Dendroclimatic Relationships of Post Oak Across a Precipitation Gradient in the Southcentral United States

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Abstract. Post oak is a dominant species along the prairie border in the southcentral United States where upland forests gradually merge into the grasslands of the Southern Plains. These vegetation changes coincide with a sharp decrease in mean annual precipitation. Increment core studies at more than 50 sites from southern Texas to central Missouri indicate that old-growth post oak forests are still widespread, probably because these typically small, poorly formed trees were not systematically logged. Analysis of five tree-ring chronologies located across the precipitation gradient indicates that post oak radial growth is directly related to precipitation and inversely related to temperature for several months during and preceding the growing season. Post oak chronologies tend to become more variable and climate sensitive westward toward the prairie border, consistent with the decline in rainfall and the westward decrease in forest cover, species diversity, and tree size. This increase in climate sensitivity for post oak reflects the importance of declining rainfall amounts to the growth and probably to the distribution of upland deciduous forests on coarse-texture soils along the Southern Plains.

The climate-explained growth variance for some post oak chronologies along the prairie border is very high, and is comparable to values typical for arid-site conifers. Selecting post oak sites from the prairie-forest transition zone or from other sites where moisture stress is frequent will provide a maximum of proxy climate information in the derived chronologies.

Key Words: dendroclimatology, remnant post oak, prairie-forest border, climate sensitivity.

TREE-RING chronologies from old, climate-sensitive trees offer a unique quantitative means to extend relatively short meteorological records well into the past. Long-term climate reconstructions based on the ring widths of many temperate species have provided accurately dated proxy information on historical changes in climate for the past 200 to 400 years (e.g., Fritts 1976; Hughes et al. 1982). A few long-lived species offer much longer chronologies and paleoclimate estimates (e.g., LaMarche 1974). Dendroclimatic reconstructions may provide a more representative record of the long-term mean and variance for a particular climate or hydrological variable correlated with tree growth than may be apparent in modern observations (e.g., Stockton and Boggess 1980).

Since all trees do not faithfully record climate variations, specific climate-sensitive species and site types must be identified and selected in order to maximize the climate information content of tree-ring chronologies. The importance of moisture supply to the growth of arid-site conifers and of low temperatures for arctic and alpine species has been documented by comparison of chronologies collected along moisture and temperature gradients (e.g., Douglass 1937; Giddings 1943; Schulman 1956; Fritts et al. 1965; Kay 1978). Dendroclimatic research in the central and eastern United States has not been extensive until recently, and only a few studies of possible systematic changes in the climate sensitivity of deciduous species along environmental gradients have been reported. Estes (1970) examined the climate sensitivity of white oak (*Quercus alba* L.), black oak (*Q.*

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velutina Lam.) and shortleaf pine (*Pinus echinata* Mill.) on different soil types in the central Mississippi valley. Charton and Harman (1973) compared white oak stands located on coarse and fine-texture soils and concluded that climate sensitivity was higher on fine soils in northwestern Indiana. In this paper we identify important monthly climate variables correlated with the growth of post oak (*Q. stellata,* Wangenh.), and present evidence for a geographic relationship between decreasing annual rainfall amounts and the climate sensitivity of this dry-site hardwood in the southcentral United States.

Post Oak in the Southcentral United States

The remnant post oak-blackjack oak (*Q. marilandica* Muenchh.)-dominated forests along the western fringe of the eastern deciduous forest constitute one of the largest relatively unaltered forest vegetation types in the eastern United States. These two oaks are the most common species in the upland Cross Timbers forests that border the Great Plains in northern Texas, central Oklahoma, and southeast Kansas (Dyksterhuis 1948; Rice and Penfound 1959; Kuchler 1974). Owing to their small stature and often poor growth form (Fig. 1), post oak and blackjack oak were not systematically logged on the scale common for the more productive timber sites elsewhere in the oak-hickory or oak-pine forests of the Interior Highlands and Gulf Coastal Plain (Davis 1940). Our tree-ring sampling at more than 50 mature and old-growth post oak-dominated forests and our observations of many other such forests extending from southcentral Texas to central Missouri indicate that parcels of the original old-growth post oak-blackjack oak forest type remain scattered throughout the forest-prairie transition zone and on certain marginal sites elsewhere. Most remnants are less than 200 acres in size, but field observations of site conditions and examination of growth trends on cores from more than 1,500 trees at these sites suggests that many remnant post oak forests have not been drastically altered from their presettlement condition. Relatively undisturbed post oak forests appear to be most extensive in Oklahoma, probably because this forest type is so prevalent in the state and because European settlement did not begin until the late nineteenth century. Old-growth post oak is also widespread in Texas, but most of these remnants have had a longer history of grazing. Elsewhere in the eastern deciduous forest the persistence of old-growth post oak-dominated remnant forests is often determined by specific site characteristics such as dry, infertile soils on steep, rocky sites in remote or relatively inaccessible areas.

