J. T. Rotenberry[1]
Northwest College and University Association for Science
Richland, Washington 99352

W. T. Hinds
Ecosystems Department, Battelle
and
J. M. Thorp
Atmospheric Sciences Department, Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

Microclimatic Patterns on the Arid Lands Ecology Reserve

Abstract

Cluster analysis of correlation coefficients is employed to detect microclimatic patterns within a 27-station network in a topographically diverse region of southeastern Washington. Correlations among stations based on 6 years of monthly maximum and minimum temperatures range between 0.95 and 0.99; those based on monthly precipitation range from 0.85 to 0.98. When all three variables are combined into a single statistic, correlations range from 0.95 to 0.99. In addition to gross topographical influences, such as elevation and aspect, microclimates were influenced by (1) concave microtopography, (2) nearness to a major river valley confluence, and possibly (3) wind differences.

Introduction

Within zonal climates, which are determined by latitude, distance from oceans, and elevation, lie a multitude of microclimates, which are largely distinguished by localized differences in slope, exposure, elevation, and local topography. Plants and animals usually are adapted to the zonal climates, but they must live in or avoid the microclimates. The spectrum of microclimates in a landscape is thus an important part of the structure of ecosystems. On the Arid Lands Ecology Reserve, a study of microclimates in a hilly region of a cold desert shrub-steppe has led to some understanding of the relationships between microclimates and the physical elements which determine them.

The Arid Lands Ecology Reserve is a large section of the Hanford Reservation dedicated to study of arid ecosystems by the U.S. Atomic Energy Commission (since subsumed by the Energy Research and Development Administration) in 1968. The ALE Reserve lies on the western edge of the Lower Columbia Basin in southeastern Washington, ranging in elevation from about 140 m to 1100 m. The dominant vegetation is *Artemisia/Agropyron* shrub-steppe (Daubenmire, 1970). Shortly after the creation of ALE, a 27-station network (Fig. 1) was set up to collect basic climatic data in a variety of habitats. The data consist of monthly total precipitation and maximum and minimum temperatures. These data are understandably restricted in utility, but simple enough to acquire to assure continuous collection through time over a broad area. The data have been recorded monthly from October 1968 to the present and provide a suitable basis for the study of microclimates in and near the Rattlesnake Hills.

[1] Present address: Department of Zoology, Oregon State University, Corvallis, OR. 97331.

Methods

Although gross climatological effects may be observed by examining isohyets and isotherms, elucidation of the more subtle microclimates requires different techniques. We have chosen to employ cluster analysis of similarity coefficients, a technique taken from numerical taxonomy (Sokal and Sneath, 1963).

