The Holdridge Bioclimatic Formations of the Eastern and Central United States

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Introduction

The Holdridge system has been proposed as one capable of defining equally weighted and comparable divisions of the biosphere using climatic parameters, biotemperature, precipitation and potential evapotranspiration ratio.

Working on the vegetation of Haiti, Holdridge (1) found the need for a system of classification that would show relations of Haitian plant communities to the vegetation of other areas. His search of the literature revealed a general consensus that the major causes of climatic differences in vegetation are temperature and precipitation. From a background of field observations and corresponding temperature and precipitation data, Holdridge produced ". . . a graphic chart which immediately shows a rhythmic and logical spatial relationship between natural plant formations."

Since that time Holdridge has continued work in the tropics. Using his system (2, 3), he and others supported in part by the Organization of American States have mapped the life zones of several Central American and South American countries. Countries with completed, published maps include Panama, Guatemala, Costa Rica and El Salvador (4). Tosi (5) has also published a map and monograph on Peru based upon the Holdridge system. A map of Colombia is in press.

This approach proved very useful in ecological and land use mapping in the American Tropics, but it had not been applied elsewhere. The object of the present study is to further clarify the Holdridge system by use of a three-dimensional model, and to map part of the United States by strict use of Holdridge's climatic criteria alone. The resulting map may enable biologists, geographers and climatologists to judge from their diverse viewpoints the possible usefulness of the Holdridge scheme for their various purposes.

Three-dimensional Model

The major unit of the Holdridge system is the life zone or bioclimatic formation, characterized by its climatic association. Other association types (edaphic, hydric, etc.) may also be present within the bioclimatic formation (3). The formations are defined by biotemperature, precipitation and potential evapotranspiration ratio values (2, 3). Two diagrams are used in classifying any given station. The data required for classification are normal mean annual biotemperature, normal annual precipitation and altitude.

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Biotemperature, found most simply by adding normal monthly temperatures above 0°C and dividing by 12, is a function of latitude, but this relation is complicated by elevational differences. Biotemperature represents a convenient integrative device for expressing the combination of climatic parameters which determine the heat factor. These include thermoperiod, photoperiod, and the angle, intensity and quality of solar radiation.

Since latitude and elevation interact to determine the normal annual biotemperature at a station, a three-dimensional relationship exists among them and the humidity factor. This three-dimensional relationship is inherent in the two charts by Holdridge, but is more easily seen in a

