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W. H. Moir
Rocky Mountain Forest and Experiment Station, Fort Collins, CO

C. D. Bonham
Department of Rangeland Ecosystem Sciences, Colorado State University, Fort Collins

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Diversity Indices Applied in Desert Grassland Communities of Otero Mesa, New Mexico

W. H. Moir
Rocky Mountain Forest and Experiment Station
Fort Collins, CO 80524

C. D. Bonham
U.S. Department of Agriculture, Forest Service
Department of Rangeland Ecosystem Sciences
Colorado State University
Fort Collins, CO 80521

Abstract

To describe plant community (alpha) diversity on rangelands, managers are confronted with a variety of commonly used indices. The choice, performance, and interpretations of these indices are often not clear. Biodiversity indices were computed for a variety of plant communities in a desert grassland of southern New Mexico. Data consisted of reported importance values, range transect data for both grazed and ungrazed pastures, and search-and-find data specifically addressed to plant community diversity. Occurrence of threatened and endangered plants was considered by a weighting procedure. Performance of each diversity index was evaluated by ranking plant communities from low to high and comparing the rankings yielded by the various indices. Data based upon importance or dominance that omit plant species of lesser importance or dominance should not be the basis of comparisons for alpha diversity. Communities described by range transect data ranked differently depending upon the index used. The most practical measure of plant species diversity may be the number of species found by search-and-find procedures.

INTRODUCTION

Diversity is a characteristic of plant communities that indicates variation among a combination of properties such as number of species, life forms, cover values, patchiness, or densities. Diversity at the community or alpha level is defined as the number of plant taxa present in the community together with some measure of how common, abundant, or dominant these taxa are relative to each other (Magurran 1988). Sometimes usage of the term *diversity* is limited simply to the number of taxa present in the community (richness). Range managers acknowledge the importance of plant diversity in helping evaluate range condition or health (West 1993).

For describing diversity in plant communities, ecologists are confronted with numerous indices (Magurran 1988). It is not uncommon for managers to apply these indices to data already reported from inventories not expressly designed for estimating diversity, a fallacious practice as we illustrate in this paper. Different indices portray different attributes of the plant community and are sensitive to methods of sampling. Selection of a particular diversity index can support an underlying bias in favor of or against particular range community plant assemblages (West 1993). Can we speak of plant diversity alone, without regard to other organisms, and make sense out of plant assemblages? In what ways are diversity measures value laden? How can managers or investigators use diversity indices for establishing management objectives? For example, how can the existence of threatened or endangered plants, clearly an important diversity element, be quantitatively assessed? Can diversity be used to describe "abundance" aspects of range communities, such as cover or biomass of forage plants?

One way of gaining familiarity with diversity indices and evaluating their usefulness is to compare the performance of some common indices across a variety of plant communities. Then diversity becomes a kind of "scorecard," somewhat akin to more familiar scorecards, such as ecological condition or forage production.

Here expressions of some common measures of community diversity are evaluated in a variety of desert grassland communities. Different measures are examined to rate both grazed and ungrazed communities, with and without adjustments for rare or endangered species. Several data sources are used to illustrate the kinds of data available to range managers and from which diversities are often computed. Results are compared by ranking different communities from low to high diversity according to the various diversity indices.

Indices are then evaluated for effectiveness in management interpretation.

METHODS

THE STUDY AREA

Otero Mesa is a vast (209,000 ha) grassland in the lower Tularosa Basin of southern New Mexico. Vegetation generally corresponds to the Shrub–Mixed Grass and Plains–Mesa Grassland Series (Dick-Peddie 1993). Only small portions of this grassland were studied, namely a 349-ha tract of ungrazed (by domestic livestock) grassland along State Road 506 and the two adjoining pastures known as McGregor range units 7 and 9 (BLM 1980). Details of the plant synecology in the ungrazed area were described by Stewart (1982) and Ludwig and Moir (1987). Range conservationists from the BLM (Bureau of Land Management) measured range condition in the pastures for purposes of computing allowable livestock numbers used in their lease bidding system (BLM 1980).

Vegetation in the areas studied is dominated by perennial grasses, mostly *Bouteloua eriopoda,* with a mixture of shrubs, succulents, perennial forbs, and annual plants (Table 1). The climate is semiarid, with summer rains accounting for over 50 percent of the mean annual precipitation of about 34 cm. Winter precipitation is erratic, but is especially important for C_3 plants (Neilson 1986). Mean annual temperature is about 14° C. A pedon in the ungrazed area of the study site indicated the soil to be a moderately deep, very cobbly Aridic Ustochrept developed from limestone parent material. Four soil series were described within the preserve tract (administered by New Mexico State University under a cooperative agreement with BLM and the Department of Defense). All soils are calcareous throughout their profiles. The principal differences between these steppic soils are primarily the solum depth, texture, and development and erodibility of the A1 horizon (Soil Conservation Service data contained in BLM 1980).