To determine the similarity in pattern between any two stations, we calculated

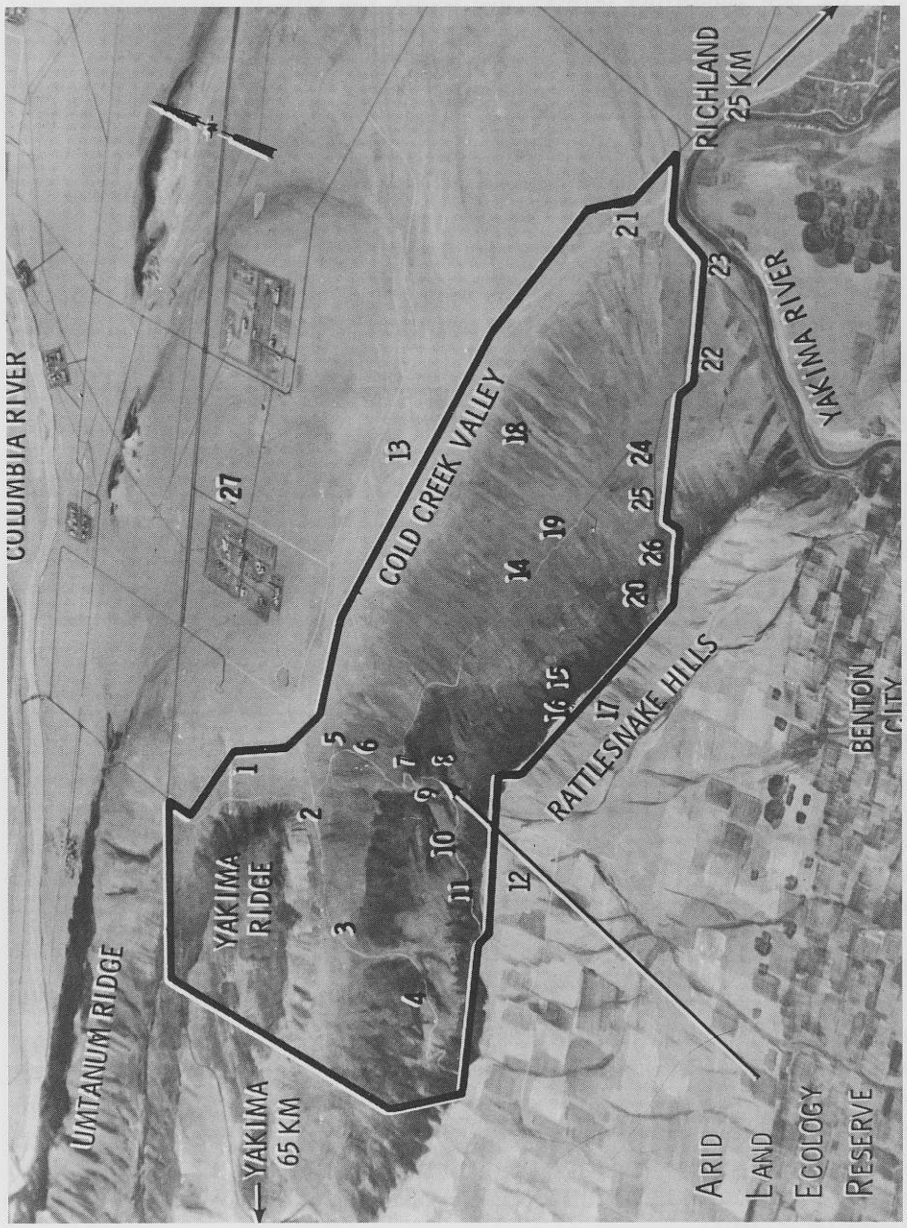

Figure 1. Arid Lands Ecology Reserve. Numbers refer to ALE Micrometeorological Network sampling stations.

the product-moment correlation coefficient (see, for example, Sokal and Rohlf, 1969) for all the past months ($n = 72$) for each of the three sets of data. These similarities (or correlations) between all possible pairs of stations were arranged into three matrices (one for each climatic data set), then reduced by means of weighted pair-group cluster analysis (Sokal and Sneath, 1963) as follows:

(1) the two sites with the highest similarity were combined to form the first cluster (A +B);

(2) the new similarities between this cluster and each of the remaining sites (Q) were calculated using the Spearman sums-of-variables method,

$$r_{(A+B)Q} = \frac{r_{AQ} + r_{BQ}}{\sqrt{2 + 2\,(r_{AB})}}$$

where r_{AB} is the similarity between unit A and unit B;

(3) steps (1) and (2) were repeated until all sites were clustered, with the new cluster now considered a single unit.

The Spearman sums-of-variables method is used in lieu of simple averages to reduce bias, since the variance of the correlation coefficient is dependent on its magnitude (Sokal and Sneath, 1963).

Each of the three separate measures of microclimate interact to make up part of the environment in which plants and animals live. To average the three correlation coefficients for each pair of stations into one number indicative of their overall microclimatic similarity, we first subjected the correlations to Fisher's z-transformation (Sokal and Rohlf, 1969). This transformation seemed desirable because the distribution of correlation coefficients is skewed while that of the z-statistic is normal. We then averaged the three z-statistics and transformed this average back into an average correlation or similarity. We then re-applied the clustering techniques to this average similarity to produce combinations of stations with similar patterns of overall microclimate.

