Some Slope-Plant Relationships in the Grasslands of the Little Missouri Badlands of North Dakota[1]

RALPH L. DIX

Biology Department, Marquette University, Milwaukee, Wisconsin

The importance of slope in the determination of the kinds and numbers of plants which occupy a site has long been recognized. It is not possible, however, to isolate the influence of slope alone from the multitude of other environmental and biotic factors which are inevitably and inseparably linked to it. The degree of slope will strongly influence such factors as soil stability and erosion, runoff, received insolation, accessibility to grazing animals and ultimately the vegetal cover supported by a site. Since the kinds and numbers of plants occupying a site are a reliable index to its past and present environment, the investigation of correlations between slope and species composition would appear a promising approach to the study of slope-plant relationships. The aim of this paper is to describe the vegetational characteristics of four grassland stands differing in slope and exposure in the Badlands of the Little Missouri River, and to interpret their similarities and differences in terms of underlying causes.

Study Area

The location of the study area is SE¼ sec. 11, T. 40 N. R. 102 W. This area is approximately one mile south of the Peaceful Valley Ranch, Theodore Roosevelt National Memorial Park, Billings County, North Dakota.

Physiographically, the general area is on the unglaciated portion of the gently sloping Missouri Plateau and is part of the Tongue River formation of the Fort Union group (Paleocene) (Leonard, 1930). This formation is composed of stratified beds of sands, clays and silts together with interspersed beds of lignite. Since the formation of the Missouri Plateau, severe dissection by the Little Missouri River and its tributaries has carved the deep gorge-like valleys characteristic of "badlands." This rapid dissection has largely been due to the shift in the outlet of the Little Missouri River in Pleistocene times from the Yellowstone River to the Missouri River, thus lowering its mouth by some 250 feet. Other contributing factors were the soft unconsolidated clays and silts of the substrata, burning lignite seams, and the semiarid climate.

The soils of the stands concerned in the present investigation have been classified by Edwards and Ableiter (1944) as the hilly phase of the Bainville clay loam series. These soils are usually less than five inches deep, quite friable, and with carbonates sufficient to cause effervescence within a few inches of the surface. They occur on slopes and are excessively drained except where scattered blocks of scoria or sandstone concretions may hold sufficient moisture to permit more favorable growth conditions.

The climate is of the semiarid, continental type with long cold winters and short warm summers. The mean annual precipitation is approximately 16 inches with about one-half of this occurring during May, June and July. Precipitation varies considerably from year to year and severe droughts are not uncommon. The frost-free season averages about 111 days.

The native vegetation of the area consists principally of grassland. The well drained loam and clay soils with moderate slopes support mainly blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), thread-leaf sedge, (*Carex filifolia*), and needle-and-thread (*Stipa comata*). On steeper slopes little bluestem (*Andropogon scoparius*), plains muhly (*Muhlenbergia cuspidata*), side-oats grama (*Bouteloua curtipendula*), and little club-moss (*Selaginella densa*) are usually the dominant species. Sandy soils are usually dominated by prairie sandgrass (*Calamovilfa longifolia*).

Since the study area is located well within the borders of a national park, grazing by livestock over a period of about twenty years has been limited to a few stray trespassing cattle. There was no evidence that livestock had been on the study area in recent years.

Methods

All stands were located along the sides of a broad ravine and within a distance of 500 yards. Of the four stands selected, two had eastern and two western exposures; north and south facing slopes were deliberately avoided to minimize the influence of these more contrasting exposures. Stands 101 and 103 were directly below stands 102 and 104, respectively.

The vegetation was sampled by use of forty ¼-M.[2] quadrats per stand. The presence of each species in each quadrat was recorded and the frequency index for each species in each stand calculated. This quadrat size was selected after preliminary field trials indicated that with

[1] *This investigation was supported in part by funds made available by the Committee on Research, Marquette University.*

Table 1. Indices of stand similarity. Numbers are in percent.

Slope: exposure, degrees	E8°	W3°	W11°	E16°
Stand Numbers	103	101	102	104
103	—	70.3	37.3	26.8
101	—	—	42.8	30.0
102	—	—	—	62.6
104	—	—	—	—

this quadrat size the most common species in each stand would have a frequency index approximating 86 percent (Curtis and McIntosh, 1950). The quadrats were placed at 20 pace intervals along four parallel lines (10 quadrats per line) which ran at right angles to the slope. The slope was measured (in degrees) with an Abney level and the exposure determined with a hand compass.

The data for each stand were tested for adequacy of sample. It was found that all species with frequencies greater than 50 percent when forty quadrats were used showed change of less than five percent when only thirty quadrats were used.

The field work for this study was done between July 5th and 20th, 1956. The taxonomic nomenclature is according to Stevens (1950).

