Distribution of Slash Pine as Related To Certain Climatic Factors

BY
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THE CONCEPT THAT CLIMATE determines the geographic distribution of vegetation is generally accepted among ecologists. Seasonal variations in temperature and rainfall are considered the most important climatic factors limiting the geographic distribution of a given species (Daubenmire, 1956).

Because of its rapid growth and value for timber and naval stores, slash pine (*Pinus elliottii* Engelm.) is one of the most important commercial tree species in the southern pine region. Most of the seedlings planted in reforestation programs in the South are slash pine (Mergen, 1955).

The natural range of the species extends from southern South Carolina westward through the Atlantic and Gulf Coastal Plains to eastern Louisiana, and southward to the Gulf of Mexico and central Florida. Seed source and racial studies indicate that slash pine is susceptible to variations in climatic conditions even within its natural range, but the species has been successfully grown in some areas outside of, but adjacent to, its natural range (Hebb, 1955).

Hocker (1956) found that average temperature and the frequency and intensity of precipitation during the summer were the most important climatic factors, of those he studied, associated with the distribution of loblolly pine (*Pinus taeda* L.). His findings indicated some localities where loblolly pine apparently could safely be planted outside the natural range. The usefulness of this knowledge prompted a similar study of the climatic factors associated with the natural distribution of slash pine.

Procedure

The degree to which climatic factors are associated with the occurrence of slash pine can be determined by a comparison of the values of these factors inside the range with similar values outside the range. A technique which permits the simultaneous comparison of a number of factors, and takes into account any correlations among them, is the discriminant function method of analysis (Cox and Martin, 1937). This method makes use of multiple regression to yield an equation in terms of those factors that differ most widely between specified groups of the dependent variable relative to their variation within these groups. Thus, the equation can be used to classify any single observation into the proper group on the basis of the values of the significant factors.

In this instance the groups are selected stations inside and outside the natural range of slash pine (Fig. 1). The factors selected were governed by the climatological records available. Average temperature, range of temperature, and length of the frost free period were chosen as the temperature factors likely to prove of value in discriminating between the two regions. Similarly, average precipitation and frequency of precipitation were selected. Frequency was divided into frequency of precipitation of

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0.01 inch or greater and frequency of precipitation of 0.50 inch or greater. The latter expression is probably a better measure of effective precipitation. An equation of the following form was fitted to these data:

$$Y = a + b_1x_1 + b_2x_2 \ . \ . \ . \ b_{21}x_{21}$$

in which

$Y = +1$ for stations inside slash pine range and -1 for stations outside the range.

x_1 to x_4 = average monthly temperature in winter, spring, summer, and autumn, respectively, in degrees F.

x_5 to x_8 = average monthly range of temperature in winter, spring, summer, and autumn, respectively, in degrees F.

x_9 to x_{12} = average monthly frequency of days with precipitation of 0.01 inch or more in winter, spring, summer, and autumn, respectively.

x_{13} to x_{16} = average monthly frequency of days with precipitation of 0.50 inch or more in winter, spring, summer, and autumn, respectively.

x_{17} to x_{20} = average monthly precipitation in inches in winter, spring, summer, and autumn, respectively.

x_{21} = average length in days of the frost-free period.

$a, b_1, b_2, \ldots b_{21}$ = constant and coefficients derived from the data.

The seasonal averages were obtained by computing the arithmetic averages of 3-month periods from 30-year monthly averages compiled by Hocker (1955). Winter includes December through February; spring, March through May; summer, June through August; and autumn, September through November. These averages were computed for 23 stations inside the range of slash pine and 27 stations in the territory adjacent to and approximately equal in area to the range (Fig. 1).

[1]Because the number of stations inside the range was less than the number outside, the initial value of the constant, a, had to be adjusted by adding to it one-half the difference between the two calculated mean discriminants of the two regions, to make them equidistant from zero.

The normal equations were solved progressively, the variables being segregated in descending order of their contributions to the sum of squares of deviations from the mean of the dependent variable.

