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PREDICTABILITY OF PATTERNS AND VARIABILITY OF PRECIPITATION IN GRASSLANDS

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ABSTRACT

Climatic instability may restrict the biotic diversity of an area by imposing frequent but unpredictable stresses upon the adaptive systems of species, while areas with relatively stable climates may have a greater number of species due, at least in part, to enhanced opportunities for resource partitioning. To provide a framework for evaluation of the biotic diversity of different grassland systems, precipitation regimes from 44 U.S. Weather Bureau stations located in tallgrass, mixed-grass, shortgrass, Palouse, and shrub-steppe habitats were analyzed. Special emphasis was given to the predictability of the pattern of precipitation and variability of precipitation. On a monthly basis rainfall regimes were most predictable (in decreasing order) in tallgrass, mixed-grass, and shortgrass prairies, while the pattern of precipitation in Palouse and shrub-steppe types was predictable only from one year to the next and then less than in the Great Plains grasslands. Shortgrass stations had significantly more variability in annual precipitation than mixed-grass areas, and tallgrass stations were the least variable. Palouse and shrub-steppe areas were intermediate in annual variability of precipitation in relation to the "true" grassland types. Stations in central and northeastern Oklahoma did not adhere to these patterns, having less predictable rainfall patterns, a smaller proportion of the yearly rainfall during the summer, and a greater frequency of years in which the rainfall deviated strongly from the long-term average than other mixed-grass or tallgrass stations. The implications of these rainfall patterns for ecosystem diversity and stability are discussed.

INTRODUCTION

Grassland ecosystems are characterized in the layman's eyes by their climatic extremes--droughts, blizzards, cloudbursts, tornados, bitter cold, intense heat, and so on. While the severity of grassland weather is frequently exaggerated, the climate does undergo strong seasonal shifts, and yearly differences are also frequently large. This climatic instability, if real, should be expected to have profound effects on the biota of grassland ecosystems.

This paper represents an attempt by a biologist to examine meteorological data from a biological point of view. The analysis grew from my attempts to explain why grassland ecosystems characteristically support such a small number of breeding bird species (three to six), a fact observed by myself (Wiens, 1971) and by Cody (1966). Part of the "conventional wisdom" of ecology holds that climatic stability may lead to stability and diversification of vegetation; this in turn provids greater opportunities for niche divergence and resource partitioning among consumers (Pianka, 1966; MacArthur, 1965). Conversely, climatic instability may act to reduce opportunities for niche diversification through its variable effects upon resource bases. In particular, I have suggested (Wiens, in preparation) that the number of bird species which can successfully exploit grassland ecosystems is limited to a rather low number by the frequent but unpredictable extreme climatic stresses; this inherent instability of grasslands may, in fact, impose general limitations on the biotic diversity of grassland ecosystems (Wiens, 1971). While many climatic features may contribute to this instability, variability in precipitation especially may act in a limiting manner through its direct effects on primary production (Rosenzweig, 1968; Holdridge, 1947) and, thus, on food supplies. Rasmussen, Bertolin, and Almeyda (1971), for example, have observed that a dry year in grasslands not only has low precipitation but is also accompanied by higher than average temperatures and wind movements and, therefore, higher evapotranspiration rates, with the result that the need for water in the system is potentially highest during the years when it is least available. Thus, I have sought to provide some substantiation, or at least parallel evidence, for my speculations on avifaunal structure in grasslands through an examination of the patterns of variation in precipitation regimes in grasslands. Because there are interesting differences between different aspects of grassland ecosystems (Wiens, in preparation), I have analyzed separately rainfall patterns for tallgrass prairies, mixed grasslands, shortgrass steppe, Palouse prairie, and northern shrub-steppe, generalizing these grassland types from Küchler (1964).

It is not my intention here to review grassland climatology. Works such as those of Borchert (1950), Trewartha (1961), or the reviews of Collins (1969) and Rasmussen (1971) have called attention to the general features of grassland rainfall--the paucity of winter precipitation, the intense but local summer storms, and the general regional homogeneity of grassland climates. Rasmussen et al. (1971) have provided a detailed review of climatological conditions in the vicinity of the IBP Grassland Biome Intensive Site at Pawnee. All of these workers, however, have approached the subject within the framework of conventional meteorological analysis, and the variables they have examined are not necessarily those of greatest potential biological importance. Chief emphasis in my analysis will be given to variability and predictability of annual precipitation in grasslands; other features of grassland rainfall patterns will be only briefly mentioned. Hopefully, one outcome of this analysis will be to encourage other IBP workers to undertake similar "spin-off" efforts and to speculate on the bases for the diversity and stability of various biotic groups.

ANALYTICAL METHODS

Precipitation data from 44 U.S. Weather Bureau stations were used in this study. Station locations are indicated in Fig. 1, and pertinent features of each station are listed in Table 1. Stations were selected to characterize major vegetational types of grassland and to provide a broad geographic sampling of climatic conditions within each type. Stations lying close to vegetational "transitions" were avoided (Fig. 1). Stations located near IBP grassland sites were included in the analysis (Table 1), but have not been analyzed separately.

Weather Bureau records for these stations from the initiation of recording through 1960 were gathered from various summaries (U.S. Weather Bureau, 1930, 1952, 1961) and transferred to data cards. From these data sets, means and variances were calculated for monthly, annual, and summer (April to September) precipitation, and the proportion of the annual mean precipitation occurring during the summer was derived (Table 1).