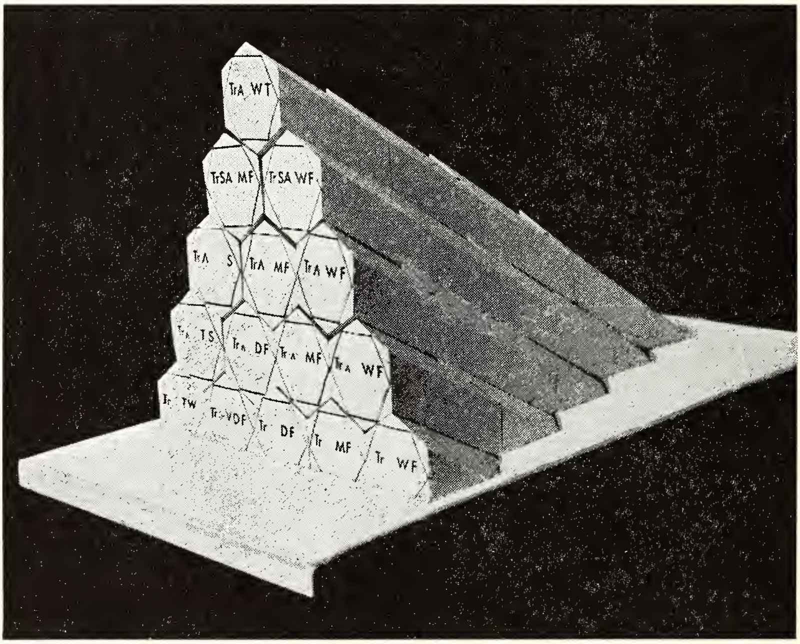

Figure 1. The complete model showing the three-dimensional expression of the diagrams made by Holdridge. Only part of the Holdridge's "Bioclimatic Formations of the World" chart is shown. Each distinguishable unit represents a bioclimatic formation, but only the names of the Tropical formations are seen. Tr—Tropical, Λ—Lower Montane, Λ—Montane, SA—Subalpine, A—Alpine, WT—Wet Tundra, WF—Wet Forest, MF—Moist Forest, DF—Dry Forest, S—Steppe, VDF—Very Dry Forest, TS—Thorn Steppe, TW—Thorn Woodland.

three-dimensional model made by Sawyer (Figure 1). Each axis of the model is logarithmic on the base 2.

Latitudinal regions progress back from the heat equator (lettered face of the model) toward the polar region. These latitudinal regions are Tropical, Warm Temperate, Cool Temperate, Boreal and Polar. Each latitudinal region is composed of a basal or sea level region named for the latitudinal region and various altitudinal belts (Lower Montane, Montane, Subalpine, Alpine and Nival). The presence of the altitudinal belts depends on the latitudinal region; Tropical has all the above mentioned, but Boreal has only Alpine and Nival. The third dimension, moisture, is classified by humidity provinces. The range in the Tropical region is from superarid to superhumid, but only superhumid to semi-arid in the Subpolar region due to less potential variability with lower temperatures. Vegetationally the humidity province is often identified by adjectives, e.g., Moist Forest for the humid province and Dry Forest for the subhumid province. This can be seen on the face of the model in Figure 1. Wet Forest (WF) runs up and to the left in the latitudinal belts of the Tropical region as well as back and to the left in the latitudinal basal regions (see right-hand base of model) giving continuity among the model parts.

A given physiognomic type can occur in more than one latitudinal region. Steppe, as defined by biotemperature, precipitation and potential evapotranspiration ratio values, may occur in three latitudinal regions (Figure 2). In the Cool Temperate region (Figure 2A) steppe conditions

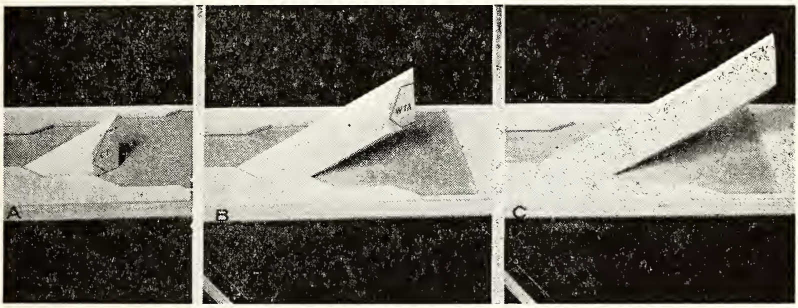

Figure 2. The three Steppe formations are shown here. All three are defined by the same biotemperature, precipitation and potential evapotranspiration ratio values, but differ in altitudinal and latitudinal relations. The Steppe formations occur in three latitudinal regions. In the Cool Temperate region, steppe conditions are found at sea level, as shown in A. In the Warm Temperate region, the steppe formation is found in the Montane belt, part added in B. In the Tropical region another Steppe formation is also found in the Montane belt, part added in C. CT—Cool Temperate, WT—Warm Temperate Montane.

exist in the basal region where elevation does not complicate the latitudinal pattern. In the Warm Temperate (2B) and Tropical regions (2C), steppe conditions can exist in the Montane belt. That is, cool temperate-like conditions can occur in Warm Temperate and Tropical regions at elevations above sea level. But the conditions still differ enough due to factors varying with latitude and altitude to result in different climates and therefore different bioclimatic formations. Further discussion and figures of the model and a review of that part of the literature on the Holdridge system published in English may be found in Sawyer (6).