The overall frequency and size of relatively undisturbed post oak forest remnants, how-

Figure 1. Old-growth post oak in the prairie-forest transition zone of central Texas (height approximately 8 m).

ever, certainly have been and continue to be greatly reduced by agricultural clearing, small-scale logging, and other developments. At the same time, many remnants are not in pristine condition owing to occasional selective cutting, heavy grazing, road construction, oil exploration, and post-settlement changes in the fire regime. The spread of cedar (*Juniperus* spp.) and mesquite (*Prosopis glandulosa* Torr.) are among the most typical recent effects of increased grazing and the altered fire regime, which have thus far been largely confined to the understory and margins of established stands.

Post oak is well suited for dendrochronology because it is often slow growing, is long lived, and produces well-defined annual growth rings that may vary in width on selected sites in response to prevailing climatic conditions (Kuechler 1859; Harper 1960; Johnson and Risser 1973; Hill 1980). Mature post oak on upland sites rarely exceed 15 m in height or 80 cm DBH (Davis 1940; Dyksterhuis 1948), but our studies indicate that many attain 250 to 300 years in age. Old-growth post oak forest remnants, therefore, provide an excellent opportunity to develop a network of long tree-ring chronologies for the reconstruction of past climate (Stockton and Meko 1983), the dating of historic buildings (Stahle 1979), and the study of environmental factors important in post oak growth and distribution. Our sampling indicates that blackjack oak is not a long-lived species, however, and probably will not be particularly useful for the study of past climate.

A number of previous studies have examined the environmental factors involved in the distribution and composition of upland deciduous forests in the southcentral United States (Bruner 1931; Dyksterhuis 1948; Rice and Penfound 1959; Risser and Rice 1971). Soil texture, through its influence on available moisture supply and soil aeration, is believed to be the predominant factor behind the mosaic of forest and grassland in the broad transition zone between upland forests and prairie in the southcentral United States (Bruner 1931; McBryde 1933; Dyksterhuis 1948; Kuchler 1974). Native upland deciduous forests are usually confined to rocky or sandy soils in this transition zone, with prairie or savanna vegetation present to the virtual exclusion of forests on fine-texture soils.

Within this region, however, there is considerable geographic variation in the structure and composition of upland forests. Rice and Penfound (1959) reported extensive quantitative evidence that the species diversity, arboreal dominance, and basal area of upland forests generally decrease westward and that the upland forests of Oklahoma form a vegetational continuum from relatively mesic forests in the eastern part of the state to more xeric stands in the west along the margin of the Southern Plains. Similar changes occur north and westward from the forested portions of northeastern Kansas and southeastern Nebraska (Albertson and Weaver 1945) and elsewhere along the eastern fringe of the Great Plains.

The east-to-west vegetation continuum in the southcentral United States parallels the decline in annual precipitation. This coincidence constitutes strong evidence that climate, in addition to local factors such as exposure and soil texture, fertility, and depth, has a pronounced influence over forest compostion and productivity in this region (Bruner 1931; Dyksterhuis 1957) and suggests that the precipitation gradient in particular controls the general location of the broad transition zone between upland deciduous forests and prairie (Borchert 1950). These climate and vegetation changes further imply that climate-sensitive tree-ring chronologies for many deciduous species may be found toward the deciduous forest frontier, where climatic conditions appear to become increasingly unfavorable for tree growth.

To investigate the relationship between climate and tree-growth in this region, we examined the influence of temperature, precipitation, and prior-growth variables on the radial growth of post oak from five sites located across the precipitation gradient and toward the prairie-forest border in the southcentral United States (Fig. 2). This study was designed to identify the important monthly climate variables correlated with post oak growth and to help identify the most climate-sensitive post oak sites on coarse-texture soil in the region. We specifically test a hypothesis stating that the radial growth of post oak will become increasingly correlated with climatic conditions as mean annual rainfall decreases toward the upland deciduous forest border. The results of this study should help