Variability and/or predictability of the pattern of annual rainfall were measured in the following ways:

1. The coefficient of variation (CV) of the annual precipitation was calculated for each station, and a mean CV (and variance) was derived from these for all stations within each grassland type (Table 2). This provides a comparative index of the degree of variation of yearly rainfall amounts about the long-term average.

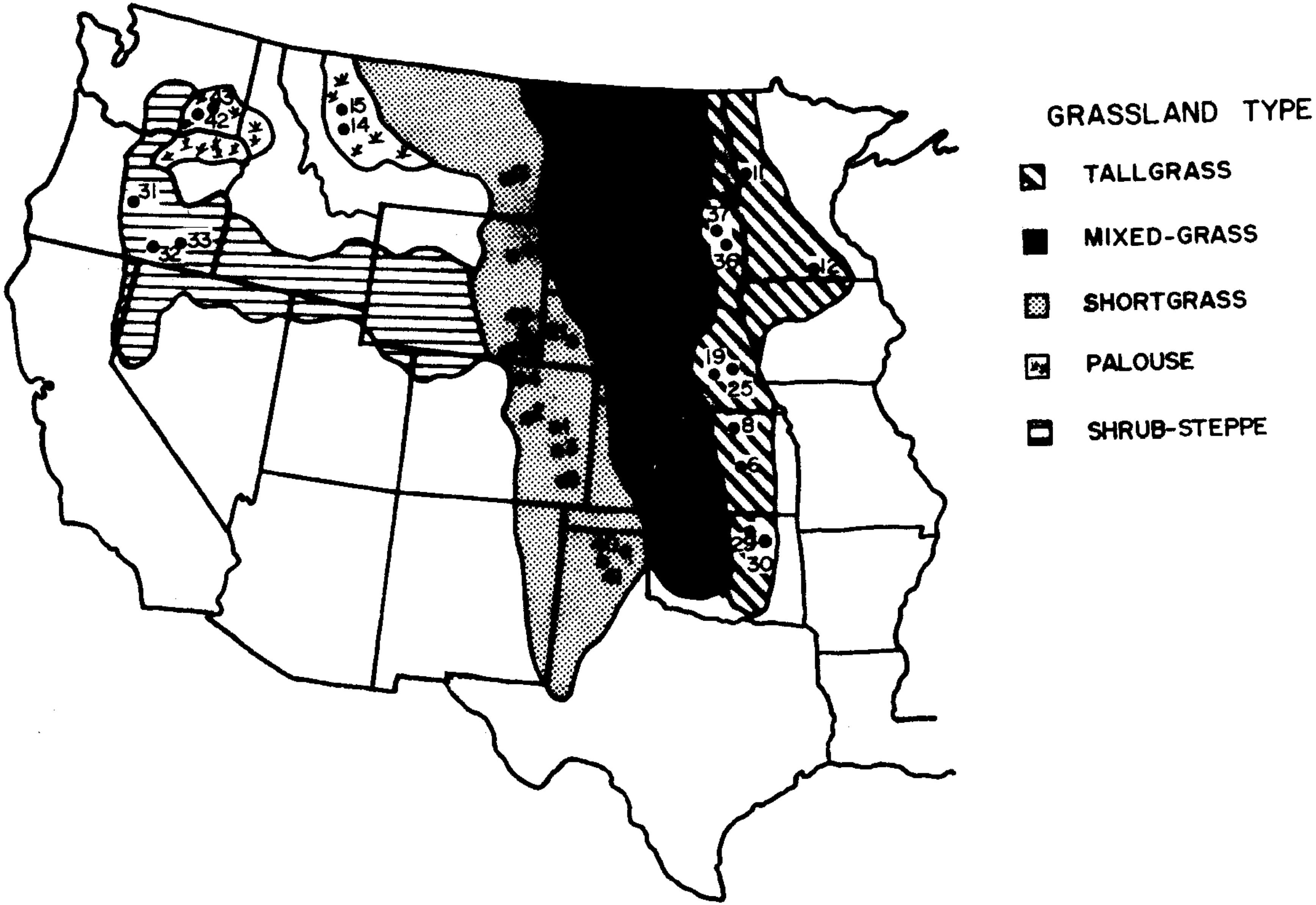

Fig. 1. Locations of U.S. Weather Bureau climatological stations used in this analysis. Station identifications are given in Table 1. Grassland types generalized from Küchler (1964).

Table 1. General features of U.S. Weather Bureau stations used in this analysis.