Methods for Mapping

The Holdridge system was applied to the part of the United States east of the Rocky Mountains. All or part of 37 states were included. The 102°W meridian was chosen as the western boundary. The eastern half of the United States was used because of its rather uniform topography, as compared to the West. Since no field work would accompany the mapping, this area was chosen because its network of Weather Bureau stations was considered adequate. Approximately 1400 stations were used.

In mapping the bioclimatic formations, Weather Bureau stations with sufficient data were classified as to their position on the two charts. These data tabulated by states have been fully presented elsewhere (6). The station, its biotemperature, annual precipitation, elevation and bioclimatic classification are given. The stations were classified using the data from *Climates of the States.* U. S. Weather Bureau, 1931-1955. The station elevation was obtained from *Climatic Summary of the United States, Supplement for 1931 through 1952* in the table, "Station Index and History." If the station had been moved during its history the elevation of the last location was used.

The stations were located on the appropriate Sectional Aeronautical Chart and their classification was marked at the town's name. These (7) charts were used in the initial mapping. Their scale (1:500,000) is large enough to show major relief and to give the small towns, yet small enough to be easily handled. Their major use is for contact flying by slow-medium speed craft, but served our purpose admirably.

When all the stations were located and annotated, the boundaries between the bioclimatic formations were easily drawn. Surprisingly little smoothing of the lines between formations was needed. If one or two stations were not in accordance with most of the surrounding stations they were disregarded. In most cases there were enough stations in sufficiently close proximity to determine whether a station was an exception.

The Warm Temperate latitudinal region is subdivided into two subregions, Low Subtropical and Warm Temperate. The important difference between the two subdivisions is the frequency of severe killing frosts. The occurrence of severe killing frosts is a regular phenomenon in warm temperate conditions, but not in subtropical conditions. This climatic factor determines the presence or absence of broadleaved evergreen trees and other tropical vegetation, thus determining the character of the vegetation.

The Subtropical region is defined as an area within the Warm Temperate region having the probability of one severe killing frost (28°F or —2.22°C) in any one year of less than 33%. The Warm Temperate Subregion is that area having a probability of killing frost greater than 33% (personal communication, Holdridge, 1962). Any given station classified in the Warm Temperate latitudinal region by the biotemperature and precipitation data can be classified either as Warm Temperate or Low Subtropical depending upon the presence or absence of frost as part of the normal climatic regime.

To determine the position of the line separating the Warm Temperate from Low Subtropical, the percentage of years having one or more killing frost for a given station was determined. A preliminary survey of frost occurrences in the South was done using the "Killing Frost Data" table in *Climates of the States* for Florida, Texas, Louisiana, Alabama, Mississippi and Georgia. It was determined that only in central and southern Florida was the frequency of frosts in the spring (January 1 on) less than one season in three. Due to the fact that the data in this table were not adequate for this use, the *Annual Summary of Climatological Data for Florida* was consulted for the years from 1931 to 1956. Using "Temperature extremes and Freeze Data" table for the threshold of 28°F, the number of years in which one minimum temperature of 28°F or lower occurred was determined. Stations with a relative frequency of frost occurrence of 32.9% or less were classified Low Subtropical, and those with 33% or greater Warm Temperate.

Results

Eleven of the life zones were extensive enough to be shown on the map (Fig. 3). The existence of others is indicated by the station on Mount Washington, N. H., classified as Warm Temperate Alpine Rain Tundra. Since most stations are in valleys, life zones at high elevations were not well represented.