Results

The analysis produced the following regression equation (Table 1).[1]

$$Y = -1.325 - 0.2923\ (x_{12}) - 1.2586\ (x_{13}) + 1.6593\ (x_{14}) + 0.5661\ (x_{15})$$

in which

Y = the calculated discriminant value.

x_{12} = average monthly frequency of precipitation of 0.01 inch or more in *fall.*

x_{13} = average monthly frequency of precipitation of 0.50 inch or more in *winter.*

x_{14} = average monthly frequency of precipitation of 0.50 inch or more in *spring.*

x_{15} = average monthly frequency of precipitation of 0.50 inch or more in *summer.*

The accuracy of a discriminant function may be expressed by the probability of misclassification. This probability is determined by the normal deviate of the regression equation, which is computed by dividing half the difference between the two regional mean discriminants by the standard deviation of a single observation, or:

$$\text{Mean deviate} = \frac{\frac{1}{2}\,(0.8147)}{0.8089} = 0.5036$$

According to the table of normal deviates (Pearson, 1930), a deviate of 0.5036 indicates a probability of misclassification of 31 percent. Thus the chance of correctly classifying a randomly selected station is about two out of three.[2]

[2]The elimination of significant variables may introduce a positive bias into the absolute value of the difference between the two mean values of the discriminant function, and a negative bias into the standard deviation. Thus, the probability of misclassification may be underestimated.

The calculated discriminant values for each station (Fig. 1) resulted in the misclassification of three stations inside the range and five stations outside the range. Actual misclassification therefore was 16 percent, or somewhat less than expected.

Because a plus value for the calculated discriminant indicates a similarity in climate to that of the slash pine region, and a minus value indicates a dissimilarity, a line following the zero discriminant value should separate the two regions (Fig. 1).

Discussion

The climatic factors found to be significant between the natural range of slash pine and the area immediately outside its range are expressions of the seasonal frequency and intensity of precipitation.

The significance of these variables does not, however, establish them as factors limiting the distribution of the species. For example, in the Southeast summer rainfall increases toward the south and east; thus, averages of summer rainfall on either side of any line roughly parallel to the coast would differ significantly if the averages were based on areas of sufficient size.

The largest difference in rainfall frequency occurs in summer, when heavy rains occur on 4.05 days per month inside the range and 3.35 days per month in the adjoining region (Fig. 2). This difference is about 20 percent of the frequency outside

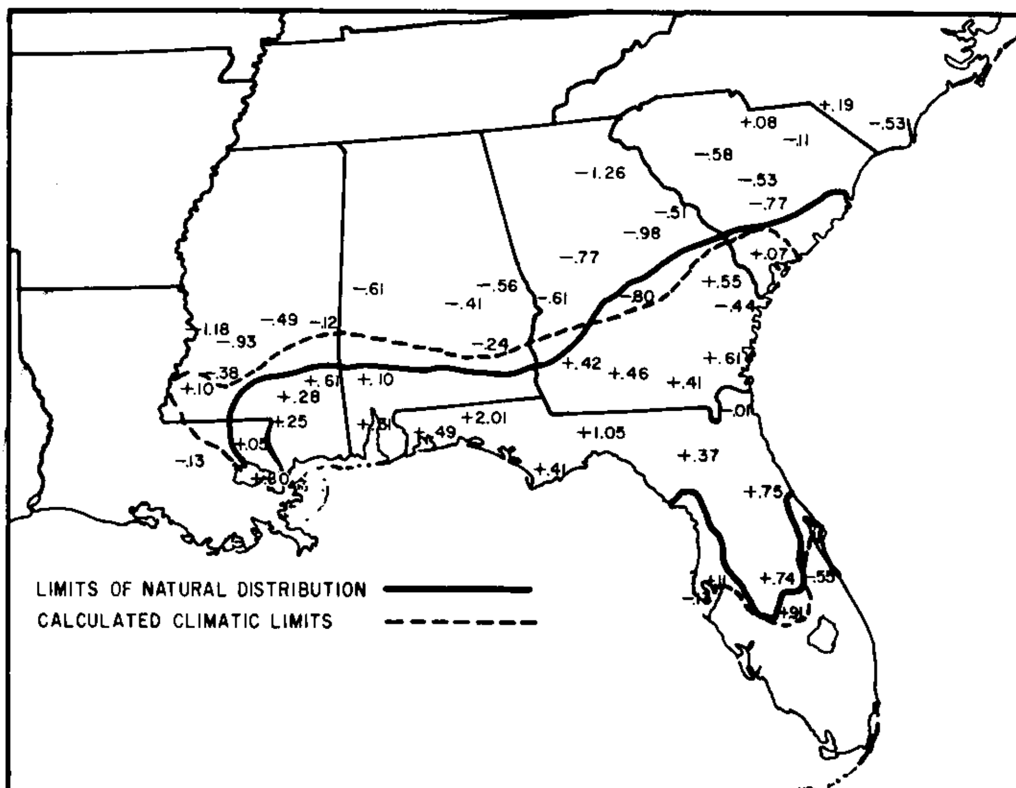

FIGURE 1. *Map showing the calculated discriminant values for the 50 climatological stations, the limits of natural distribution of slash pine, and the calculated climatic limits.*