DATA SOURCES AND COMPUTATIONS

Several vegetation data sources were used in this study (Table 1). The proportionate values in the body of Table 1 can be multiplied by totals at the bottom of each column to obtain actual values reported in the different data sources. Data for five plant communities came from summary tables in Stewart (1982). Her tabular reports included only those plant taxa having the greatest importance, calculated as the sum of relative density, relative frequency, and relative cover for each plant taxon. We use these data as an example of available data from which diversity is sometimes computed. The second source of data was BLM transects from permanent Parker three-step clusters in pastures grazed by cattle. The transect indicated as BLM-8 was in the McGregor Range unit known as the Mesa Horse Camp (MHC) pasture; transect BLM-9 was in the unit known as the Rutherford Winter pasture. Range conditions of the plant communities represented by these transects were respectively "good" and "fair" as calculated using BLM standards.

Finally, in late July 1990 several areas were sampled by procedures expressly designed for obtaining estimates of vascular plant community (alpha) diversity. These were time-controlled search-and-find techniques. The first exercise was to search exhaustively (by essentially random walking) an approximately 0.2-ha area in the Mesa Horse Camp pasture (Plot MHC-1). All vascular plants were tallied during two hours of searching (computed on the basis of one person searching). Canopy coverage (Daubenmire 1959) was assigned to each plant taxon using subjective visual estimates rather than measurements from quadrats. This method seemed justified, since interest resided in both the richness and evenness components of diversity rather than actual cover, biomass, or frequency. This sampling "overkill" was far in excess of the time that would be spent measuring range condition and trend by the standard procedures used by BLM. The intention was to obtain a seasonal measure of maximum alpha diversity.

The second search-and-find procedure took place in paired 0.2-ha plots, one of them (MHC-2) in the Mesa Horse Camp pasture and the other one (NA-506) in the natural area along highway 506. Each search was limited to 20 minutes (by a single searcher). At the end of that time each plant taxon was assigned a subjective abundance class based on cover (5 = abundant, 4 = very common, 3 = common, 2 = uncommon, 1 = rare). We consider this method more practical than that used in the first search-and-find procedure, because a range conservationist could sample the diversity of numerous plots during a working day.

The search-and-find exercises occurred July 19, 1991, about eight days after the onset of summer rains. Warm-season vegetation was greening up, and one ephemeral species, the zephyr lily *(Zephyranthes longifolia),* was in fruit dispersal phenology.

We computed several conventional indices of diversity (Magurran 1988) for each data set using AID (analysis of information and diversity) programs developed by Overton et al. (1987). The diversity indices are given in Table 2, using notation of Overton et al. (1987). Diversities were computed from proportionate values of each taxon (Table 1) in order to minimize differences in sampling or reporting methods.

Rare, endemic, or threatened plants are major biodiversity concerns among many biologists and publics. One of these in particular, *Toumeya papyracantha*(grama grass cactus), is considered a diversity element warranting special management to ensure that adequate numbers will be maintained *in situ* (Spellenberg 1993). For computing weighted measures, a coefficient, w_i, was assigned to all plant taxa. This allowed additional weights to be assigned to *Toumeya,* such that the sum of the weights is equal to N_j, the total number of taxa in plot j. The exact weight given to *Toumeya* is not important for our purposes, although we note the probability of occurrence, p_i, is very small, and therefore the weights to be effective must be relatively large. We assigned weights of 1.0, 7.5, and 15 to this cactus. The results are reported respectively as plots MHC-1w0, MHC-1w1 and MHC-1w2 in Table 3.

If *Bouteloua eriopoda* declines on poor ranges, so does *Toumeya,* which depends especially upon the cover of this grass for survival (Fletcher and Moir 1992). Since this grass

TABLE 1. PLANT COMMUNITIES AT OTERA MESA, NEW MEXICO. THE VALUES IN THE BODY OF THE TABLE ARE PROPORTIONATE VALUES. TO COMPUTE REPORTED VALUES (BY DIFFERENT WORKERS), MULTIPLY THE PROPORTION FOR EACH TAXON BY THE TOTAL AT THE BOTTOM OF EACH COLUMN.