Station			Grassland Type[a]	Record Length (years)	Mean Annual Precipitation (cm)	Percent of Precipitation In Summer[b]	Elevation (m)
Number	State	Name					
1	Colo.	Burlington	S	70	43.4	79	1,268
2	Colo.	Byers	S	36	34.6	76	1,646
3	Colo.	Cheyenne Wells	S	63	40.9	79	1,304
4	Colo.	Grover[c]	S	55	34.9	78	1,547
5	Colo.	Two Buttes	S	59	36.2	76	1,242
6	Kan.	Cottonwood Falls	T	56	82.0	72	384
7	Kan.	Hays[c]	M	93	58.1	77	610
8	Kan.	Manhattan	T	103	80.4	74	335
9	Kan.	Ness City	M	65	52.5	77	689
10	Kan.	Norton	M	68	54.0	77	713
11	Minn.	Ada	T	59	52.2	79	276
12	Minn.	Albert Lea	T	64	75.4	73	375
13	Mont.	Miles City	S	76	34.0	72	725
14	Mont.	Missoula	P	77	35.3	56	983
15	Mont.	St. Ignatius[c]	P	52	39.4	62	884
16	N. Dak.	Crosby	M	53	35.8	78	596
17	N. Dak.	Dickinson[c]	M	69	39.3	78	775
18	N. Dak.	Pettibone	M	51	43.2	78	566
19	Neb.	Bradshaw	T	53	74.5	78	523
20	Neb.	Brewster	M	47	55.0	78	762
21	Neb.	Bridgeport	S	64	40.1	78	1,115
22	Neb.	Broken Bow	M	65	58.0	80	755
23	Neb.	Hay Springs	M	79	49.6	73	1,168
24	Neb.	Lexington	M	65	55.8	76	727
25	Neb.	Lincoln	T	83	70.2	75	362
27	Okla.	Chickasha	M	52	79.2	65	333
29	Okla.	Foraker[c]	T	15	83.9	68	389
30	Okla.	Pawhuska	T	61	92.9	67	270
31	Ore.	Fremont	SS	40	24.4	38	1,311
32	Ore.	Frenchglen	SS	39	26.1	45	1,311
33	Ore.	Valley Falls	SS	46	30.0	41	1,319
34	S. Dak.	Bison	M	24	37.4	77	792
35	S. Dak.	Bowdle	M	49	47.2	78	607
36	S. Dak.	Brookings	T	64	50.6	80	496
37	S. Dak.	Clear Lake	T	35	61.8	78	549
38	S. Dak.	Cottonwood[c]	M	51	38.4	78	736
39	S. Dak.	Lemmon	M	46	39.0	76	782
40	Tex.	Pampa	S	30	51.6	72	983
41	Tex.	Panhandle[c]	S	36	56.8	71	1,052
42	Wash.	Benton City[c]	P	50	20.9	32	144
43	Wash.	Hanford	P	29	15.7	30	117
44	Wyo.	Gillette	S	40	37.7	70	1,384
45	Wyo.	Laramie	S	78	28.3	70	2,191
46	Wyo.	Wheatland	S	47	33.7	73	1,444

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[a] T = tallgrass, M = mixed-grass, S = shortgrass, P = Palouse, SS = shrub-steppe.

[b] April to September.

[c] Stations located near IBP Grassland Biome study sites.

Table 2. Precipitation characteristics of grassland types as recognized by Küchler (1964). See text for further explanation of measures. The Oklahoma Stations (numbers 27, 29, and 30) are omitted from this analysis.

Grassland Type	N (Stations)	Mean Length of Record (Years)	Annual Precipitation				Percent Annual Precipitation in Summer[a]		Frequency of Deviation[b]				Maximum/Minimum Annual Precipitation[c]	
			Mean (cm)		Coefficient of Variation				By ≥0.5 $\bar{x}$		By ≥0.25 $\bar{x}$			
			$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Shortgrass	12	54.5	39.4	8.03	0.285	0.038	74.5	3.53	8.0	1.28	40.5	9.89	3.75	0.617
Mixed-grass	14	58.5	49.5	11.48	0.258	0.025	77.2	1.58	4.8	2.76	34.1	7.33	3.97	0.621
Tallgrass	8	59.3	72.4	13.82	0.233	0.031	76.1	2.85	2.4	2.72	24.5	5.50	3.04	0.563
Palouse	4	52.0	27.7	11.32	0.247	0.035	45.0	16.37	3.0	1.41	24.0	4.20	3.35	0.424
Shrub-steppe	3	41.7	26.9	2.90	0.271	0.028	41.3	3.51	5.7	4.04	37.7	8.02	3.57	0.783

[a] April to September.

[b] Percent of years when annual precipitation deviates from the long-term average ($\bar{x}$) by at least the indicated amount.

[c] Maximum recorded annual precipitation ÷ minimum recorded annual rainfall.

2. The extreme dry (minimum) and wet (maximum) years recorded for each station were determined, and the ratio of wet to dry values was calculated (Table 3). These values were then also combined to give a mean ratio for each grassland type (Table 2). This measure is indicative of the magnitude of extreme variations in rainfall for individual stations or grassland types.

3. More biologically important, perhaps, than variation around a long-term mean or the extreme conditions is the frequency of occurrence of years which deviate strongly from "average." From the standpoint of bird (or mammal or insect, etc.) populations, the occurrence of unusually dry or wet years (with the attendant effects on production and food supplies) may impose crucial limitations. To measure this I calculated for each station the percent of all years in which the yearly rainfall amount deviated from the long-term mean, first, by at least 0.25 of the long-term mean, and second, by at least 0.50 of the long-term mean (Table 3). As before, these values were summarized for each grassland type (Table 2).

4. Variation in precipitation does not necessarily imply instability, for variations may be large but of regular, predictable occurrence (e.g., seasonal patterns). To test the predictability of rainfall regimes I applied autocorrelation analysis to the monthly precipitation records for each station (Kendall and Stuart, 1967). The autocorrelation coefficient is positive when the series of monthly precipitation values is positively correlated and negative when the series is inversely correlated. Autocorrelation coefficient values near zero indicate independence of the two rainfall values and, thus, also indicate unpredictability. This sort of approach has previously been applied to an analysis of patterns of lizard diversity in North American deserts by Pianka (1967). In my analysis, the

Table 3. Analyses of variation in annual precipitation for stations listed in Table 1. See text for further explanation.