Clusters resulting from each of the four similarity matrix reductions are geographically delimited by encircling on a map the stations belonging to each. In this way a map much like a topographic map may be built up, only now isolines enclose areas of equal or greater microclimatic pattern similarity, rather than equal or higher elevation. The similarity levels at which we wish to define groups and to separate out subgroups are arbitrary, for there is no convenient method to test for statistical differences between groups.

Results

Not surprisingly, correlations within all four data sets were quite high, confirming the notion that climatic patterns are basically the same all over the Reserve. Similarities between stations for maximum and minimum temperatures generally ranged between 95 and 99 percent, as did those for the overall analysis. Similarities for monthly precipitation were more variable, ranging from 85 to 98 percent. Because of the large sample sizes involved, standard errors of the correlation coefficients were quite small; differences in correlation coefficients as small as one tenth of a percent were statistically significant ($P \leq 0.01$).

Maximum Temperatures. Clustering of stations based on maximum temperatures, illustrated by the dendrogram in Figure 2, shows two large groups distinguishable at 98 3/4 percent, plus a single anomalous site, station 15 (the relation between dendrograms and maps is the same for each data set, so other dendrograms will not be shown). Plotted on a map, the two major groups clearly resolve themselves into high and low elevation stations (Fig. 3A). Interestingly, the altitudinal range within the high elevation group (1 in Fig. 3A) traverses over 800 m (from about 300 m

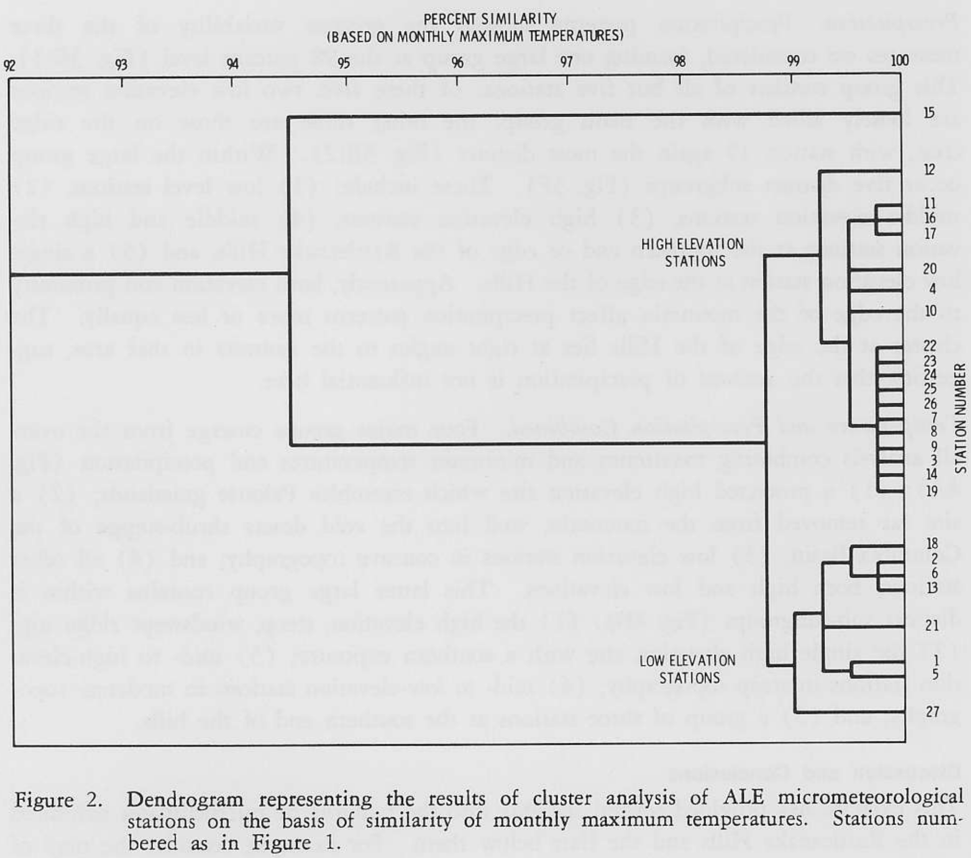

Figure 2. Dendrogram representing the results of cluster analysis of ALE micrometeorological stations on the basis of similarity of monthly maximum temperatures. Stations numbered as in Figure 1.