Four latitudinal regions were mapped in the eastern and central United States—Tropical, Low Subtropical, Warm Temperate and Cool

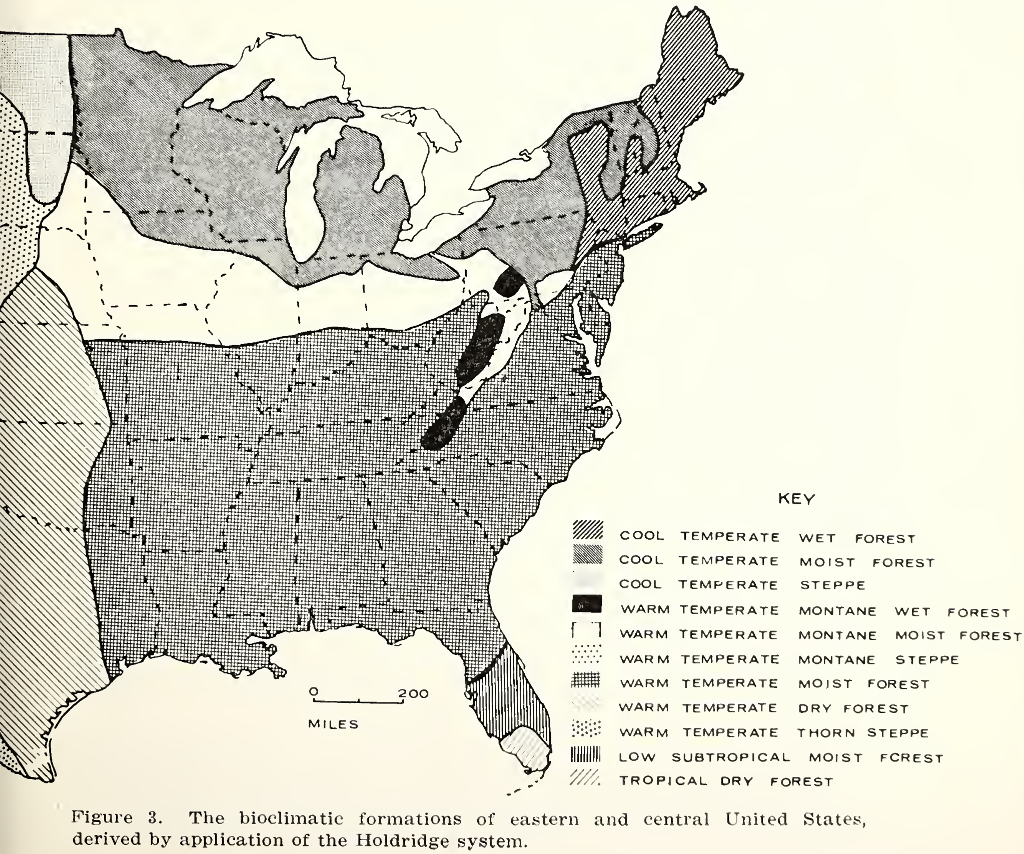

Figure 3. The bioclimatic formations of eastern and central United States, derived by application of the Holdridge system.

Temperate. The Tropical region was found only in the southernmost tip of Florida and is characterized by Dry Forest. In central Florida there is a small area of Low Subtropical Moist Forest. The Warm Temperate region is characterized by three vegetational types, Dry Forest, Moist Forest and Thorn Steppe. Warm Temperate Moist Forest covers the greatest area of any of the bioclimatic formations; its westernmost boundary is in eastern Texas, Oklahoma and Kansas where it gives way to Dry Forest. Warm Temperate Dry Forest is a rather narrow north-south band in Texas, Oklahoma, Kansas and Nebraska. To the west of the Dry Forest is Warm Temperate Thorn Steppe.

North of the Warm Temperate region (basal area) lies the Montane belt of the Warm Temperate region. In the central and southern Appalachian region Montane Wet Forest and Montane Moist Forest are found as altitudinal belts.

The initial reaction to a Montane belt crossing the Midwest is that the region is not mountainous. But, seen in Figure 2, the Warm Temperate Montane section like all other altitudinal belts actually continues to the base line, i.e., sea level. Therefore, it would be expected to reach down to low elevations in areas of transition between two latitudinal regions as is found in the Midwest.

