring within stands provided for an increase in change in diversity in such a way as to distinguish stands which were greatly dissimilar. The commonly-occurring species which linked various groups of stands together were also casily identified by analyzing the hierarchical structure with respect to individual species cover contributions within stands and within the various groups formed. Thus, it appears that this procedure could serve as a useful method to the grassland manager in determining the vegetational similarities and dissimilarities of various subunits occurring within his geographical area. Indicator species, which are necessary for particular management purposes, could be evaluated as to their importance in linking certain groups of vegetation units together. Furthermore, rare or endangered plant species could be evaluated with respect to their association in vegetation types or groups of stands.

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