The Effect of Drought on Growth Decline of Loblolly Pine on Littleleaf Sites

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ABSTRACT

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Loblolly pine is the recommended alternative for shortleaf pine on high-risk littleleaf sites, yet it suffers from a decline resembling littleleaf disease on these sites. Analysis of radial growth data collected from 17 loblolly pine stands near Union, SC, showed that severe droughts during 1951, 1954, 1956, 1970, and 1980 and a less severe but prolonged drought during 1962–1964 reduced radial growth of all trees. Growth decline of trees with declining crowns started in 1975 and continued through 1983. The lack of correlation between distinctive short-term climatic events and the initiation of growth decline in 1975 indicates that the decline evident in these loblolly trees was not due to drought and was likely due to the complex of factors causing a disease similar to littleleaf disease in shortleaf pine.

Littleleaf disease of shortleaf pine (*Pinus echinata* Mill.) is common on eroded, poorly drained soils of the Piedmont (1,15). The term "littleleaf" is descriptive of the crown symptoms that develop on shortleaf pine during disease manifestation, namely, chlorotic and shortened needles that remain on current twig growth. Affected trees decline and soon die. Loblolly pine (*P. taeda* L.) is considered less susceptible to littleleaf disease and is recommended as an alternative to shortleaf pine on these sites (3,4,13,15). Over the last 30 yr, loblolly has been used to replace shortleaf pine in many high-risk areas where littleleaf disease has been severe. Although considered less susceptible (12), loblolly pine often shows littleleaf-like symptoms and has sustained severe damage on high-risk sites where product objectives of large trees require 50- to 80-yr rotations.

Previous work has shown a relationship between littleleaf crown symptoms in loblolly pine and reductions in annual radial increment (11). Recent droughts may have accelerated development of littleleaf symptoms, since stressed trees are generally more susceptible to disease. The actual impact of these droughts is unknown, however. This research, using the techniques of dendrochronology and dendroclimatology, examines the possible influence of specific drought events on growth decline in littleleaf symptomatic loblolly pine trees.

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MATERIALS AND METHODS

Sample collection. Sample collection was described previously (11). Briefly, in each of 17 stands of loblolly pine growing on sites of varying littleleaf risk, a 100-tree transect determined the incidence of three crown symptom types in dominant and codominant loblolly pines. Symptom type—severe decline, light decline, or healthy—of each sampled tree was recorded. Trees with severe decline showed distinct yellow, often dwarfed, sparse foliage confined to branch tips, followed by branch dieback; sometimes, abundant crops of small cones persisted in the crown. Trees with light decline lacked twig and branch dieback and were otherwise similar to severely declined trees except for degree of foliage yellowing and sparsity. Healthy trees had no distinct symptoms.

Core preparation. For every tenth tree in the transect, two increment cores were removed at a height of 1.4 m. The cores were air-dried, glued into pregrooved blocks, and sanded to expose a tranverse face suitable for measurement. The cores were then cross-dated to detect cores with missing rings, using drought years to identify index rings, and radial increments were measured to 0.01 mm. Radial increment data were then processed through a series of dendrochronology techniques.

Standardization of cores. Standardization removed low-frequency growth variation, especially that attributable to increasing age and circumference (5). Briefly, this involves fitting a growth curve to the observed data for each tree. Values predicted by the curve line represent the potential growth for the tree through the chronology. Observed growth fluctuates around this long-term potential growth largely because of changes in macroclimate. Standardized ring-width index values were then calculated by dividing the observed growth value for a given year by the predicted growth value for that year. The standardized indices of all trees were then averaged to obtain an annual mean growth chronology. The computer programs INDEX and SUMAC (7) were used to calculate the indices and mean chronology.

Determination of response function. The response function is used to identify relationships between ring-width indices and climatic variables. The program, RESPONS, calculates response functions using principal component analysis to reduce the number of climatic variables and transform the variables into uncorrelated (orthogonal) variables (6). Stepwise multiple linear regression is conducted using the smaller set of variables. The resulting regression coefficients are then converted into a new set of coefficients associated with the original variables.

A response function was developed using indices of healthy trees on the high-risk littleleaf sites. Climatic data were from the Santuck, SC, weather station for the period 1950–1983 (10). This is the closest recording station to the survey area; all sites are within 10 mi. The response variable in the model was ring-width index. Monthly mean temperature and total precipitation for each month from May of the year prior to growth to October of the current growth year were the 36 concomitant variables entered into the model. The 18-mo time period was chosen because growth of loblolly pine may extend from March through October (8) and to determine if climate during the year previous to the current growth year caused any carry-over or lag effects. A lag effect may be caused by an increase or decrease in available soil moisture, transpiration, or stored food during the previous growing season (5).