	Station Number	Percent of Years Deviating from Mean Annual Precipitation						Extreme Recorded Annual Precipitation (cm)		
		By ≥0.5 $\bar{x}$			By ≥0.25 $\bar{x}$			Minimum	Maximum	Maximum/Minimum
		+	-	Σ	+	-	Σ			
Burl	1	6	4	10	20	21	41	15.7	69.7	4.44
Byers	2	8	6	14	31	31	62	13.9	57.5	4.14
Cheyenne	3	6	4	10	21	22	43	19.7	68.2	3.46
Grover	4	4	4	8	18	18	36	13.3	58.9	4.43
2 Buttes	5	7	0	7	20	24	44	20.3	79.9	3.93
	6	2	0	2	11	12	23	49.4	145.1	2.93
	7	3	1	4	15	23	38	23.4	110.1	4.71
	8	3	1	4	13	13	26	38.4	153.4	3.99
	9	5	2	7	20	22	42	20.2	82.3	4.07
	10	4	2	6	21	25	46	24.5	98.5	4.02
	11	2	2	4	12	10	22	25.6	84.8	3.32
	12	0	0	0	9	9	18	39.2	106.5	2.72
	13	4	0	4	14	16	30	17.8	57.8	3.25
	14	4	1	5	8	13	21	17.0	57.0	3.34
	15	2	0	2	12	10	22	22.3	63.9	2.87
	16	0	2	2	19	21	40	13.7	53.0	3.87
	17	1	1	2	17	10	27	17.1	79.1	4.64
	18	2	2	4	14	16	30	17.7	73.7	4.17
	19	8	0	8	17	17	34	37.5	128.6	3.43
	20	4	0	4	17	17	34	30.5	101.2	3.32
	21	2	0	2	16	16	32	20.1	60.1	2.98
	22	0	0	0	11	11	22	32.1	86.5	2.69
	23	1	2	3	19	14	33	21.1	74.5	3.54
	24	3	0	3	14	9	23	28.8	101.7	3.53
	25	0	0	0	17	12	29	35.6	104.7	2.94
	27	6	0	6	17	17	34	41.5	120.5	2.91
	29	0	0	0	20	27	47	47.9	122.5	2.56
	30	7	0	7	16	16	32	49.5	147.8	2.99
	31	2	2	4	12	17	29	11.3	49.2	4.36
	32	5	5	10	23	23	46	12.2	43.4	3.56
	33	2	0	2	20	17	37	16.3	45.5	2.77
	34	8	4	12	21	21	42	12.5	62.9	5.04
	35	2	4	6	16	12	28	20.2	72.8	3.61
	36	2	0	2	14	12	26	28.4	82.1	2.89
	37	0	0	0	11	6	17	43.9	90.3	2.06
	38	4	2	6	18	20	38	18.1	70.2	3.87
	39	4	2	6	20	15	35	14.1	62.8	4.46
Pampa	40	3	0	3	17	17	34	26.0	83.6	3.21
Panhandle	41	8	3	11	25	25	50	27.2	108.1	3.97
	42	2	0	2	14	16	30	12.6	49.3	3.90
	43	3	0	3	7	17	24	8.7	28.6	3.29
	44	0	0	0	20	22	42	20.7	56.3	2.73
	45	3	3	6	14	12	26	9.8	45.1	4.63
	46	6	2	8	19	28	47	15.0	57.4	3.81

interval of time (or lag) between compared monthly precipitation values was varied from 1 to 12 months. In essence, then, I asked: "Given the rainfall amount of any month, n, what is the likelihood that the rainfall of month n+1, n+2, n+3, ..., n+12 will be quite similar or quite dissimilar?" This approach thus looks at climatic stability in a somewhat different way by examining the average predictability of the rainfall pattern. The computer program for this analysis is given in Appendix I.

RESULTS AND DISCUSSION

The results of these analyses for the five grassland types are given in Tables 2 and 4 and Fig. 2.

Patterns of Annual Precipitation

It is no surprise that the series tallgrass—mixed-grass—shortgrass is paralleled by steadily decreasing mean annual precipitation (see Borchert, 1950). The tallgrass stations combined have a mean annual rainfall roughly 1.5 times that of the collection of mixed-grass sites, which in turn average 1.25 times more precipitation than the shortgrass stations (Table 2). All of these differences are significant (Table 4). Palouse prairies and northern shrub-steppe are characterized by less yearly rainfall than any of the Great Plains grassland types, but are quite similar to each other.

Roughly three-fourths of the yearly rainfall in the Great Plains grasslands occurs in summer, while both Palouse and shrub-steppe types occupy the rain shadow of the intermontane western regions (Trewartha, 1961), and are dominated by winter season precipitation.

Table 4. Matrix of significance of differences between grassland types for precipitation features listed in Table 2. NS = $p > 0.05$, * = $p < 0.05$, ** = $p < 0.01$.

Grassland Types Compared	Mean Annual Precipitation	Coefficient of Variation of Annual Mean	Percent of Precipitation in Summer	Frequency of Deviation from Annual Mean		Mean Maximum ÷ Minimum Annual Precipitation
				$\geq 0.5\ \bar{x}$	$\geq .25\ \bar{x}$	
Shortgrass-Mixed	*	*	*	**	NS	NS
Shortgrass-Tallgrass	**	**	NS	**	**	*
Shortgrass-Palouse	*	NS	**	**	**	NS
Shortgrass-Shrub-steppe	*	NS	**	NS	NS	NS
Mixed-Tallgrass	**	*	NS	NS	**	**
Mixed-Palouse	**	NS	**	NS	*	NS
Mixed-Shrub-steppe	**	NS	**	NS	NS	NS
Tallgrass-Palouse	**	NS	**	NS	NS	NS
Tallgrass-Shrub-steppe	**	NS	**	NS	**	NS
Palouse-Shrub-steppe	NS	NS	NS	NS	**	NS