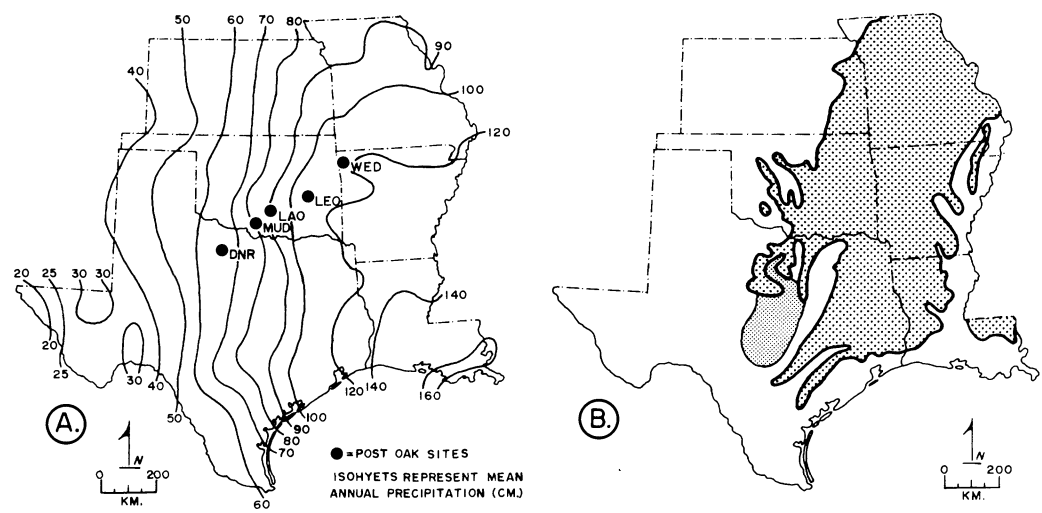

Figure 2. A: The five post oak chronologies are plotted relative to the mean annual precipitation gradient in the southcentral United States (1931–1960, Court 1974). The chronologies from east to west are Wedington Mountain, Ark. (WED); Lake Eufaula, Okla. (LEO); Lake of the Arbuckles, Okla. (LAO); Mud Creek, Okla. (MUD); and Nichols Ranch, Tex. (DNR). B: Approximate distribution of post oak in the southcentral United States (heavy shading), generalized from Kuchler (1964) and Fowells (1965). Post oak is found from the Atlantic coast to central Texas, and is a dominant or lesser component of the Cross Timbers, oak-hickory, oak-pine, cedar glade, and southern mixed-forest vegetation types in the southcentral United States (Kuchler 1964). Post oak is present on a more scattered basis in the juniper-oak and mesquite-oak savannahs mapped by Kuchler in central Texas (light shading). A few small outlying stands of post oak exist west of these limits, but the species is not native to the lower Mississippi alluvial valley or the coastal prairies of Texas and Louisiana.

in the identification and selection of post oak sites for the development of climate-sensitive tree-ring chronologies, and should suggest evidence on the climatic factors involved in post oak growth and distribution in the southcentral United States independent of the considerable body of information based on geographic changes in vegetation types.

Materials and Methods

The effect of decreasing mean annual precipitation on the variability and climatic sensitivity of post oak growth was examined with tree-ring chronologies from five sites located from northwest Arkansas to northcentral Texas. These sites (Fig. 2) were selected by virtue of their location relative to the rainfall gradient and prairie-forest border, and all represent relatively undisturbed mature and old-growth post oak-dominated stands more than 40 acres in size growing on coarse-texture soil. Wedington Mountain and Lake Eufaula are located on gradual to steeply sloping stony fine sandy loams derived from acid sandstone. Lake of the Arbuckles is located on gradual to steeply sloping, gravelly sandy loams derived from a conglomerate of sandstone, limestone, and quartz fragments. Mud Creek and Nichols Ranch are located on generally level, deep, fine sandy loams and loamy fine sands, respectively.

More than 40 tree-ring cores were extracted from at least 25 trees at each site. Chronologies were developed with standard techniques outlined by Stokes and Smiley (1968) and were compiled with programs RWLIST, INDEX, and SUMAC (Graybill 1979). Program RWLIST prints the ring width measurements and plots the 20-year means for each core, so that these data may be examined for measurement errors and a growth trend. Standardized ring width indices are computed for each core with program INDEX by fitting one of several optional growth curves to the raw ring width data to remove the nonclimatic growth trend related to increasing tree age and circumference, the effect of different growth rates among trees, and certain nonsynchronous long-term growth surges or suppressions believed to result from microsite factors unique to individual trees. Ring width indices for each selected specimen are then averaged into a mean index chronology for each site with program SUMAC. Only those specimens with strong crossdating, a high average correlation with all other specimens from the site, and similar statistical characteristics are included in the final site chronology (e.g., Graybill 1982).

In comparing the climate response of post oak across the climate gradient, however, we have restricted the analysis to chronologies of equal length and number of specimens that were derived from old-growth trees only (i.e., trees dating from at least 1800 to 1977). This precaution was necessary because the ring width variance and correlation with climate variables for some oak chronologies may decline with the increasing age of the trees (e.g., Hill 1980). A higher proportion of younger, more sensitive ring series in certain chronologies across the transect could inflate the climate relationship relative to chronologies based solely on less sensitive old-growth specimens. Correlation analysis among all available old cores at each site for the period 1800 to 1977 was used to select a subsample of the ten most highly correlated old-growth cores representing ten different trees (the highest number of old trees available for all five sites). These ten old-growth specimens were then used to develop mean index chronologies for the common period of 1800 to 1977 at all five sites (Fig. 3). The chronology statistics and response function analysis discussed below are based on these old-tree chronologies. Two shorter chronologies representing young trees only (i.e., single cores available for six trees <100 years old) were also developed for the eastern and westernmost sites (Wedington Mountain, Ark., and Nichols Ranch, Tex.) for comparison with the results based solely on old-growth trees.