Taxa by growth forms	SPAI/NOS	EULA/LAT	LATR/BO1	LATR/BO2	LATR-FL1	BLM-8	BLM-9	MHC-1	MHC-2	NA-506
SHRUBS > 0.5 m tall										
Atriplex canescens					0.007					
Ephedra trifurca										0.016
Flourensia cernuum				0.003	0.030		0.042	0.001	0.015	0.032
Larrea tridentata		0.135	0.001	0.075	0.180		0.177	0.049	0.076	0.079
Prosopis juliflora								0.005	0.030	0.016
Senecio longilobus										0.016
Yucca elata	0.001	0.001	0.001	0.001				0.005	0.030	0.016
SHRUBS < 0.5 m tall										
Croton pottsii		0.039		0.010	0.005			0.097	0.076	0.064
Dalea formosa		0.001	0.001							
Dyssodia acerosa		0.002	0.035	0.051			0.034	0.010	0.046	0.016
Eurotia lanata		0.021						0.005	0.030	0.032
Gutierrezia sarothrae		0.011	0.091	0.074	0.057	0.177	0.283	0.073	0.076	0.048
Parthenium incanum					0.002			0.001	0.015	0.016
Zinnia grandiflora								0.001	0.015	0.016
BUNCH GRASSES										
Aristida arizonica										0.032
Erioneuron pulchellum							0.011	0.010	0.030	
Hilaria mutica	0.034									
Muhlenbergia porteri										0.016
Setaria macrostachya										0.016
Sporobolus airioides	0.527						0.015			
Sporobolus flexuosus						0.170		0.073	0.046	0.048
Unidentified						0.054	0.023			
Aristida sp.										0.048
MAT GRASSES										
Bouteloua eriopoda		0.554	0.746	0.582	0.122	0.543	0.031	0.487	0.076	0.079
Bouteloua gracilis	0.114	0.071	0.050	0.044	0.086	0.008	0.125	0.010	0.030	0.064
Bouteloua hirsuta							0.018			
Unidentified						0.004	0.005			
Muhlenbergia arenacea				0.046	0.168		0.019		0.015	0.032
Muhlenbergia arenicola						0.021	0.050	0.001		
Muhlenbergia torreyi						0.017		0.010	0.030	
Panicum obtusum							0.027	0.001	0.015	0.016
Scleropogon brevifolius	0.069				0.166		0.019			
RHIZOMATOUS FORBS										
Leersia ericoides								0.010	0.030	0.016
Perezia nanum	0.037		0.003				0.011	0.049	0.061	0.064
Desmanthus								0.073	0.046	0.032
Polygala sp.										0.016
Sphaeralcea sp.		0.036				0.006		0.001	0.015	
Unidentified										0.016

TAPROOTED FORBS										
Haplopappus spinulosus								0.010	0.030	0.048
Lesquerella fendleri							0.015			
Lesquerella montana							0.045			
Lepidium sp.								0.001	0.015	
Linum sp.								0.001	0.015	
Thelysperma sp.								0.001	0.015	0.016
BULBOUS FORB										
Zephyranthes longifolium								0.001	0.015	0.016
TALL SUCCULENTS										
Opuntia leptocaulis										0.016
Opuntia spinosior								0.010	0.046	0.016
Opuntia phaeacantha							0.052	0.005	0.030	0.032
DWARF SUCCULENTS										
Echinocereus viridiflorus								0.001	0.015	
Toumeya papyracantha								0.015		
NON-VASCULAR PLANTS										
Cryptogams	0.218	0.129	0.072	0.114	0.177					
Total	94.8	92.4	77.9	88.0	87.4	72.0	81.3	100.0	101.0	102.7
Count (all taxa)	7	11	9	10	11	9	19	30	29	32
						good	fair			

was already dominant, a special weight for it was considered unnecessary for maintaining the endangered cactus.

After computing diversities for each community sample, the communities were ranked from low to high for each diversity index within each of the data sources. The rankings are given by the sequence of communities (abbreviated as numbers) in the columns of Table 3. The last column gives an averaged rank order from low to high of the numbered communities across all the indices.