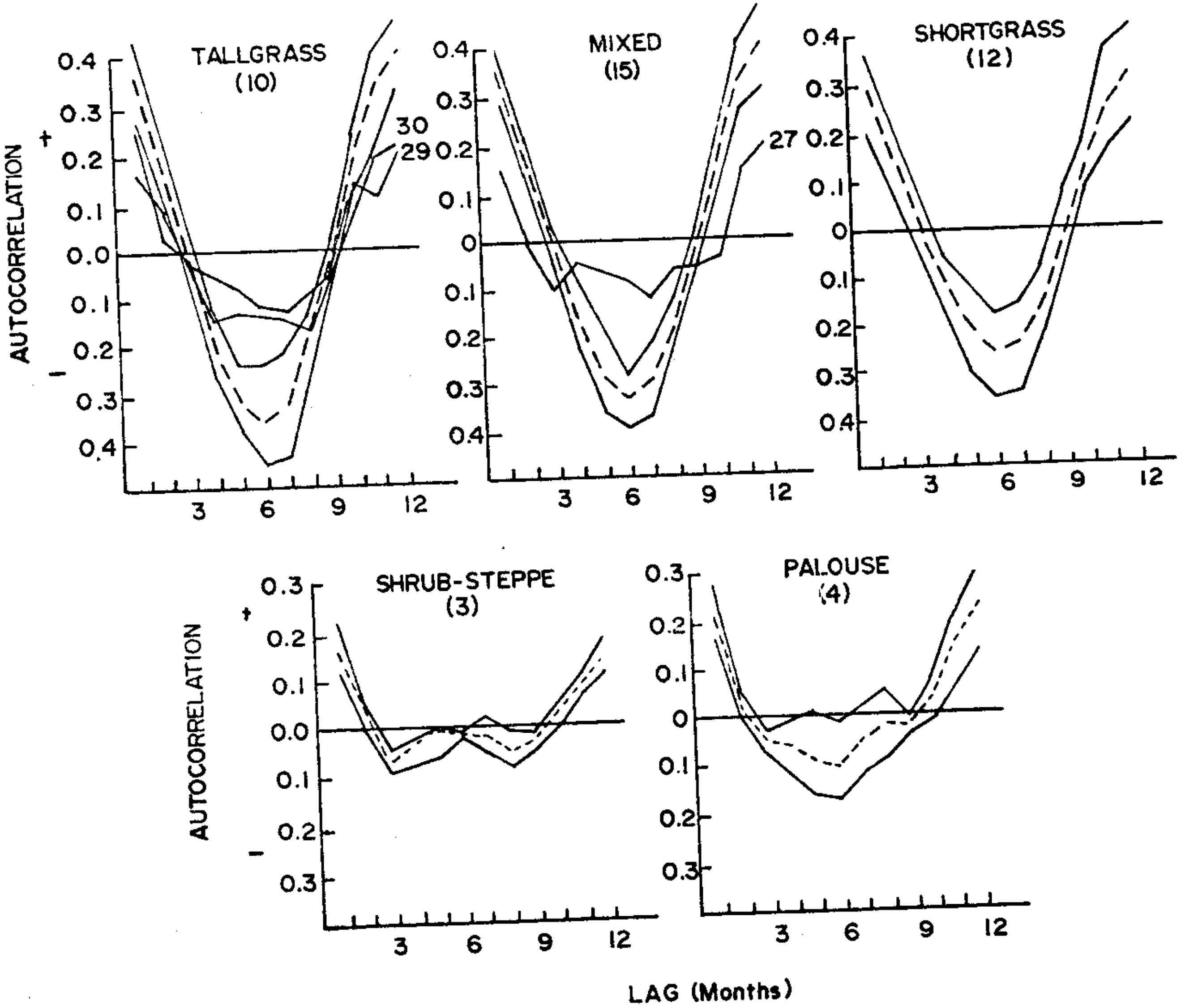

Fig. 2. Autocorrelation of monthly total precipitation, for lags of 1 to 12 months, for stations in five grassland types. Points above the zero line indicate positive autocorrelation and mean that the precipitation for a given month is positively correlated with the precipitation for the month at a given lag period away. Points below the zero line indicate inverse autocorrelation, meaning that conditions may be expected to change during the given lag interval. Points near the zero line indicate that there is little autocorrelation and that precipitation is unpredictable. Solid lines enclose the range of autocorrelation curves for a given grassland type, while the dashed line indicates the mean autocovariance for all stations within a type (N is given in parentheses). The Oklahoma stations (numbers 27, 29, 30) are considered

Predictability of Patterns of Precipitation

The results of autocorrelation analysis (Fig. 2) allow an evaluation of the predictability of rainfall patterns over a 12-month period, regardless of total annual precipitation differences or differences in variability. The strong seasonality of rainfall in tallgrass, mixed-grass, and shortgrass areas is apparent. In each there is a strong negative autocorrelation with a 5- to 7-month time lag (i.e., if it is wet (dry) now, it is highly likely that it will by dry (wet) in 5 to 7 months. The seasonal predictability of the rainfall pattern of tallgrass prairies is slightly greater than that of mixed-grass types, which in turn are somewhat more predictable than shortgrass prairies. The three Oklahoma stations (two tallgrass, one mixed-grass) deviate markedly from these autocorrelation patterns (Fig. 2), and for that reason have not been included in the general analysis for these grassland types (Table 2); possible causes of this aberrancy will be discussed later in this paper.