Results

The similarities in species composition in each pair of the four stands were objectively determined by employing Sorenson's Index of similarity (Sorenson, 1948):

$$K = \frac{2c}{a + b} \times 100$$

In this formula K is the coefficient of similarity between two stands (A and B), a is the sum of frequencies for all species in stand A, b represents the sum of frequencies of all species in stand B, and c is the sum of frequencies shares by those species occurring in both stands. For example, the similarity coefficient (K) between stands 103 and 101 (Table 2) was determined by summing all frequencies in stand 103 ($a = 285$), summing all frequencies in stand 101 ($b = 349$), and summing the frequencies shared by these two stands ($c = 223$). This latter figure was obtained by adding 62 for blue grama, 75 for western wheatgrass, 15 for red mallow *(Sphaeralcea coccinea)*, etc. According to this formula, when the two stands are identical, $K = 100$ (i.e., the stands are 100% alike), while, when they have no species in common, $K = 0$.

Similarity coefficients for the four stands are presented in Table 1. The positions of the stands in this table were arrived at by placing those stand pairs with the highest similarity coefficients closest together and those with the lowest similarity coefficients farthest apart. Thus, stands 103 and 101 are most alike (70.3 percent), while stands 103 and 104 are least alike (26.8 percent).

The frequency index values for the leading species of the study are given in Table 2. In this table the stands are arranged according to their similarity coefficients, while the vertical positions of the species were determined by an inspection process which attempted to place those species with the highest frequency index values in stands 103 and 104 at the top and bottom of the species column, respectively. The total number of species which occurred in the quadrats of each stand are given at the bottom of Table 2. The sum of frequencies for each species in the four stands is given in the right hand column, while the slope, expressed in degrees, and the direction of exposure are presented at the top of each stand column.

The behavior of six leading dominants along the gradient of similarity coefficients, as estab-

Table 2. Frequency index values for the leading species of the study. Only those species with frequency index values of at least 15 percent in at least one stand are given.

Slope: exposure, degrees	E8°	W3°	W11°	E16°	Sums of Species Frequencies
Stand Numbers	103	101	102	104	
Bouteloua gracilis	92	62	52	25	231
Agropyron smithii	75	92	27	30	224
Sphaeralcea coccinea	15	32	5	5	57
Stipa viridula	15	20	20	7	62
Artemisia frigida	25	55	42	22	144
Selaginella densa	15	—	12	35	62
Comandra pallida	—	—	30	12	42
Carex filifolia	7	20	62	50	139
Stipa comata	5	10	17	2	34
Calamagrostis montanensis	5	—	15	7	27
Gutierrezia sarothrae	—	—	22	15	37
Eurotia lanata	2	5	20	17	44
Solidago missouriensis	—	—	17	20	37
Brauneria angustifolia	2	2	17	25	46
Eriogonum multiceps	2	—	10	20	32
Andropogon scoparius	—	—	37	60	97
Muhlenbergia cuspidata	2	5	40	70	117
Bouteloua curtipendula	2	2	7	72	83
Helianthus rigidus	—	—	2	50	52
Liatris punctata	—	—	—	17	17
Total Number of Species	19	22	43	47	
Sums of Stand Frequencies	285	349	589	714	

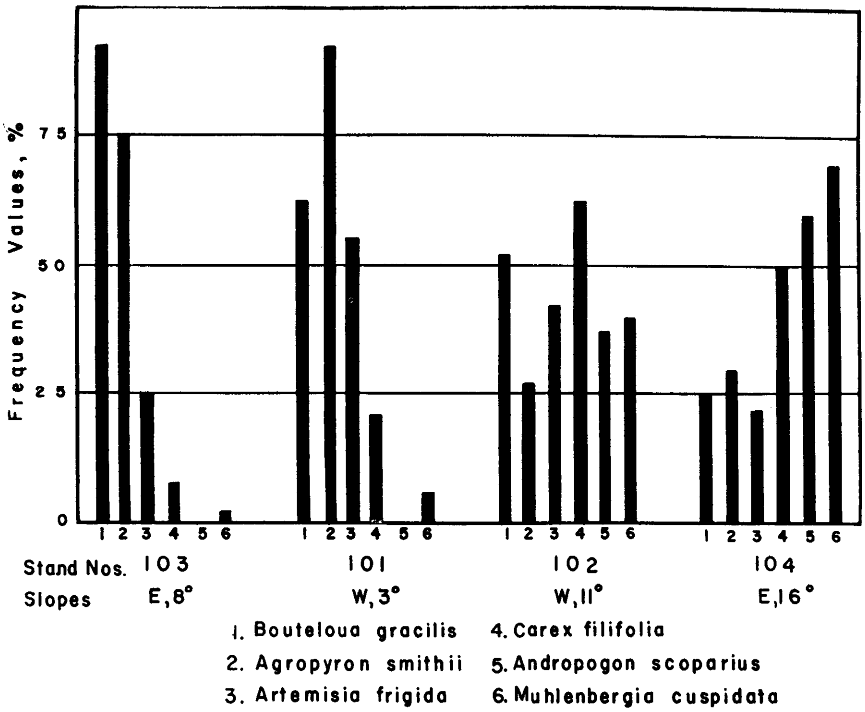

FIGURE 1. Frequency index values for six leading dominants. Stands are arranged according to similarity coefficients.