We selected three standard statistics to depict the changing characteristics of the five post oak chronologies from sites located across the precipitation gradient (Fig. 4). Mean sensitivity is an average of the relative variability in tree-ring index values from one year to the next. The absolute difference of adjacent ring width indices is divided by the mean of the two index values, and the results are averaged for the entire chronology (Fritts 1976). First-order serial correlation measures the correlation between a ring width index and the preceding index and reflects the tendency for narrow rings to be followed by narrow rings and wide by wide rings. This growth persistence often results from the influence of prior climate conditions on biological factors such as the accumulation or depletion of stored food reserves. The average correlation among all series is computed for all possible linear correlations between the component specimens of a chronology for the common period of 1800 to 1977 and reflects the degree of covariation between all specimens in the mean index chronology. The average correlation is usually high for climate-sensitive chronologies when the same climate conditions have tended to limit uniformly the growth of most trees at a site. Chronologies with the highest mean sensitivity and average correlation and the lowest serial correlation are generally considered to have the best dendroclimatic potential (Fritts and Shatz 1975).

To test the hypothesis that the radial growth of post oak becomes increasingly limited by climate as annual precipitation declines westward toward the prairie-forest border, response function analysis (Fritts 1976) was used to identify the relationship between monthly climate variables and post oak growth at the five collection sites. Response function analysis involves modified multiple regression of regional climatic data and ring width indices. In this case, average temperature and total precipitation for 14 months beginning with June of the previous growing season and extending through July of the current season for 46 years (1932–1977) were selected from the climate division average appropriate for each post oak site (the Texas Low Rolling Plains division was used for the Nichols Ranch site, which is located on the border of two divisions). These 28 climate and 3 prior-growth variables (i.e., ring width index values for three preceding years) were entered into stepwise regression as candidate predictors (independent variables) of ring width indices from 1932 to 1977 (dependent variables).

Divisional average rather than single-station climate data were used because of differences in the microclimate of, and distance between, the tree sites and individual weather

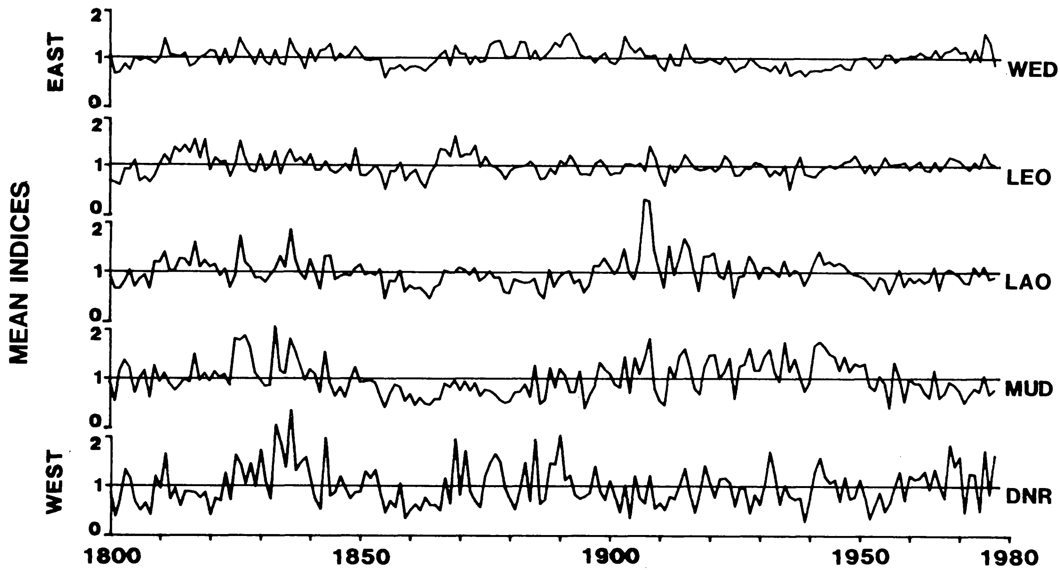

Figure 3. Mean index ring-width chronologies for the five post oak sites are based on ten trees each for the period 1800 to 1977 and become more variable from east to west (i.e., top to bottom) across the precipitation gradient.

stations. Divisional climate data are also usually more representative of the regional climate than of single stations and often share more common variance with tree-ring data (Blasing, Duvick, and West 1981).

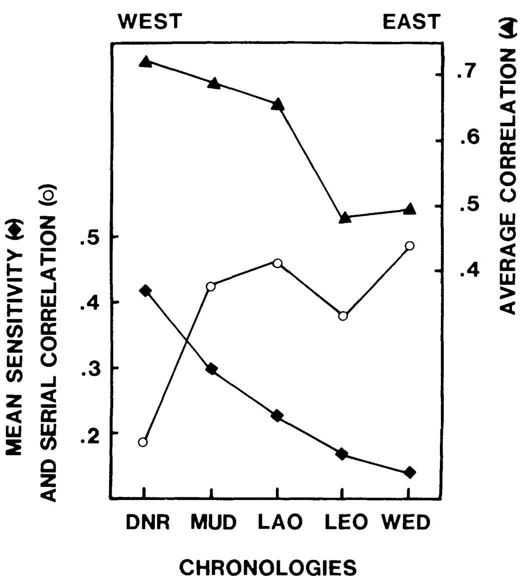

Figure 4. Selected chronology statistics for five post oak chronologies arranged across the precipitation gradient indicate an east to west increase in ring width sensitivity and average correlation, and a general decrease in first-order serial correlation for post oak on coarse texture soils in the south-central United States.