RESULTS

The easiest measurement to obtain in the field is the number of taxa present, or simple richness. To be useful in comparing different sites, count rules must be fixed, because the number of plant taxa counted will depend upon time spent observing as well as the area covered. Communities one through five in Table 3 were sampled by Stewart (1982) using fixed rules, but her tabular reports included only those plant taxa having the greatest importance values. Community five (LATR-FL1 in Table 3) was ranked the most diverse by all measures; this community was high in reported taxa, and most taxa had relatively even and rather low importances (p=.002–.177). Community three (LATR/BOER1) was ranked least diverse by most measures. This community had low evenness, expressed particularly by the high importance of *Bouteloua eriopoda* (p=.746). We note that the Simpson and McIntosh evenness measures (J[SDI] and J[MDI]) have opposite interpretations, the former ranking community three relatively high, the latter ranking community three low. The other communities were sequenced four, two, one between communities three and five by Simpson's diversity index (SDI) and the McIntosh evenness measure (J[MDI]). By contrast, the information measure (HE) and McIntosh diversity (MDI) ranked these communities in opposite order between communities three and five. The Simpson evenness measure (J[SDI]) ranked communities one through four in a sequence different from rankings under the other measures.

What does all this mean? When few taxa are reported, community diversity measures (except richness) become overly sensitive to evenness (given in Table 1 as proportionate importance). Evenness, and thus diversity, can be reported as high or low, depending on the choice of measure used (e.g., J[MDI] or J[SDI]). Because Stewart reported so few taxa in each community, each of the seven diversity measures in Table 3 is unreliable. Community one with the fewest reported taxa jumps around in the rankings depending upon the diversity measure. Community five consistently ranks highest. For censored data, i.e., reports that omit plant taxa, different interpretations of diversity could be made for any plant community. For this reason (which was not clear at the onset of this study), data in which plant taxa inclusion is based upon importance or dominance and that clearly underrepresent the number of plant taxa in the community should not be the basis for comparisons of diversity.

The two BLM plots had nearly consistent ranks relative to each other, with the community rated as fair (BLM-9) mostly ranking above (more diverse than) the community rated as good (BLM-8). We note that the Simpson evenness

TABLE 3. RANKINGS OF NUMBERED PLANT COMMUNITIES BY VARIOUS DIVERSITY INDICES (COLUMNS 2–8). THE RANKINGS ARE WITHIN EACH OF THREE DATA SOURCES INDICATED BY THE SEPARATED ROWS. THE LAST COLUMN RANKS THE NUMBERED COMMUNITIES BY AVERAGING OVER ALL THE INDICES.

Numbered	Individual Rank Order							Average
Community	N	HE	SDI	MDI	J(H)	J(SDI)	J(MDI)	Rank Order
1 SPAI/Nostoc	1	3	3	3	3	2	3	3 LATR/BOER1
2 EULA/LATR	3	1	4	1	2	4	4	4 LATR/BOER2
3 LATR/BOER1	4	2	2	2	4	1	2	2 EULA/LATR
4 LATR/BOER2	2	=4	1	4	1	3	1	1 SPAI/Nostoc
5 LATR-FLCE	=5	5	5	5	5	5	5	5 LATR-FLCE
6 BLM-8 good	6	6	6	6	6	7	6	6 BLM-good
7 BLM-9 fair	7	7	7	7	7	6	7	7 BLM-fair
8 MHC-1w0	11	8	8	10	8	9	8	8 MHC-1w0
9 MHC-1w1	8	9	9	9	9	8	9	9 MHC-1w1
10 MHC-1w2	=9	10	10	8	10	10	10	10 MHC-1w2
11 MHC-2	=10	11	11	11	12	11	12	11 MHC-2
12 NA-506	12	12	12	12	11	=12	11	12 NA-506

SPAI=Sporobolus airloides, EULA=Eurotia (Ceratoides) lanata, LATR=Larrea tridentata, BOER = Bouteloua eriopoda, FLCE=Flourensia cernua, MHC=Mesa Horse Camp pasture, NA=natural area along state road 506, w = weighted for Toumeya papyracantha, numbered communities preceded by = have the same diversity as the community above.
Ranks within community groups (1–5,6–7,8–12) are ordered from lowest to highest diversity.

measure reversed the ranking: the community with greater dominance (in this case BLM-8 with *Bouteloua eriopoda* having p=0.543) ranked higher than the community (BLM-9) with greater evenness. The chosen diversity measure again affected the ranking. Unlike the five communities with censored data, the ranked differences in the two BLM communities can be explained most simply by differences in the number of reported taxa. BLM-9 had considerably more reported taxa than BLM-8 (Table 1). Unfortunately the BLM plots suffer the same problem as the data of Stewart. Only those plants measured along the transect are reported. Finally, we note that the BLM ratings of good and fair, based (in those days) upon the presumed successional status of the community, are not the same as ratings based upon diversity. The better of the two samples from a livestock forage viewpoint (which was assumed to relate to successional status) was the poorer on the basis of plant diversity.