lished by the Sorenson Index, is illustrated in Figure 1. An examination of these bar diagrams reveals that each species demonstrates some sort of behavior pattern with regard to this order of stands. It may be observed, for example, that blue grama and western wheatgrass decrease while little bluestem and plains muhly increase from left to right. These bar diagrams further illustrate the relatively lower frequencies of the dominant species and the larger number of species with intermediate frequencies in stands with steeper slopes.

Raunkiaer's five frequency classes were employed to determine the distribution of frequencies in each of the four stands (Table 3). The interpretation placed upon this table is that it indicates the distribution of the number of species within particular mean area groups; *i.e.*, it shows the number of species with mean areas equal to, larger than, and smaller than the quadrat area. When randomly distributed, a species having a frequency of 60 per cent will have a mean area of approximately one quadrat area. Similarly, species with frequencies lower than 60 percent will have mean areas greater than one quadrat area, while species with frequencies greater than 60 percent will have mean areas less than one quadrat area (Curtis and McIntosh, 1950). It is not supposed that these frequency distributions are in any way a measure of stand homogeneity.

Discussion

The ordering of stands by use of similarity coefficients is a mathematical method of demonstrating the similarities in species composition between a group of stands and does not, of itself, imply or suggest the underlying nature of the obtained order. When environmental characteristics of the included stands are compared to this order, however, correlations between the ordination and environment may suggest fundamental causes.

An inspection of Table 1 clearly shows that the stands fall into two pairs—stands 103-101 (70.3) and stands 102-104 (62.6). Conversely, the highest similarity coefficient between the two pairs is 42.8 between stands 101 and 102.

Stands 102 and 104 occurred on rather steep slopes (11° and 16°) and soil erosion was strongly evident in both. These slopes are capped with sandstone concretions, and horizontal beds of this material outcrop throughout the stands. These beds, since they are impervious to water, create situations suggestive of small perched water tables. During wet periods water percolates through the soil and, meeting these impervious layers, is held briefly before gradually seeping to the surface to become available for plant growth over an extended period of time. These stands, therefore, receive water in excess of precipitation. From the exposure of these stands it would be expected that, due to protection from the hot and dry southwesterly winds of June and July (Sampson and Weyl, 1918, and Renner, 1936), the east facing stand 104 would be more mesic, or at least less xeric, than the west facing stand 102.

Stands 103 and 101 occurred on more gentle slopes (8° and 3°) and are, paradoxically, areas of both deposition and erosion.

Table 3. Number of species in Raunkiaer's five frequency classes.

Stand Numbers	0-20 %	21-40 %	41-60 %	61-80 %	81-100 %
103	16	1	—	1	1
101	18	1	1	1	1
102	35	5	3	—	—
104	37	5	3	2	—

That is, eroded soils from above are transported across these stands or temporally deposited there to be eroded away by the water from some future rainstorm. Over the years, the deposition process has stayed well ahead of erosion and has resulted in the formation of the broad terraces on which these stands are located. The horizontal beds of standstone are far beneath the surface and additional moisture due to seepage is lacking in these stands. Stand 103 has a slope of 8° and receives directly the runoff from stand 104 (16°). This runoff water enters stand 103 at a relatively high velocity and, though slowed by a decrease in slope, moves across the stand at a rate too rapid to permit its efficient infiltration into the soil. Stand 101 is on a slope of only 3° and receives runoff from stand 102 (11°). This runoff water enters stand 101 at a somewhat lower velocity than the water entering stand 103 and, being further slowed by the slight slope of this stand, moves across it at a sufficiently slow rate to permit good penetration. Although stand 103 is located on an east facing slope, its comparative steepness with regard to stand 101 renders it more xeric than that stand.

From the above it appears that the ordination of the stands determined by the Sorenson Index is based upon a moisture gradient. This suggestion is strengthened by considerations of the vegetation. Stands 103 and 101 are dominated by blue grama and western wheatgrass, species with ranges centered in and mostly confined to the semiarid Great Plains (Weaver and Albertson, 1956 and Hitchcock and Chase, 1950) while, conversely, the dominants of stand 104, little bluestem and side-oats grama, are important species of the more humid midwestern prairies (Weaver and Fitzpatrick, 1934, and Curtis, 1955). Increases along the ordination (from left to right) in the total number of species which occurred in the quadrats and in the sums of their frequencies are also indicative of a moisture gradient since more favorable moisture conditions tend to favor a greater variety of dominants and an increase in total density.