to 1100 m), while the low elevation stations (Fig. 3A:2) range only from 140 m to 200 m. Further, within each of the major groups minor groupings are evident, although in some instances a "group" consists of but a single station. At lower elevations, the Cold Creek Valley breaks down into three subgroups (Fig. 3B:1), with a lone station out in the flats forming a fourth (Fig. 3B:2). Altitudinal bands appear much more pronounced in the higher elevation subgroups (Fig. 3C). The largest subgroup (Fig. 3C:1) is at mid-elevation, averaging 370 m; the next (Fig. 3C:2) is slightly higher, about 610 m. Three stations on the crest of Rattlesnake Mountain (1100 m) form the highest elevation subgroups (Fig. 3C:3), and a station with a southern exposure on the west side of the crest forms the fourth (Fig. 3C:4). The single anomalous station is located on a steep northern exposure just a few meters below the crest, lying in a well-protected area (Fig. 3A:3).

Minimum Temperatures. The patterns of minimum monthly temperatures are quite different from the preceding ones, and not as easily defined. Three clear-cut groups, however, do emerge (Fig. 3D). One is at middle elevations and encompasses 11 stations (Fig. 3D:1); the second, at the highest elevations, includes station 15, which we showed earlier to be anomalous with respect to maximum temperatures (Fig. 3D:2). The third group consists of three stations in the valley floor located in gentle depressions or "frost pockets" (Fig. 3D:3). The eight remaining stations, which covered virtually all elevations, are each more or less distinct.

Precipitation. Precipitation patterns showed the greatest variability of the three measures we considered, forming one large group at the 98 percent level (Fig. 3E:1). This group consists of all but five stations: of these five, two low elevation stations are loosely allied with the main group; the other three are those on the ridge crest, with station 15 again the most distinct (Fig. 3E:2). Within the large group occur five distinct subgroups (Fig. 3F). These include: (1) low level stations, (2) middle elevation stations, (3) high elevation stations, (4) middle and high elevation stations at the southern end or edge of the Rattlesnake Hills, and (5) a single low elevation station at the edge of the Hills. Apparently, both elevation and proximity to the edge of the mountain affect precipitation patterns more or less equally. The cluster at the edge of the Hills lies at right angles to the isohyets in that area, suggesting that the *amount* of precipitation is not influential here.

Temperature and Precipitation Combined. Four major groups emerge from the overall analysis combining maximum and minimum temperatures and precipitation (Fig. 4A): (1) a protected high elevation site which resembles Palouse grasslands; (2) a site far removed from the mountain, well into the cold desert shrub-steppe of the Columbia Basin; (3) low elevation stations in concave topography; and (4) all other stations, both high and low elevations. This latter large group contains within it distinct sub-subgroups (Fig. 4B): (1) the high elevation, steep, windswept ridge top; (2) the single high elevation site with a southern exposure; (3) mid- to high-elevation stations in steep topography; (4) mid- to low-elevation stations in moderate topography; and (5) a group of three stations at the southern end of the hills.

Discussion and Conclusions

This exercise has provided several insights into the patterns of microclimates exhibited in the Rattlesnake Hills and the flats below them. For example, consider the map of overall microclimates (Fig. 4B): within the mid-elevation group occurs a very well-defined cluster consisting of three stations (Fig. 4B:5; sites 22, 23, 24, Fig. 1). This subgroup lies at the southeastern end of the Hills, covering elevations from about 180 m to 330 m. This end of the Hills lies at the confluence of two major valleys—the Yakima River Valley and the Lower Columbia Basin. These three stations always appear within the same cluster, whether for maximum or minimum temperature or