A separate regression analysis was performed to determine if the growth-climate relationship had remained the same during the period 1950–1983. A growth-limiting factor such as root disease may have changed the relationship between radial growth and climate, possibly making the trees more or less sensitive to climatic influences. Separate regressions were performed for the time periods 1950–1974 and 1975–1983, representing before and after decline. These time periods were chosen because of the visual difference in radial increment responses of the two health classes. Dependent variables input into the regression models were ring-width indices. Independent variables were monthly soil-moisture deficits calculated according to a method of Zahner and Myers (14). Soil-moisture deficits are defined as the difference in inches of rain between that actually supplied to trees and that which could be used by trees under existing weather conditions. Calculated soil-moisture deficits were used as a relative measure of drought severity.

RESULTS

Mean chronologies of annual radial increment were developed for each of the three crown symptom types: healthy, light decline, and severe decline (Fig. 1). Before 1975, all three chronologies seemed to be responding to the same macroclimatic influences. For example, the severe drought during 1954 shows up as a relatively narrow ring in all three chronologies. After 1975, however, growth of the trees with light and severe decline symptoms was markedly less than that of the healthy trees.

The elements of the response function were plotted by month for both temperature and precipitation (Fig. 2). A positive element indicated a direct response of annual increment to the climatic variable and a negative element indicated an inverse response (10).

For the temperature portion of the response function, three elements were significent: July of the prior year and August and September of the current year. Each significant element was negative, indicating that above-average annual increment was associated with below-normal temperatures. Significant elements for precipitation were August and October of the prior year and June, July, August, and October of the current year (Fig. 2). All elements were positive, indicating that greater-than-average annual radial increment was associated with above-normal precipitation during these months.

For the time period before decline in radial increment (1950–1974), the regression lines for the declined and healthy symptom classes were similar (Fig. 3). In this analysis, the severe and light symptom classes were combined, creating the declined symptom class. The correlation coefficients for the two symptom classes were negative, indicating that as soil moisture deficit increased, radial increment decreased. After decline in radial increment, the regression lines were divergent (Fig. 4). The healthy trees were still responding similarly to the previous period, but the declined trees were not.

DISCUSSION

An inspection of the response curves (Fig. 2) reveals that low temperature in general and high precipitation in general favor increased radial increment of healthy loblolly pines. Some variables in specific months have statistically significant effects, as shown by the response functions.

The element of July (prior year) may have been significant as a response function because greater-than-normal temperatures are associated with excessive transpiration and high rates of respiration, which may have caused a depletion of carbohydrates (9). Depletion of carbo-

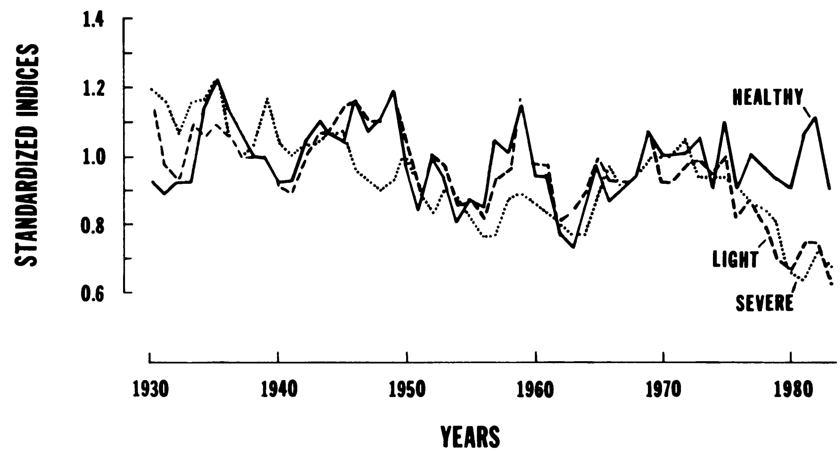

Fig. 1. Chronologies of three crown symptom types (healthy, light, and severe) of loblolly pine trees growing on littleleaf sites in the Sumter National Forest in South Carolina. The index value equals the actual annual increment divided by the expected annual increment.