Prior-growth variables are usually included in response function analysis to account for growth persistence in tree-ring data and to avoid the autocorrelation of residuals. Principal components analysis is used to derive orthogonal monthly climatic variables prior to regression to avoid problems arising from the intercorrelation of seasonal temperature and precipitation values (e.g., Fritts 1976, 370). In this analysis only the first 11 to 13 eigenvectors with eigenvalues ~1.0 or greater and together expressing more than 78 percent of the variance in the original climate data were passed to regression. Stepwise regression was terminated when the addition of a new variable failed to increase the explained variance (i.e., r^2 adjusted for loss of degrees of freedom, Stockton and Meko 1983).

The 31 elements or weights of the response functions in Figure 5 correspond to the 14 temperature, 14 precipitation, and 3 prior-growth variables and express the relationship between post oak growth, climate, and prior growing conditions. Each element is proportional to the relative effect of the corresponding climate or prior-growth variable on the ring width index. A positive element indicates a direct relationship and a negative element indicates an inverse relationship (Fritts 1976). Significant response elements ($P < 0.05$) are shaded in Figure 5.

Because this study attempts to identify a

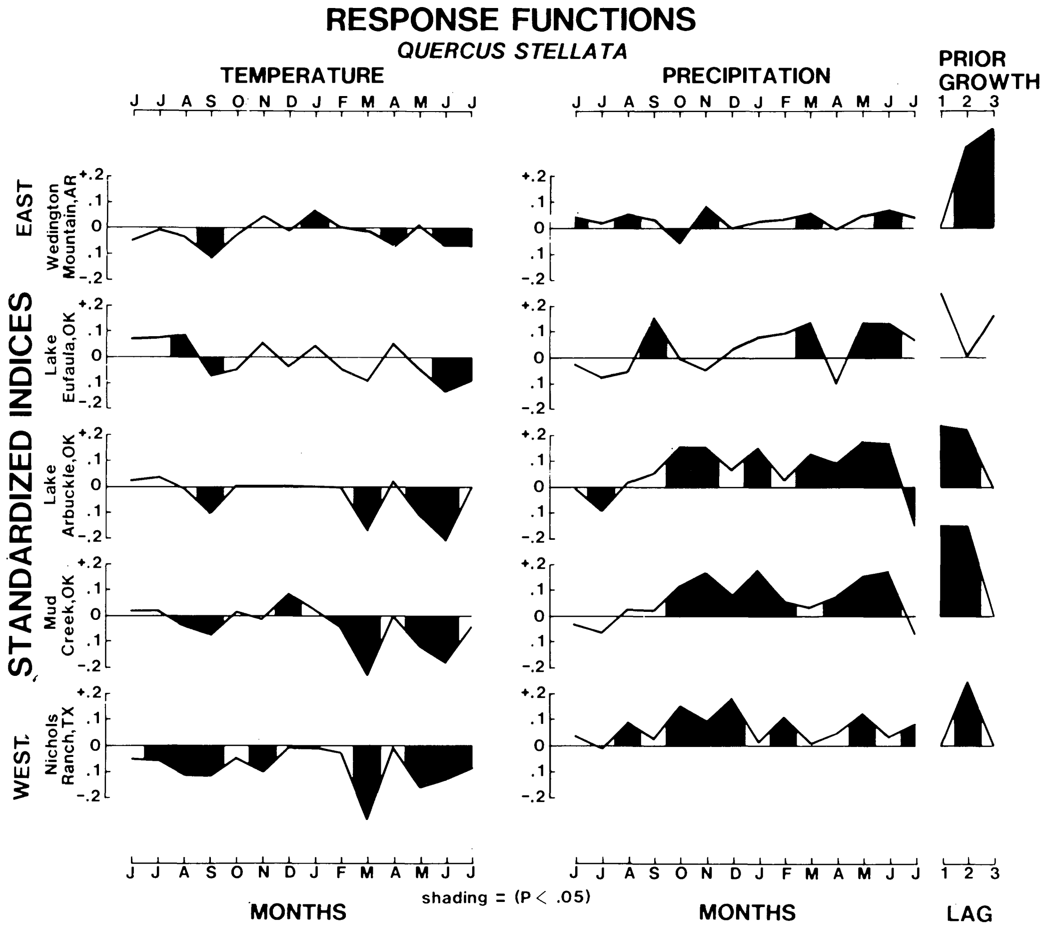

Figure 5. Response function results for the five post oak chronologies are arranged from east to west (i.e., top to bottom). The strength of the predominantly negative temperature and positive precipitation relationship with post oak growth tends to increase westward in the direction of decreasing annual rainfall toward the prairie-forest border.