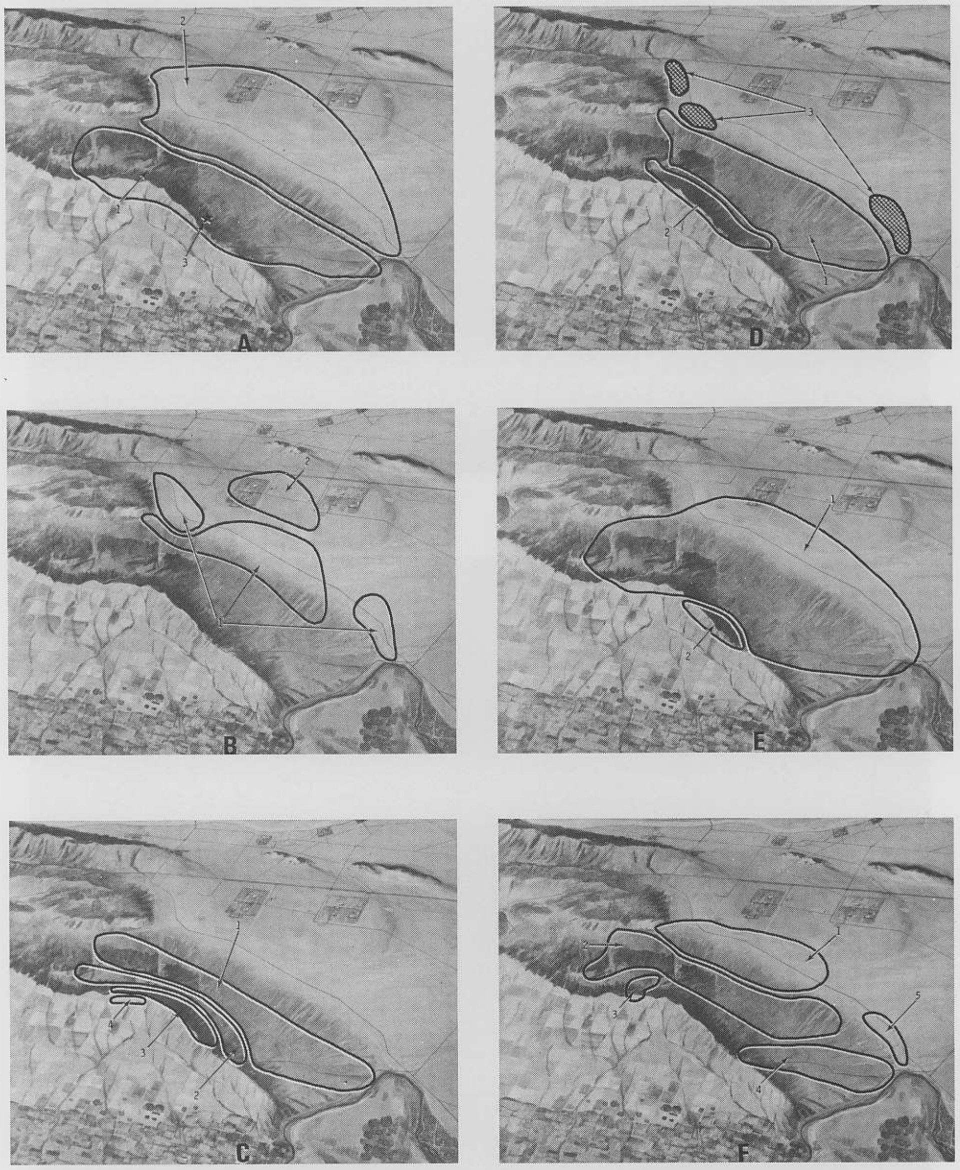

Figure 3. Results of independent cluster analyses of each microclimatic variable: A. monthly maximum temperatures, major clusters; B. monthly maximum temperatures, lower elevation subgroups; C. monthly maximum temperatures, higher elevation subgroups; D. monthly minimum temperatures, major clusters and "frost pockets"; E. monthly precipitation, major clusters; F. monthly precipitation, lower elevation subgroups. Clusters and subgroups designated by number referred to in the text.