Palouse and shrub-steppe are much less predictable in the seasonal distribution of their rainfall than the Great Plains grasslands. Given a time lag of roughly 2 to 10 months, autocorrelation values are relatively close to zero, indicating the unpredictable patterns of monthly rainfall. The shrub-steppe stations especially lack well-defined repetitive precipitation patterns.

Variability of Precipitation

As suggested above, long-term variability in precipitation may have more important influences on the biotic composition of grasslands than seasonal or year-to-year variations. When the magnitude of difference between extreme wet and dry years is considered (Tables 2 and 4), shortgrass and mixed-grass prairies have a significantly greater range between extremes than tallgrass prairies, substantiating in a general way the observation of Rasmussen et al. (1971) that as mean annual precipitation decreases the rainfall becomes more variable from year to year. Palouse and shrub-steppe types are intermediate in the magnitude of variation between extreme years, but do not differ significantly from any of the other grassland types in this respect, nor from each other.

The coefficient of variation of mean annual precipitation indicates a similar pattern of variability. Shortgrass stations have a significantly higher CV than mixed-grass stations, which in turn are significantly more variable than tallgrass stations (Tables 2 and 4). Again the intermediate condition of Palouse and shrub-steppe types is indicated.

Finally we may examine the frequency of occurrence of years which deviate markedly from the long-term average in their precipitation. In shortgrass areas, roughly 1 out of every 12 years can be expected to differ from the long-term average by at least half that average (i.e., be half again as wet or have half the "normal" precipitation), while 1 of every 2 1/2 years deviates from "normal" by at least one-quarter of the mean (Table 2). In mixed-grass prairies, on the other hand, extremely wet or dry years (those which deviate from $\bar{x}$ by ±0.50 $\bar{x}$) are only 60% as frequent as in shortgrass areas, and unusually wet or dry years (those which deviate by ±0.25 $\bar{x}$) are also less frequent, although not significantly so. In tallgrass prairies extremely wet or dry years occur only once in every 42 years, on the average, unusually wet or dry years roughly 1 of every 4 years. Palouse and shrub-steppe types are intermediate, although unusually wet or dry years are significantly more frequent in shrub-steppe than Palouse areas. Significance levels for all these comparisons are given in Table 4.

The Oklahoma Stations

The autocorrelation analysis (Fig. 2) showed that the three Oklahoma stations differed markedly from the remaining stations in their vegetation types. These stations were characterized by having less predictable rainfall patterns (Fig. 2), a smaller proportion of the yearly rainfall during the summer, and a greater frequency of extremely or unusually wet or dry years (Tables 1 and 3) than other mixed-grass or tallgrass stations. Trewartha (1961) has observed that this area lies in a zone characterized by a bimodal distribution of rainfall in the warm season; this, combined with a possibly greater influence of Gulf coastal weather systems, may produce these differences. Since one of the IBP Grassland Biome sites (Osage) is located in this area, this anomalous rainfall pattern should be kept in mind in comparisons of abiotic-biotic interrelationships with other sites in the Grassland Biome network.

CONCLUSION: PATTERNS OF ECOSYSTEM STABILITY

I have argued elsewhere (Wiens, in preparation) that extreme variations in primary production (especially production lows), induced at least partially by variations in rainfall, may severely limit the resources available to consumers. If one accepts the premise that successful exploitation of grassland as a habitat requires certain distinctive adaptations in any biotic group, then relatively few species may be able to coexist in grasslands at times of resource limitation. The inherent irregularity of the environment may thus act to repeatedly restrict the evolutionary diversification of ecologically similar species or the development of closely coevolved relationships between different elements of the biota (Wiens, 1971).

This analysis has indicated that, among the range of grassland types considered, shortgrass prairies should be expected to be the least stable, tallgrass situations the most stable. Correspondingly, tallgrass areas should support a more diverse biota with finer niche partitioning among ecologically similar species. Population densities might also be expected to be most stable in tallgrass habitats, most variable in shortgrass areas. Shrub-steppe and Palouse grasslands were shown to be intermediate in their predictability and variability, but there are reasons to suspect that at least some consumer assemblages may be more stable than expected. First, the rainfall in these areas occurs predominantly in the winter, and because of the time lag between precipitation and production in these areas, variations in rainfall might be expected to be "damped out" and have less severe manifestations in resource supplies. In shortgrass areas, where no time lag exists, resource levels should be much more directly affected by rainfall and thus be more sensitive to rainfall variations. Second, the vegetation of both Palouse and shrub-steppe habitats is structurally more stable than that of Great Plains grasslands, and consumers such as birds which respond strongly to habitat structure may thus encounter greater stability in the western areas. In arid shrub-steppe, for example, where the vegetation is dominated by woody plants such as sagebrush (*Artemisia*) and rabbit brush (*Chrysothamnus*), much of the annual net primary production may be realized as incremental addition of new material to existing structure, and areas may thus have an essentially unchanging habitat structure over a number of years despite variations in precipitation. The same is true, to a lesser extent, of Palouse prairies where plant growth and habitat structure are dictated by dispersion of perennial clump bases. By contrast, in "true" grasslands each year's production determines the habitat structure since most of the plant material is reduced to litter each winter. Thus, variations in rainfall will likely be directly manifested as variations in habitat structure.