change in the relationship between climate and post oak growth across the environmental gradient, a direct comparison of the climatic analysis among all sites is necessary. To insure comparability the time interval (1932–1977) and the specific months in each year included in the response function analysis (previous June to current July) were standardized for each chronology. A 14-month year including climate conditions prior to the growing season was selected because climate of the previous summer, autumn, and winter often has an important effect on tree growth through an increase or decrease in soil moisture, transpiration, and stored food reserves (Fritts 1976). The 14-month year was terminated at the end of July of the current growing season because dendrometer studies in Georgia (Jackson 1952) and southern Illinois (Zimmerman, Rolfe, and Arnold 1977) indicate that more than 90 percent of the total radial growth of post oak is completed between March 26 and July 21 in the former location and between April 10 and August 1 in the latter.

Results

The five post oak chronologies for the period 1800 to 1977 indicate a pronounced east-to-west increase in chronology variance (Fig. 3). Crossdating of low- and high-frequency trends is good among neighboring sites, especially among the western chronologies. Several single years (e.g., narrow rings for 1801, 1855, 1911, 1925, 1939, and 1953 and wide rings for 1826, 1915, and 1975) and certain longer trends (e.g., 1825–1838, 1855–1865) crossdate across the entire region (approximately 560 km).

The increase in post oak growth variance and crossdating from east to west is reflected by the statistics plotted in Figure 4. Mean sensitivity and the average correlation among all series increase, while autocorrelation tends to decline westward in the direction of decreasing mean annual rainfall. Mean ring width declines systematically westward across the first four sites, but increases to the largest value observed at the westernmost site, Nichols Ranch (mean ring widths from east to west are 0.69, 0.64, 0.64, 0.57, and 0.74 mm). This result is contrary to expectations and is discussed below.

The results of the response function analysis indicate that all five chronologies show a significant positive relationship with precipitation and a significant negative relationship with temperature for several months during and preceding the growing season (Fig. 5, and Table 1). These results generally agree with previous studies in Oklahoma, which found post oak growth to be directly related to total annual rainfall (Harper 1960; Stockton and Meko 1983) or to rainfall of the current spring and previous summer (Johnson and Risser 1973). Prior growth enters regression for all five sites, and is significant for one or more lags at four sites (Fig. 5). Though prior growth accounts for additional variance in the ring width indices at all sites, our interpretations will be based only on the tree-growth variance explained by the monthly climate variables because we are primarily interested in the relationship between post oak growth and decreasing annual rainfall.

The correlation between post oak growth and monthly temperature and precipitation tends to increase westward in the direction of decreasing rainfall (Fig. 5). The strength of the growth/climate association (as measured by the vertical scaling of the response elements), the number of monthly climate variables significantly related to growth, and the overall percentage of tree-growth variance explained by the climate variables all tend to increase westward toward the deciduous forest frontier (Fig. 5 and Table 1).

The results for the two available young-tree chronologies are generally consistent with the results based on old trees, suggesting a westward increase in the climate sensitivity for post oak of all age classes. The young-tree chronology statistics calculated for the common period of 1910 to 1977 indicate increased climate sensitivity westward between the Wedington Mountain and Nichols Ranch sites (i.e., mean sensitivity from 0.24 to 0.49, first-order serial correlation from 0.51 to 0.12, and average correlation from 0.46 to 0.84). The increase in the growth variance explained by climate between the two young-tree chronologies is not as pronounced as observed between the old-growth chronologies for these two sites. The variance explained by climate between the two young-tree chronologies increases from 50 to 70 percent, and the number of significant monthly temperature and precipitation elements increases from 11 to 15. Although the variance explained by climate for the young trees is more than double that for old trees at

Table 1. Summary of Response Function Results

	Percent Growth Variance Explained by			N Significant Variables[a]			
Site	Climate	Prior Growth	Total	Temp	Precip	Prior Growth	Step
Wedington Mtn., Ark.[b]	24	40	64	5	6	2	6
Lake Eufaula, Okla.	32	9	41	4	4	0	8
Lake Arbuckle, Okla.	54	14	68	4	9	2	9
Mud Creek, Okla.	38	37	75	7	8	2	8
Nichols Ranch, Tex.	63	6	69	8	7	1	8

[a] $P < 0.05$.
[b] Sites are listed from east to west. The growth variance explained by climate and the number of significant monthly temperature and precipitation variables tend to increase westward in the direction of decreasing mean annual rainfall.

the Wedington Mountain site, the overall shape of the response functions and the significant monthly temperature and precipitation elements are similar for both the young- and old-tree chronologies at both sites.