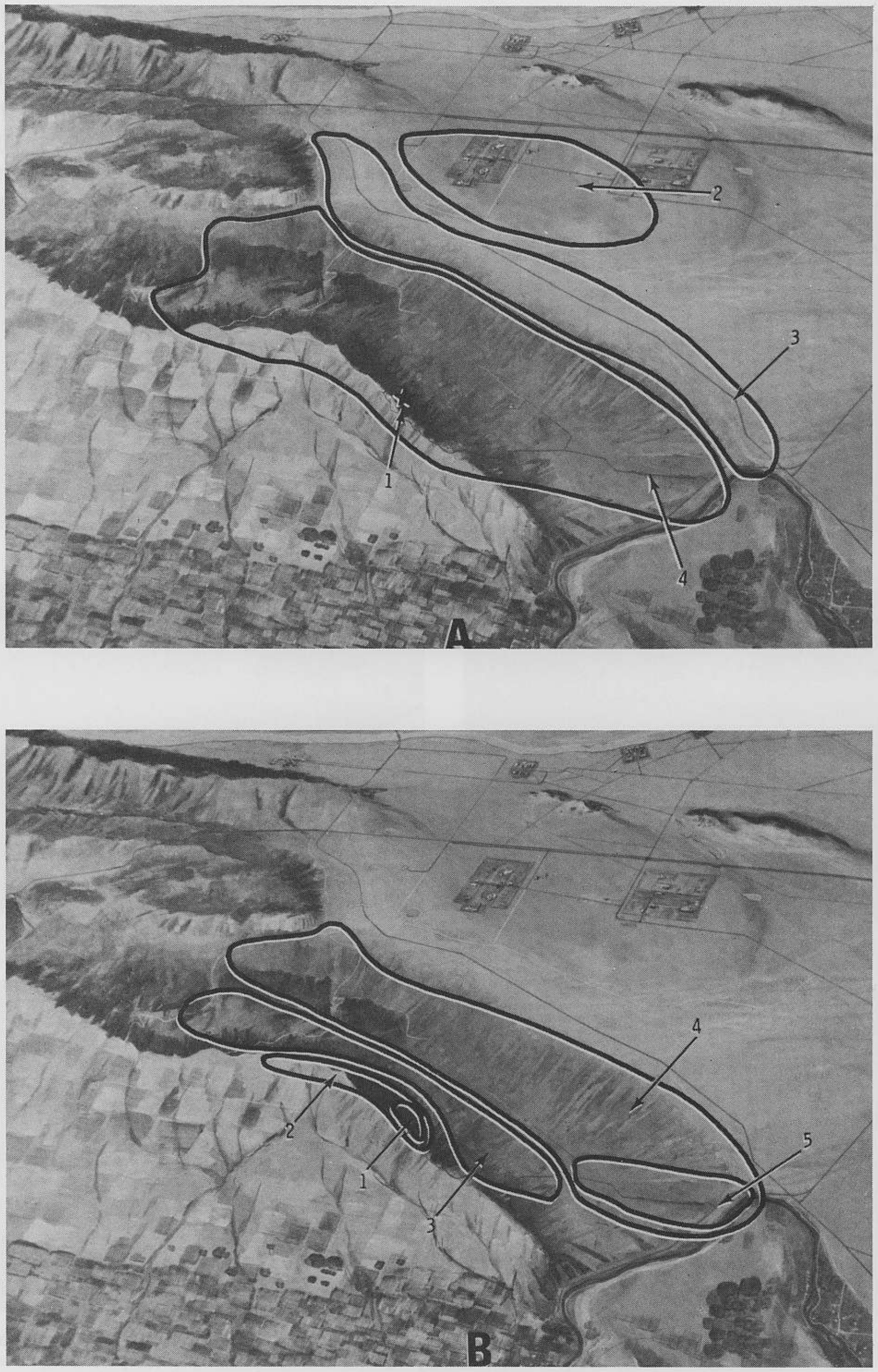

Figure 4. Results of cluster analysis of all microclimatic variables combined. A. major clusters; B. higher elevation subgroups. Clusters and subgroups designated by number are referred to in the text.

precipitation (although not as a distinct 3-unit cluster except for precipitation). Apparently, the edge effect of the valley confluence is very important in determining the close relationships of these sites, for they form the only cluster that lies perpendicular to isotherms, isohyets, and terrain contours.