Warm Temperate Montane Moist Forest continues west from Pennsylvania, across Ohio, Indiana, Illinois, Iowa (cf. 8) and into the eastern portion of Nebraska and South Dakota. Here it changes to Warm Temperate Montane Steppe which covers much of South Dakota, Nebraska and smaller areas of North Dakota and Kansas.

Three bioclimatic formations are found in the Cool Temperate Region—Wet Forest in eastern New York and most of New England. Moist Forest from New York and Pennsylvania to Minnesota, and Steppe in the eastern part of North and South Dakota.

Discussion

While it is of some interest to compare (6) Figure 3 with various maps of climate (9, 10) and vegetation (11, 12) of the region, it seems doubtful that this would constitute a valid "test" of the Holdridge system. The reader's evaluation of this system may depend more upon his background and viewpoint than upon the objective findings presented above. Rather than discuss or criticize the system from a given viewpoint, it seems more helpful to offer certain precautions to the reader who may himself judge its usefulness, if any, for his purposes.

Figure 3 is obviously not a map of actual vegetation types, and should not be expected to conform with such maps, which differ among themselves in theoretical and classification bases. According to Holdridge (personal communication, 1963):

> "The life-zone system does not or should not pretend to delineate homogeneous communities or associations of vegetation. The life-zone is a climatic division defined by biotemperature, precipitation, potential evapotranspiration and elevation in a logarithmic system which makes all life-zones equivalent in significance. Within each life-zone there may be several vegetation associations dependent on soils, lesser climatic variables and the presence or absence of open

water. The one climatic association of each life-zone wherein none of the secondary variations are significant, corresponds to a zonal soil and zonal climate. This, of course, may or may not be present in an area where the life-zone is present, but since the physiognomy of the climatic association most clearly typifies the life-zone it has been utilized on the chart as a name for the life-zone."

Thus, the tall grass prairie, a type of vegetation of undeniable importance in this country, is absent in Holdridge's present classification, as it fails to meet the criteria given. But when life-zone boundaries are placed objectively in accordance with climatological data, their implications as to the reasons for an apparent discrepancy may help in reaching a proper interpretation of the factors responsible for the physiognomics of the existing vegetation. Other discrepancies may, of course, be real. Not all ecologists are likely to agree with Holdridge's (personal communication, 1963) interpretation of the several low vegetation types actually present in the mapped Warm Temperate Dry Forest as resulting, in a dry forest climate, from protracted disturbances such as fire, early man, and grazing. Hence, differences in opinion as to the theoretical climax of a region may affect evaluation of the system. Southern Iowa appears to come out wrong in Figure 3 to those who consider bluestem prairie as the climatic climax there, but not to others who regard Iowa as having in reality a moist forest climate.

"There is no sound reason to presume that any one of the several classificatory maps correctly portrays the climate-vegetational relationship, or that Holdridge's model is valid or invalid, approximate or precise, simply because it accords or fails to accord, in whole or in part, with the distribution as depicted by other generalized classifications." (Personal communication, Dr. Joseph Tosi, 1963).

Again, is it possible to test the Holdridge system by comparing our Figure 3 with such generalized climatic maps as Thornthwaite (9) or Trewartha's (10) modification of Köppen? It is uncertain whether such comparisons are testing the Holdridge scheme or the others. Holdridge's concept is a broadly synthesizing one intended for the biosphere as a whole, whereas our application involves a relatively small geographic area.

The system may be regarded from either the traditional ecological conception of types, or from the continuum viewpoint. For some ecological purposes, the regions, belts, provinces, and climatic association names can be disregarded, and the present hexagon boundary lines (5) not accorded special significance. The remaining three-axis skeleton graph, showing gradients of precipitation, biotemperature, and evapotranspiration, provides a meaningful framework for certain ecological analyses, such as plotting limits of the geographic range of an entity in relation to these important climatic parameters.

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