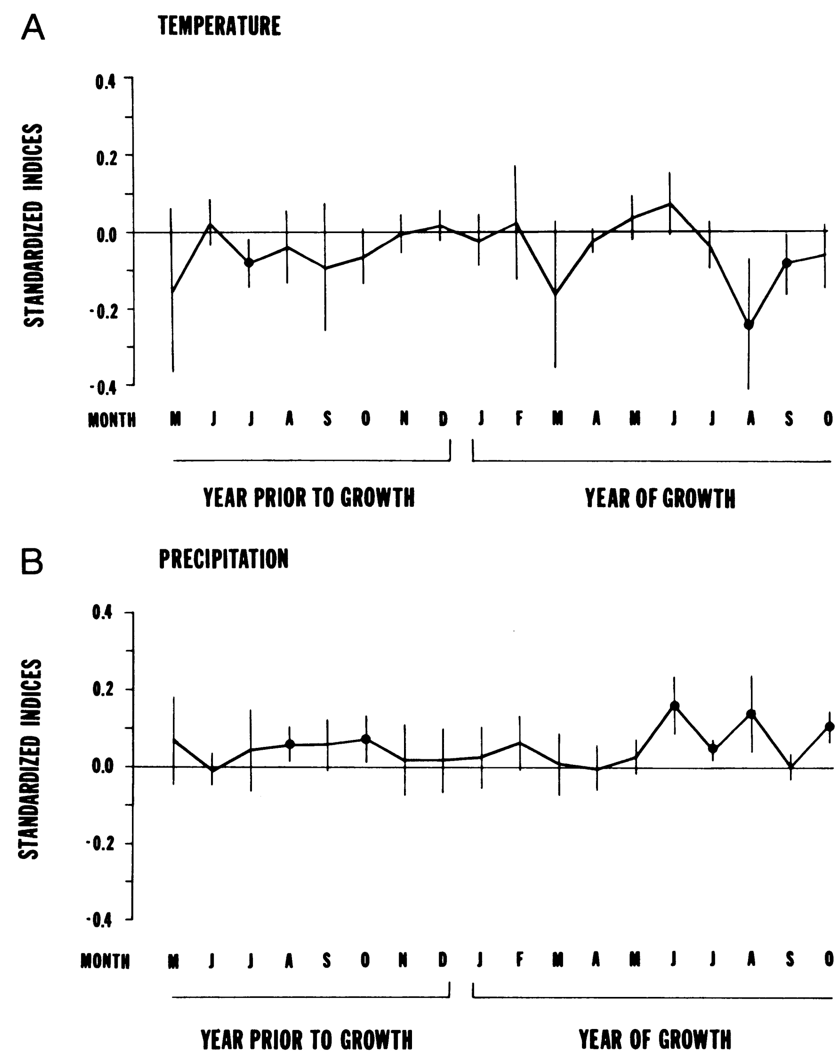

Fig. 2. Response function of **(A)** temperature and **(B)** precipitation data for healthy loblolly pine trees growing on littleleaf sites; vertical lines indicate the 95% confidence intervals. Significant (α = 0.05) elements are marked by solid dots.

hydrate stores for the next growing season will result in reduced radial increment (5). The elements of August and September of the current year were probably also related to greater-than-normal temperatures, leading to rapid transpiration and increased water stress on the tree during a time when soil moisture is low. Above-average temperatures are associated with greater-than-normal respiration, leaving less carbohydrates for cambial growth (5).

Above-average amounts of precipitation during August and October (prior year) will increase the amount of available soil water, which may increase the production of carbohydrates. Stored carbohydrates increase the number of leaf primordia that will overwinter and expand the next growing season (9). A greater number of leaf primordia will increase the photosynthetic area, which will, in turn, increase production of carbohydrates and growth regulators.

The significant precipitation elements of June, July, August, and October during the year of growth indicate that above-average precipitation increased the amount of available soil moisture during the summer and fall when soil water deficits were common. Lack of available soil moisture is directly related to increased internal water deficits and, ultimately, reduced increment (9).