the range and represents for the season an amount of rainfall that is greater than the difference in total summer precipitation between the two regions (Table 2). Because soil moisture is replenished much more effectively by heavy than by light rains (Shreve, 1914), the substantial difference in frequency of heavy rains during a large part of the growing season could be an important factor in the occurrence of the species. Low frequency of summer rains would affect first-year seedling survival. That the observed difference is enough to preclude seedling establishment seems doubtful, but as one of several critical factors it could be important. Plant distribution is often limited by failure of the reproductive phase, and in southern pines inadequate soil moisture during the growing season may limit the formation of flower buds (Wenger, 1957) and retard the development of cones and seed (Wakeley, 1954).

The second largest difference in rainfall frequency occurs in winter when heavy rains are more frequent in the adjoining area than in the slash pine range. Although not in itself significant, this variable ap-

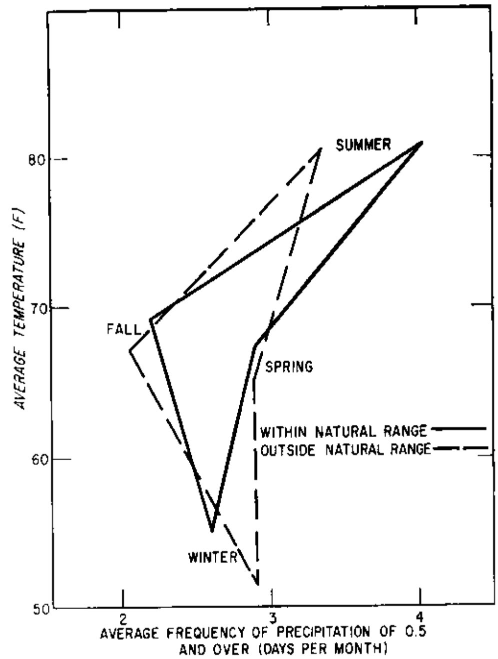

FIGURE 2. *Average temperature and average frequency of precipitation for the area within the natural range of slash pine and the area immediately without the range.*

TABLE 1. Analysis of variance for the discriminant function showing average seasonal values for the significant variables (variables listed in order removed).

Source of variation	D.F.	Sum of squares	Mean square	F	Seasonal averages (in days) Within	Outside	In-out
x_{15} Average monthly frequency of precipitation $\leq$ 0.50 inch, summer	1	11.2331	11.2331	15.25**	4.05	3.35	+0.70
x_{14} Average monthly frequency of precipitation $\leq$ 0.50 inch, spring	1	3.8200	3.8200	5.19*	2.91	2.87	+0.04
x_{13} Average monthly frequency of precipitation $\leq$ 0.50 inch, winter	1	1.9793	1.9793	2.69	2.60	2.91	−0.31
	2	5.2110	2.6055	3.54*	------	------	------
x_{12} Average monthly frequency of precipitation $\leq$ 0.01 inch, fall	1	3.2317	3.2317	4.39*	7.28	7.10	+0.18
Other variables	17	8.7972	0.5175				
Residuals	28	20.6187	0.7364				
Mean	1	0.3200	0.3200				
Total	50	50.0000					

**Significant at the 1 percent level.
*Significant at the 5 percent level.

TABLE 2. Average seasonal precipitation and average frequency of precipitation inside and immediately outside the range of slash pine.

Season	Average precipitation		Average frequency of precipitation 0.5 inch	
	Inside	Outside	Inside	Outside
	Inches		Days per month	
Winter	11.7	12.3	2.60	2.91
Spring	13.2	12.9	2.91	2.89
Summer	18.6	15.6	4.05	3.35
Fall	11.1	9.9	2.18	2.08

parently is associated with the frequency of autumn rainfall, x_{12}, since the latter becomes significant only after the effect of winter differences is segregated. Because of the lower level of life processes during the dormant season, this difference probably is not very important in the occurrence of slash pine. The northern boundary of the species range is well to the south of regular snowfall, although glaze storms occasionally occur. Heavier rains in late winter can inhibit or prevent pollination; thus, the more frequent heavy winter rains in the adjoining territory could be an additional limiting factor.