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APPENDIX I

Computer program used in the analysis of precipitation regimes by stations. Data input was in the form:

Column	Data
1-4	State
5-8	Station
9	Grassland Type: 1 = Tallgrass 2 = Mixed-grass 3 = Shortgrass 4 = Shrub-steppe 5 = Palouse 6 = Desert
10-13	Year
14-17	January rainfall (to nearest 0.01 inch)
18-21	February rainfall (to nearest 0.01 inch)
22-25	March rainfall (to nearest 0.01 inch)
26-29	April rainfall (to nearest 0.01 inch)
30-33	May rainfall (to nearest 0.01 inch)
34-37	June rainfall (to nearest 0.01 inch)
38-41	July rainfall (to nearest 0.01 inch)
42-45	August rainfall (to nearest 0.01 inch)
46-49	September rainfall (to nearest 0.01 inch)
50-53	October rainfall (to nearest 0.01 inch)
54-57	November rainfall (to nearest 0.01 inch)
58-61	December rainfall (to nearest 0.01 inch)
62-66	Total Annual rainfall (to nearest 0.01 inch)

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      PROGRAM WEINPPT (TAPE4,TAPE6,INPUT,OUTPUT)
C       TO COMPUTE MONTHLY AND YEARLY MEANS, STD. DEVIATIONS,ETC. AND
C       AUTOCORRELATIONS FROM VARIOUS SITES FOR JOHN WIENS.
      COMMON PPT(120,15),KEY(2,120),AVG(15),SD(15),CV(15),CI(15),SAM(15)
     1,AUTO(12,2),SITE,NYR,TYP
      COMMON /L1/ LSITE,LYR,LTYP,BUF(13)
      INTEGER TYPE(6),HEAD(15),SITE,TYP,SPAN,SEAS(12)
      DATA SEAS/3*(15),6*(14),3*(15)/,HEAD/7HJANUARY,8HFEBRUARY,5HMARCH,
     15HAPRIL,3HMAY,4HJUNE,4HJULY,6HAUGUST,9HSEPTEMBER,7HOCTOBER,
     28HNOVEMBER,8HDECEMBER,6HYEARLY,9HGROWING S,9HNON-GRO S/,TYPE/
     310HTALL GRASS,9HMIX GRASS,10HSHORTGRASS,10HSHRUBSTEPP,7HPALOUSE,
     46HDESERT/
C - - -
      MYR=120
      MC=15
      MMO=12
      WRITE (6,200)
  200 FORMAT (*1           PRECIPITATION ANALYSIS  -  FOR JOHN WIENS*)
C - - -  BOOTSTRAP FIRST CARD IN
      READ (4,110) LSITE,LTYP,LYR,BUF
  110 FORMAT (A8,I2,I4,12F4.2,F5.2)
    1 CONTINUE
C - - -  ZERO ARRAYS
      DO 10 J=1,MYR
      KEY(1,J)=KEY(2,J)=0
   10 CONTINUE
      DO 11 I=1,MC
      AVG(I)=SD(I)=CV(I)=CI(I)=SAM(I)=0.
   11 CONTINUE
      DO 12 I=1,MMO
      DO 12 J=1,2
   12 AUTO(I,J)=0.
C - - -  INPUT DATA FROM ONE SITE
      CALL READER (IEND,SPAN)
      WRITE (6,201) SITE,TYPE(TYP),SPAN,NYR
  201 FORMAT (6(/),*   RESULTS FROM THE *A9*SITE OF THE *A10* TYPE.  *
     1*SPAN OF RECORD IS*I4* YEARS WITH*I4* YEARS REPORTED*//)
C - - -  COMPUTE TOTALS BY SEASON, SET FLAGS FOR INCOMPETE SEASON TOTALS
      DO 22 LY=1,NYR
      PPT(LY,14)=PPT(LY,15)=0.
      DO 22 IM=1,MMO
      IS=SEAS(IM)
      PPT(LY,IS)=PPT(LY,IS)+PPT(LY,IM)
      IF ((SIGN(1.,PPT(LY,IM)).EQ.-1.).A.(PPT(LY,IM).EQ.0.))
     1 KEY(IS-13,LY)=1
   22 CONTINUE
C - - -  COMPUTE SUMS, SUMS OF SQUARES, SAMPLE SIZES
      DO 24 LY=1,NYR
      DO 23 I=1,13
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```
      IF ((SIGN(1.,PPT(LY,I)).EQ.-1.).A.(PPT(LY,I).EQ.0.)) GO TO 23
      AVG(I)=AVG(I)+PPT(LY,I)
      SD(I)=SD(I)+PPT(LY,I)*PPT(LY,I)
      SAM(I)=SAM(I)+1.
   23 CONTINUE
      DO 24 I=14,MC
      IF (KEY(I-13,LY).EQ.1) GO TO 24
      AVG(I)=AVG(I)+PPT(LY,I)
      SD(I)=SD(I)+PPT(LY,I)*PPT(LY,I)
      SAM(I)=SAM(I)+1.
   24 CONTINUE
C - - -  COMPUTE MEANS, STD. DEVS., CV S., CI S.
      DO 26 I=1,MC
      IF (SAM(I).LE.1.) GO TO 25
      SD(I)=SQRT((SD(I)-AVG(I)*AVG(I)/SAM(I))/(SAM(I)-1.))
      AVG(I)=AVG(I)/SAM(I)
      IF (AVG(I).LE.0.) GO TO 26
      CV(I)=SD(I)/AVG(I)
      N=SAM(I)-1.
      CI(I)=SD(I)*T(N)/SQRT(SAM(I))
      GO TO 26
   25 SD(I)=-0.
   26 CONTINUE
C - - -  OUTPUT THESE STATISTICS
      WRITE (6,203)
  203 FORMAT (23X,*MEAN*,15X,*STD DEV*,12X,*COEF VAR*,12X,*95% C I*,14X,
     1*NUMBER*//)
      DO 28 I=1,15
   28 WRITE (6,205) HEAD(I),AVG(I),SD(I),CV(I),CI(I),SAM(I)
  205 FORMAT (3X,A10,1X,F15.2,5X,F15.2,2(5X,F15.3),9X,F10.0)
C - - -  COMPUTE AUTOCORRELATIONS WITH 1 TO 12 MONTH LAGS
      DO 42 L=1,11
      K=L+1
      CALL COREL (AUTO(L,1),PPT,1,K,NYR ,AUTO(L,2))
   42 CONTINUE
      CALL COREL (AUTO(12,1),PPT,2,1,NYR ,AUTO(12,2))
C - - -  OUTPUT AUTO CORRELATIONS AND SAMPLE SIZES FROM WHICH THEY CAME.
      WRITE (6,207) (I,I=1,12)
  207 FORMAT (4(/),*      AUTOCORRELATIONS*//*   LAG*12I10/)
      WRITE (6,208) ((AUTO(I,J),I=1,12),J=1,2)
  208 FORMAT (* *,7X,12F10.3/* NUMBER *12F10.0//)
      GO TO (1,50) IEND
   50 CONTINUE
C - - -  DO ANALYSIS BY TYPES
      STOP
      END
      SUBROUTINE READER (IEND,SPAN)
      COMMON PPT(120,15),KEY(2,120),AVG(15),SD(15),CV(15),CI(15),SAM(15)
     1,AUTO(12,2),SITE,NYR,TYP
      COMMON /L1/ LSITE,LYR,LTYP,BUF(13)
      INTEGER SITE,TYP,FYR,SPAN
C - - -
C - - -  IEND = 1  UNLESS END-OF-FILE IS READ, THEN  IEND = 2
      IEND=1
```