Discussion

The results of the response function analysis indicate that high temperatures and low precipitation are limiting to post oak growth for several months during and preceding the growing season (Fig. 5), probably through their effect on available soil moisture, evapotranspiration, and net photosynthesis. Trends in the chronology statistics (Fig. 4) suggest a westward increase in climate stress for post oak, reflected by increasing variance in annual growth increments, which become more coherent among trees in each stand, and by a decrease in the influence of prior growing conditions. The results of the response functions parallel these trends, indicating that moisture supply becomes increasingly correlated with post oak growth as mean annual precipitation declines westward toward the upland deciduous forest border with the Southern Plains. These observations appear to be generally representative of a population tendency for post oak in the southcentral United States, since the statistics and response functions derived for the full chronologies from these five sites (based on 41 to 50 cores from 25 or more mature and old-growth trees each) for the two young-tree chronologies and for four additional chronologies not included in this study are consistent with the results in Figures 4 and 5. Preliminary analysis of 25 recently collected post oak chronologies also indicates an increased climate signal for post oak in the prairie-forest transition zone.

The model of increasing climate sensitivity for post oak as rainfall declines is supported by the response function results in spite of certain problems concerning the design of this analysis that could affect the tree growth-climate relationship. For example, some sites are probably better represented by their divisional climate data than others simply by virtue of their central location within the division. The Mud Creek site is farther west and has better chronology statistics than the Lake Arbuckle site, but the growth variance explained by climate is higher for the Lake Arbuckle chronology (Table 1). Both sites are located in the same climatic division, but Mud Creek is near the southwestern edge of the division whereas Lake Arbuckle is near the center. Differences in the strength of the climate response among the chronologies might also arise from other factors, such as different site conditions (e.g., slopes, exposure, soil fertility) or unique microclimatic characteristics at the collection sites that may not be perfectly modeled by the standard 14-month climate year used in this analysis. In light of these potential problems, the response function results provide reasonably good support for the predicted relationship between declining rainfall and growth variability, and they help to explain in climatic terms the trends in chronology variance and correlation depicted in Figures 3 and 4.

The large mean ring width observed at the westernmost site was unexpected, however, and contradicts the model of increased climate stress for post oak in a low-annual-rainfall regime. Several considerations might account for the higher growth rate at Nichols Ranch. This analysis was restricted to "old growth" specimens, but some differences in the maximum age of the trees included have not been entirely eliminated. The median estimated germination dates for the ten specimens at each site are (from east to west) A.D. 1750, 1753, 1745, 1703, and 1770. These average age estimates may explain some of the increase in mean ring width since the Nichols Ranch chronology has the youngest age estimate and includes a greater proportion of typically larger juvenile rings in the 1800 to 1980 period used to calculate mean ring width.

At the same time, a higher growth rate is possible under increased climate stress if other environmental limiting factors are reduced. The Nichols Ranch site is a forest outlier that is much more open and has fewer species than the sites farther east. This probably results in less competition and may allow a more pronounced growth response to favorable climate conditions than might be possible at more crowded sites. If correct, this could result in a higher overall growth variance explained by climate.

Although the five sites are located on coarse-texture soils, there are important differences in soil fertility and available water capacity among the sites. The three western sites are classified as alfisols, which have a higher base saturation and are probably more fertile than the inceptisols found at the two eastern sites (Soil Conservation Service 1969, 1971, 1973, 1975, n.d.a., n.d.b.). Low fertility probably prevents a maximum growth response to favorable climate conditions and thereby reduces the potential climate-explained variance in the eastern sites. Finally, the available water capacity is low for the Hector soil series at Wedington Mountain and Lake Eufaula owing to shallowness and high stone content, but it is moderate to high at Lake Arbuckle, Mud Creek, and Nichols Ranch. Combined with reduced forest cover, this may allow more complete use of the available rainfall for the post oak at Nichols Ranch.

Some of these westward changes in forest and soil characteristics at the collection sites are no doubt involved in the increased correlation between climate and post oak growth. Since the rainfall decline is so pronounced and is responsible for many of the changes in site conditions, however, it ultimately appears to be the most important factor involved in the increasing correlation between post oak growth and climate toward the prairie-forest border. The relative importance of climate over soil conditions in explaining the increased climate sensitivity of our post oak data is supported by the tendency for the climate correlation to increase westward between the two eastern sites, which are located on the same soil series, and between the three western sites, which are located on similar soils (all three are in the ustalf suborder). Furthermore, the two eastern sites, if anything, would appear to be more climate sensitive solely on the basis of site conditions since they are steeper and have much more shallow, rocky soils than the three western sites.