The Mesa Horse Camp plots (MHC-1, MHC-2) and the natural area plot (NA-506) were specifically sampled for diversity, and had considerably more reported taxa than the plots discussed above. Interestingly, plot MHC-1, which had a two-hour search, was the least diverse by all except the richness measure (N) of Table 3. This was the case regardless of assigning various weights to the endangered cactus, *Toumeya.* Plots MHC-2 and NA-506, which were measured by a time-limited search-and-find technique, appeared in the field to have about the same plant diversity. However, NA-506 ranked higher by all the measures except the McIntosh and Pielou evenness measures (J[MDI] and J[H]). Since each had about the same number of taxa (30–32), the relative scores reflected the evenness (or dominance) component of diversity. The MHC-2 plot had four dominant taxa *(Larrea tridentata, Bouteloua eriopoda, Croton,* and *Gutierrezia);* the NA-506 plot had one dominant taxon *(Bouteloua eriopoda)* and thus was more uneven in diversity. We also note that plots MHC-1 and MHC-2 contained small cacti, but not NA-506, which had a higher diversity ranking in most instances. Structural diversity is not provided for in the equations of Table 2, although it may influence other kinds of diversity such as avian community diversity.

DISCUSSION AND CONCLUSIONS

Diversity indices at the plant community level have their interpretative limitations (West 1993), and this study shows no exceptions. Nevertheless, it is becoming increasingly important for managers to know the kinds of biological diversity existing on lands they manage (Probst and Crowe 1991). The performance of indices across the various communities in this study has yielded different results. How do managers choose an index without some bias? We propose that the simplest measure is perhaps the most useful in yielding interpretations and making comparisons. Simply count the number of plant taxa present using a standardized procedure. The richness column of Table 3 (N) is easily understood and easiest to obtain for an individual familiar with the flora.

However, a mere count of the number of taxa is also of limited interpretative or management value. A grassland with mostly adventive plants has a meaning different from that of another with the same number of mostly native plants. Undesirable taxa (for whatever reason) are no different in their count than preferred taxa (although one approach would be to give them negative weights). Indeed, all the indices studied here have a similar disadvantage: the index gives no insight to the content of the sample, but it is the content that we are most interested in. A pasture dominated by *Gutierrezia* and with little *Bouteloua* might have the same evenness and richness measures as a pasture dominated by *Bouteloua* with little *Gutierrezia.* But each pasture has different management implications.

This study reveals other limitations to common diversity measures. If estimates of alpha diversity are specifically intended, then data collected to sample productivity, range condition, or ecological status (conventional scorecards) seem inappropriate as surrogates. If diversity estimates as such are needed, then a single visit to a sample plot may also be insufficient, because of the seasonality of plant expression (e.g., West and Reese 1991). For example, *Toumeya,* which mimics grama grass in form, is best sampled when flowering, because of the difficulty of finding it at other seasons.

Can diversity scorecards be developed that provide for specific elements of diversity according to some kind of social or cultural standard? We increased values of community diversity in community MHC-1 by giving more and more weight to the endangered grama grass cactus (but the higher weights did not change its rank). It remains to be tested how far one can go with weighting. Instead, maintaining a viable population of the endangered cactus may in itself be a sufficient diversity criterion for management not requiring any diversity index. A desired landscape description might include maintaining special populations, or high alpha plant diversity with a stand, or high overall primary production each in different areas. This elevates the description of diversity to a landscape (or beta) level where various social and cultural values can be accommodated. In such a case community diversity must be evaluated in the context of landscape diversity.

The performance of diversity measures across different communities suggests that sampling only for diversity cannot replace sampling for other community properties such as productivity or ecological succession (West and Reese 1991).

In summary, there was no single diversity index that served as a best measure of the true diversity (as defined in the introduction) in the desert grassland communities examined. In our opinion the most practical estimates of site or pasture diversity can be obtained by simply counting the number of plant species present in the samples. This is emphasized because of the common approach taken today: that of using various equations with species cover or biomass data in indices of diversity. Yet, the output of these equations bears no relationship to the true diversity of a given community. For instance, one gram of biomass of one species is not ecologically equivalent to one gram of biomass of another species. The same is true for units of species ground cover. Is the function of the two species in the system the same? Are the two species ecologically equivalent within the system? Presently, diversity indices are not related to any known ecological or community theories. Neither do these indices provide "value" (i.e., importance) in comparison of plant communities. Yet, this is precisely what is needed.

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