The successional relationships between these stands, if they occur at all, are not clear. All of the stands, due to the extreme erodability of the fine clay soils, undergo frequent disturbances by either erosion, deposition or both, and little opportunity is afforded for vegetal stabilization. The species composition of these stands is primarily controlled by soil moisture and exposure, and these factors are, in turn, determined by the physiography and not by previous vegetation. It seems doubtful, therefore, that, successional relationships exist between these stands. Rather, physiographic situations present environmental conditions which fall, to a greater or lesser degree, within the ecological amplitude of certain species of the flora. These species are then sorted out by physiographic situations and the stands are related to each other only in so far as their physical environments fall within the ecological amplitudes of the same species. Successional relationships in the Little Missouri Badlands have been treated by Hanson and Whitman (1938), Judd (1939) and Whitman and Hanson (1939).

The results of this study indicate that the most important single factor in determining the kinds and numbers of plants which occupy those sites is soil moisture; other variables, such as exposure, slope and topography, are correlated with soil moisture and are apparently important only in so far as they influence it. This does not imply, however, that soil moisture alone determines the species composition of these sites, since such factors as past history, available soil nutrients, and excessive salts also play significant roles (Hanson and Whitman, 1938).

It seems apparent from this study that interpretations of future research on the phytosociological characteristics of the grasslands of the Little Missouri Badlands would be significantly aided by detailed considerations of the physical environment—especially of physiographic and edaphic factors.

Summary

The roles of slope and exposure in determining the species composition of some grassland types in the Badlands of the Little Missouri River of North Dakota were investigated. Four stands, differing in slope and exposure, were selected as study areas; the stands had slopes and exposures of: 16° E., 8° E., 3° W., and 11° W.

The stands were sampled by the frequency method employing 40 ¼-M.[2] quadrats per stand. Slopes and exposures were also measured. Similarity co-efficients between the stands were calculated and an ordination of stands established.

The behavior of the dominant species along this ordination indicated that it was based upon a moisture gradient. Blue grama and western wheatgrass, species of the more xeric Great Plains, were found to be more important at one end of the gradient, while little bluestem, side-oats grama, and plains muhly, species of the more mesic Midwestern prairies, were more important at the opposite end of the ordination. This ordination also correlated with apparent soil moisture, total number of species which occurred in the quadrats and in the total frequency per stand.

The relationships between the stands appeared not to be successional, since the species composition of the stands was based principally upon physiographic and edaphic factors.

Acknowledgment

Deep appreciation is expressed to Messrs. John W. Jay, Jr., and Ches-

ter L. Brooks, Superintendent and Historian, respectively, Theodore Roosevelt National Memorial Park, for many courtesies extended to the author during the course of this study.

LITERATURE CITED

CURTIS, J. T. 1955. A prairie continuum in Wisconsin. Ecology 36: 558-566.

——— AND R. P. MCINTOSH. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31: 434-455.

EDWARDS, M. J. AND J. K. ALBEITER. 1944. Soil survey of Billings County, North Dakota. U. S. Dept. Agr. Bur. Plant Indus. Ser. 1934 No. 25, 111 pp.

HANSON, H. C. AND W. WHITMAN. 1938. Characteristics of major grassland types in western North Dakota. Ecol. Monog. 8: 57-114.

HITCHCOCK, A. S. AND A. CHASE. 1950. Manual of the grasses of the United States. U. S. Dept. Agr. Misc. Pub. No. 200. 1051 pp.

JUDD, B. I. 1939. Plant succession on scoria buttes of western North Dakota. Ecology 20: 335-336.

LEONARD, A. G. 1930. The geology of North Dakota. N. Dakota Univ. Bull. 11.

RENNER, F. G. 1936. Conditions influencing erosion on the Boise River watershed. U. S. Dept. Agr. Tech. Bull. 528: 1-32.

SAMPSON, A. W. AND L. H. WEYL. 1918. Range preservation and its relation to erosion control on Western grazing lands. U. S. Dept. Agr. Bull. 675: 1-35.

SORENSEN, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. Konge. Dan. Vidensk. Selsk. J5: 4: 1-34.

STEVENS, O. A. 1950. Handbook of North Dakota plants. North Dakota Institute for Regional Studies, Fargo, N. D. 324 pp.

WEAVER, J. E. AND F. W. ALBERTSON. 1956. Grasslands of the Great Plains. Johnsen Publishing Co., Lincoln, Nebraska. 395 pp.

——— AND T. J. FITZPATRICK. 1934. The prairie. Ecol. Monog. 4: 109-295

WHITMAN, W. AND H. C. HANSON. 1939. Vegetation of scoria and clay buttes in western North Dakota. Ecology 20: 455-457.