The low elevation stations in the concave microtopography group (Fig. 4A) separate out as a cohesive cluster only in terms of minimum temperature; precipitation and maximum temperature patterns are not nearly as closely related for these stations. However, the fact that they group so solidly in the average (or combined) calculation indicates that minimum temperatures are of first importance in their microclimates, hence their label "frost pockets." These minimum temperature patterns are probably related in part to the temperature inversion which forms in the Cold Creek Valley nearly every night (Hinds and Thorp, 1971).

Exposed ridgetops on steep slopes (sites 16 and 17 at an elevation of 1100 m, see Fig. 1) never clustered with a comparable site on an exposed, but more moderately sloped, ridgetop a couple hundred meters lower in elevation (site 12, elevation 940 m). Causes of this lack of congruence remain obscure, but the distinction occurred throughout, in terms of both temperature and precipitation patterns. Possibly wind differences alter precipitation and temperature patterns: the higher elevation sites have a stony lithosol with little fine material, indicating extreme wind removal rates, in contrast to the lower site (12), which has a relatively deep loessal soil. Certainly the vegetation is different: site 12 supports a dense stand of cheatgrass (*Bromus tectorum*) and a few shrubs (*Artemisia tridentata* and *Chrysothamnus nauseosus*), while the higher sites, 16 and 17, support cushion plants, such as *Phlox hoodii* and *Happlopappus stenophyllus,* and small grasses (*Poa sandbergii*). The cluster analysis suggests the vegetation change is correlated with a change in climatic patterns as well as the obvious change in substrate.

A different problem is illustrated by the large cluster at mid-to-low elevations in Figure 4B:4, which includes nine sites at elevations ranging from 200 to 500 m. This cluster is well removed from strong topographic influences, relatively uniform in appearance, and not affected by steep slopes or excessive exposure to wind or insolation. The vegetation tells a different story, however, because an ecotone, between communities with and without *Agropyron spicatum,* lies at an elevation of about 300 m, right through the heart of this large cluster. We think this occurrence reflects a missing element in our analysis, probably some measure of magnitude in the microclimatic measurements (although edaphic influences are certainly possible). Our clusters were based upon correlation coefficients, which reflect patterns much more sensitively than amounts. The ecotone involving *Agropyron* correlates with increasing precipitation and warmer night temperatures that accompany increasing elevation in this area (Hinds and Thorp, 1971), whereas patterns as determined by our cluster analysis are very similar.

Our analyses have clearly shown that patterns of temperature and precipitation may produce significantly different microclimatic patterns. Two extensions of this work seem desirable. First, some way of including relative or absolute magnitudes of microclimatic factors must be found; and second, to relate microclimates to the landscape, we need to sample vegetation quantitatively in the immediate vicinity of our stations, then attempt to relate plant community structure to the various microclimatic variables or clusters we have been measuring. Such relationships should provide insights into how varied weather patterns, that is, environmental heterogeneity, affect floral species presence and abundance.

Acknowledgments

This work was done by Battelle, Pacific Northwest Laboratories, for the U.S. Atomic Energy Commission under contract AT(45-1)-1830.

Rottenberry was supported by USERDA contract E(45-1)-2042 while on a Northwest College and University Association for Science appointment.

Literature Cited

Daubenmire, R. 1970. Steppe vegetation of Washington. Wash. St. Agr. Expt. Sta. Bull., No. 62: 1-131.

Sokal, R. R., and F. J. Rohlf. 1969. Biometry. W. H. Freeman and Co., San Francisco. 766 p.

———, and P. H. A. Sneath. 1963. Principles of Numerical Taxonomy. W. H. Freeman and Co., San Francisco. 359 p.

Hinds, W. T., and J. M. Thorp. 1971. Annual Summaries of Microclimatological Data from the Arid Lands Ecology Reserve, BNWL-1629, Battelle, Pacific Northwest Laboratory, Richland, WA. 36 p.

Received June 3, 1975.
Accepted for publication October 2, 1975.