```
      NYR=0
      FYR=LYR
   10 SITE=LSITE
      LSYR=LYR
      TYP=LTYP
      NYR=NYR+1
      DO 12 I=1,13
      PPT(NYR,I)=BUF(I)
   12 CONTINUE
      READ (4,110) LSITE,LTYP,LYR,BUF
  110 FORMAT (A8,I2,I4,12F4.2,F5.2)
      IF (EOF(4)) 90,14
   14 IF (SITE.EQ.LSITE) GO TO 10
      SPAN=LSYR-FYR+1
      RETURN
   90 IEND=2
      SPAN=LSYR-FYR+1
      RETURN
      END
      SUBROUTINE COREL (AUT,PPT,JY,JM,LY,S)
C - - -  COMPUTE CORRELATIONS FOR UP TO LY YEARS STARTING WITH THE (JY,JM)
C        ELEMENT OF PPT VS. THE (1,1) ELEMENT, THEN INCREMENTING EACH ONE
C        MONTH AT A TIME.
      DIMENSION PPT(120,15)
      KY=JY
      KM=JM
      S=X=Y=XS=YS=XY=0.
      IY=IM=1
    5 CONTINUE
C - - -  IF EITHER OF THE PAIR OF ELEMENTS IS BLANK, DONT INCLUDE THAT PAIR
      IF ((SIGN(1.,PPT(IY,IM)).EQ.-1.).A.(PPT(IY,IM).EQ.0.)) GO TO 10
      IF ((SIGN(1.,PPT(KY,KM)).EQ.-1.).A.(PPT(KY,KM).EQ.0.)) GO TO 10
      S=S+1
      X=X+PPT(IY,IM)
      XS=XS+PPT(IY,IM)**2
      Y=Y+PPT(KY,KM)
      YS=YS+PPT(KY,KM)**2
      XY=XY+PPT(IY,IM)*PPT(KY,KM)
   10 CONTINUE
C - - -  INCREMENT THE SUBSCRIPTS
      CALL INCR(KY,KM)
      IF (KY.GT.LY) GO TO 20
      CALL INCR(IY,IM)
      GO TO 5
   20 CONTINUE
C - - -  COMPLETE COMPUTATION OF THE CORRELATION COEFFICIENT
      IF (S.LE.1.) GO TO 30
      XY=XY-X*Y/S
      XS=XS-X*X/S
      YS=YS-Y*Y/S
      AUT=XY/SQRT(XS*YS)
      RETURN
   30 AUT=-0.
      RETURN
```

```
      END
      SUBROUTINE INCR (NY,NM)
      NM=NM+1
      IF (NM.LE.12) RETURN
      NM=1
      NY=NY+1
      RETURN
      END
      FUNCTION T(KT)
C - - -  TO RETURN A T VALUE FOR A 95 PERCENT CONFIDENCE INTERVAL
C         (0.975 ONE-TAILED) WITH KT DEGREES OF FREEDOM.
      DIMENSION X(30),XF(6),XS(4)
      DATA X/12.706,4.303,3.182,2.776,2.571,2.447,2.365,2.306,2.262,
     1 2.228,2.201,2.179,2.160,2.145,2.131,2.120,2.110,2.101,2.093,
     2 2.086,2.080,2.074,2.069,2.064,2.060,2.056,2.052,2.048,2.045,2.042
     3 /,XF/2.030,2.021,2.014,2.008,2.004,2.000/,XS/1.994,1.990,1.987,
     4 1.984/
C - - -
      IF (KT.GT.100) GO TO 50
      IF (KT.GT.30) GO TO 10
      T=X(KT)
      RETURN
   10 IF (KT.GT.60) GO TO 30
      I=(KT-31)/5 +1
      T=XF(I)
      RETURN
   30 I=(KT-61)/10 +1
      T=XS(I)
      RETURN
   50 T=1.972
      RETURN
      END
```