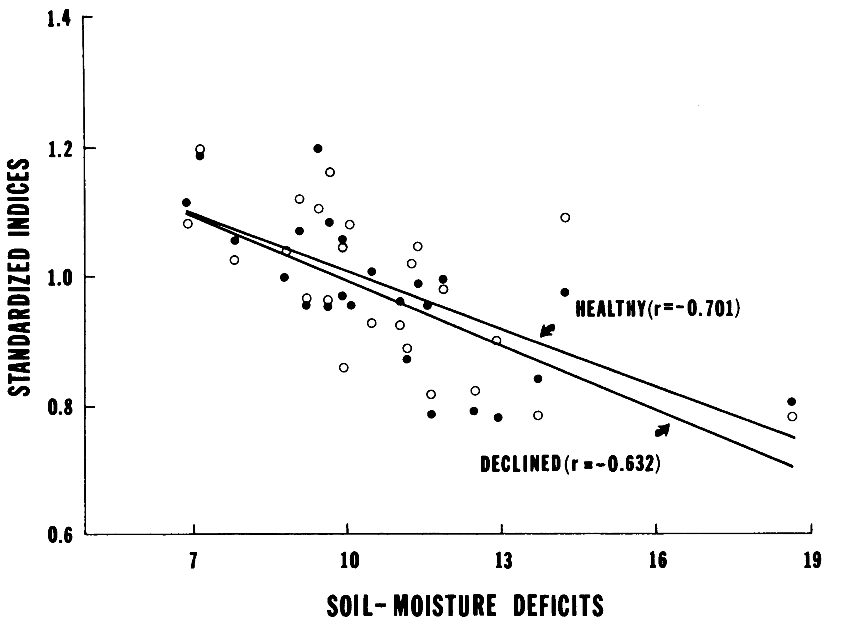

Fig. 3. Scatterplot and regression lines of standardized growth indices of healthy (•) and declined (o) trees with soil-moisture deficits for the time period 1950–1974, before the decline in annual increment.

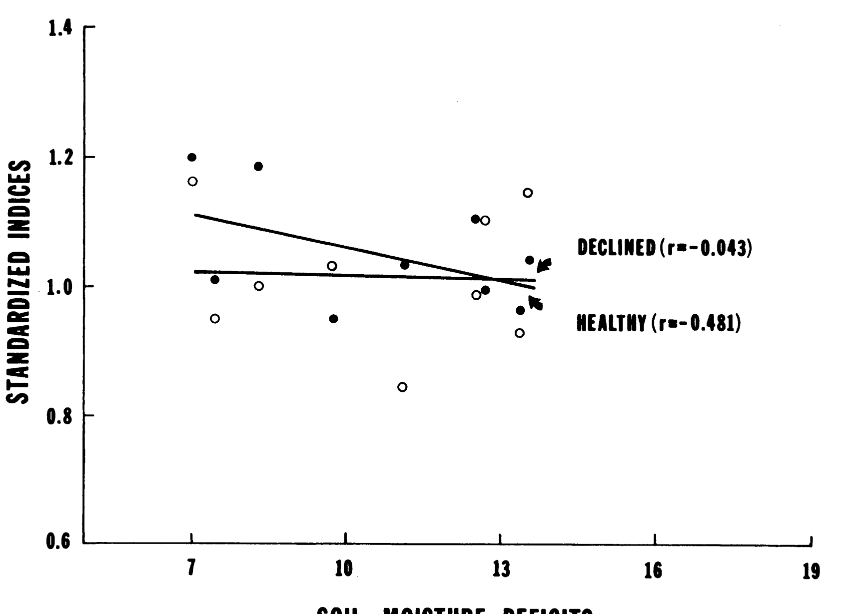

Fig. 4. Scatterplot and regression lines of standardized growth indices of healthy (•) and declined (o) trees with soil-moisture deficits for the time period 1975–1983, the period of growth decline.

Because of their high clay content, soils of high-risk littleleaf sites have low amounts of available soil-moisture, commonly resulting in large soil-moisture deficits from June throughout the rest of the growing season. Further, they are not usually fully recharged during the growing season (14) because infiltration is slow and resultant losses to surface flow are great. Internal water deficits that develop can decrease growth by decreasing the production and downward translocation of growth regulators from the crown that results in the inhibition of cell enlargement in the cambium (9).

The high-risk littleleaf sites are stressful to trees of all symptom classes because of their poor internal soil drainage and low amount of available soil moisture storage capacity. This is exacerbated by restricted root distribution and rootlet mortality caused by root pathogens, such as *Phytophthora cinnamomi* Rands and *Pythium* sp.

The effect of drought on annual increment of loblolly pine was examined for trees growing on high-risk sites where it was thought growth would be most limited by macroclimatic factors. The response function gave evidence that above-average precipitation during 4 mo late in the growing season increased annual increment. Conversely, below-average precipitation (drought) during the growing season had a direct influence on annual increment.

Climatic influence on annual increment of symptomatic trees was less evident during the years after decline in annual increment. The decreased response of these trees may be due to root infection by *P. cinnamomi*, which decreases the absorptive capacity of the tree, causing internal water deficits and slowed radial increment, even in favorable growth years (2). The inability to find a climatic trigger that predisposed these trees to sustained decline indicates that drought was not the primary cause of the decline. Instead, the decline of loblolly pine is likely due to the same complex of edaphic, biologic, and pathologic factors responsible for the manifestation of littleleaf disease in shortleaf pine.

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