Many factors such as higher average annual evaporation, a lower average frequency of rainy days per year, greater variance in annual rainfall amounts (Court 1974), more days per year with maximum temperatures over 32°C (Baldwin 1973), and a greater frequency of hot desiccating winds (Borchert 1950) are probably associated with lower mean annual rainfall in explaining the apparent westward increase in potential evapotranspiration for post oak. The southwestward increase in average temperature, however, is considerably less pronounced than the decrease in annual precipitation and does not seem adequate to explain fully the strong westward increase in the post oak temperature response (Fig. 5). Based on divisional climate data for 1931 to 1977 from northwest Arkansas to northcentral Texas (Low Rolling Plains division), average growing season temperature (March through July) and average annual temperature increase only approximately 15 and 19 percent, respectively (i.e., from 18.5° to 21.3°C and 14.6° to 17.4°C). Since annual precipitation decreases 98 percent between these same climatic divisions,[1] we suspect that the post oak temperature response is coupled in part with the steep decline in annual precipitation. Even though the increase in average temperature is relatively small, high temperatures can hasten internal moisture stress and limit growth more often in the western portions of the study area, where the average available moisture supply is much lower. The intercorrelation of temperature and precipitation may also in part explain the westward increase in the temperature response of post oak, since summer temperature in the Great Plains is negatively correlated with precipitation (Namias 1983). Toward the southern end of the species range in southcentral Texas, however, temperature may become more directly limiting to post oak growth.

The east-to-west trend in climatic sensitivity supports a model of increased climate stress for post oak under a lower mean annual rainfall regime. A similar model is probably appropriate for blackjack oak in this region, since Johnson and Risser (1973) report a direct correlation between a blackjack oak chronology and rainfall in central Oklahoma. These data on the climatic response of the two most important upland forest species in the study area are consistent with the interpretation that the westward decline in species diversity, arboreal dominance, and basal area for upland deciduous forests on coarse-texture soils in the southcentral United States is due largely to the effect of decreasing annual precipitation on available soil moisture (Bruner 1931; Dyksterhuis 1957; Rice and

Penfound 1959). We emphasize coarse soils because native woodland vegetation has generally been replaced by grasslands on upland fine-texture soils in the transition zone between forest and prairie, although a similar climate transition may exist for vegetation on fine-texture soils farther east. This evidence implies that a prolonged shift to a cooler/wetter or warmer/drier climatic regime would ultimately result in a westward or eastward migration of upland forests, respectively (e.g., Borchert 1950, 35–36). The sandy sites occupied by shinnery oak (*Q.* spp.) in the Low Rolling Plains and High Plains of western Texas and Oklahoma, for example, would probably support post oak and blackjack oak in a more mesic climatic regime than currently exists.

A comparable gradient in the climate sensitivity of white oak (*Q. alba* L.) appears to exist in the Prairie Peninsula region of Iowa, Illinois, and Indiana, where a decrease in tree cover (Kucera 1952) and an increase in environmental stress on white oak (Charton and Harman 1973) have been related to a decrease in available soil moisture, and because white oak chronologies from Iowa tend to have a stronger climatic signal than their counterparts from areas of greater mean annual rainfall farther to the east and south (e.g., DeWitt and Ames 1978; Duvick 1979).

Remnant old-growth forests are perhaps most widespread along the western margin of the eastern deciduous forest, but similar conditions exist throughout the eastern United States where noncommercial stands with old climate-sensitive trees can be found. Chestnut oak (*Q. prinus* L.) is a good example, as it is widespread on poor rocky sites from New England to Alabama and has provided drought-sensitive chronologies more than 300 years long in the Northeast (e.g., Cook and Jacoby 1977; Cook 1982; E. R. Cook, personal communication). The wide ecological amplitudes of chestnut oak, bur oak (*Q. macrocarpa* Michx.), and American beech (*Fagus grandifolia* Ehrh.) suggest that they may also show systematic changes in the tree growth/climate relationship across certain environmental gradients within their native ranges. Old-growth stands of these species may also be fairly common owing to their low commercial value on adverse sites.

Conclusions

Post oak chronologies from selected sites in the prairie-forest border region have considerable value for the estimation of past climate conditions. The percent of variance in post oak growth explained by climate for the Lake Arbuckle and Nichols Ranch sites (Table 1) is directly comparable to the climate-explained variance typically found in chronologies from arid-site conifers in western North America, which have provided high-quality estimates of past climate and hydrological variables (Fritts 1976, 400). A recent reconstruction of annual precipitation in southern Oklahoma from A.D. 1700 to 1980 based on post oak chronologies (including data from the Lake Eufaula and Lake Arbuckle sites), for example, was well correlated with independent precipitation data both during and preceding the calibration period (Stockton and Meko 1983). Although several other species occur in remnant post oak-blackjack oak-dominated forests of the Cross Timbers region, only post oak appears to be sufficiently old, readily datable, and widespread enough to have high potential for dendroclimatology. By selecting post oak sites along the prairie-forest border in the south-central United States, and from other strongly moisture-stressed sites elsewhere in the species range, tree-ring chronologies with a maximum amount of climate information can be derived.

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Note

1. Mean annual precipitation plotted in Figure 1

is based on single-station data for the period 1931–1960 (Court 1974) and decreases only approximately 50 percent between the eastern and westernmost tree-ring sites.

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