Differences in frequency of rains in spring and fall, although significant, are quite small. In the spring, heavy rains occur on 0.04 more days per month inside the range than outside. In the fall the difference in frequency of heavy rains is not significant, but light rains occur on 0.18 more days per month inside the range than in the adjacent area. Because these differences are so small, it seems unlikely that they have a real effect on the occurrence of the species.

The failure of average monthly temperatures and monthly temperature ranges to be significant is probably because they do not adequately express temperature variations between the two areas. Average minimum, yearly minimum, and periodic minimum temperatures are likely more important in limiting the distribution of a species. Cold periods following warm periods in late winter and early spring frequently kill trees; consequently, their number and duration might limit the distribution of a species. It has also been shown recently that the difference in day and night temperatures has a significant effect on growth of loblolly pine seedlings (Kramer, 1957); closely related species such as slash pine might be similarly affected. Unfortunately the lack of data precluded an analysis of these factors.

It is realized that parent material and soil formation are also correlated to a very high extent with species distribution. Local site conditions and site-climatic interactions can and do overshadow climatic effects and may account for some of the deviation between the limits of natural distribution and the calculated climatic limits in Figure 1.

The conclusion is that analysis of climatic factors by means of the discriminant function will show which factors are associated with the distribution of a species. This information may be useful in indicating where the species might be planted outside its natural range. However, significant association of climatic variables with species occurrence does not show how they operate to limit the distribution of the species. The greatest value of discriminant-function analysis probably lies, therefore, in its usefulness in planning further research, because it shows where additional work is likely to be most profitable.

The line following the calculated zero discriminant value closely parallels the line of actual distribution of slash pine. Many areas in South Carolina, Georgia, Alabama, Mississippi, Louisiana, and east Texas, which are adjacent to the natural range of slash pine, may lack sufficient precipitation during the growing season for optimum development of the species. Slash pine is now being planted in many of these areas, but plantations are for the most part too young to provide satisfactory data on growth rates throughout the period of a rotation. Scattered reports of stagnation, slowing of growth, and failure to express dominance in plantations from sapling to pole size may possibly be attributed to insufficient summer rainfall. Before deciding to plant slash pine in these localities, the alternative of planting species of southern pine native to the region should be considered. In central Florida the calculated distribution line extends farther south than does the line of natural distribution used in this study, although in general they are parallel.

Regions outside the natural range of slash pine which proved to have climatic conditions significantly similar to the natural slash pine area are small zones in South Carolina, southern Mississippi, and western Louisiana. Slash pine should prove a valuable species for planting within these zones on suitable sites. The results of this study suggest, however, that the planting of slash pine outside its natural range should be undertaken with caution, and only after careful consideration of all local climatic variations and specific site conditions.

Summary

The relationship of climatic variables to the natural distribution of slash pine was studied. The variables used were monthly averages of temperature and precipitation by seasons, and average length of the frost-free period, for 23 stations within the range of natural distribution of slash pine and 27 stations in the area outside of, but adjacent to, its range.

The data were analyzed by the discriminant function method. The following variables, listed in the order selected, were found to be significant in discriminating between the two regions:

- Average monthly frequency of precipitation $\geqq$0.50 inch, summer
- Average monthly frequency of precipitation $\geqq$0.50 inch, spring
- Average monthly frequency of precipitation $\geqq$0.50 inch, winter[3]
- Average monthly frequency of precipitation $\geqq$0.01 inch, autumn

The analysis does not establish these variables as limiting factors to the growth of slash pine. Further study is needed to determine how these climatic differences may operate to affect the occurrence of the species.

When the regression equation is applied to individual stations, a plus value for Y indicates climatic conditions similar to those in which slash pine grows naturally, and a minus value indicates dissimilar conditions. On a map showing the weather stations a line tracing the zero (Y) values should, therefore, separate the two regions. This line parallels closely the boundary of natural distribution of the species (Fig. 1).

Areas of South Carolina, Georgia, Alabama, Mississippi, and Louisiana which are outside but adjacent to the northern limit of natural distribution of slash pine appear suitable climatically for the species. Other areas in these same states that are farther removed from the zone of natural distribution, but where slash pine is presently being planted, may lack sufficient frequency of heavy rains. Planting in these areas should be undertaken with caution and with careful consideration of the site requirements and silvical characteristics of the species.

[3]Significant in combination with the fourth variable removed.

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