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An ecological study of the Sweet Briar College old-growth white oak forest

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ABSTRACT

Quantitative data on the composition and structure of all strata of vegetation were collected from an old-growth white oak (*Quercus alba*) forest community on the campus of Sweet Briar College in Amherst County, Virginia. In addition, increment growth cores were extracted from representative larger white oak trees for age determination and analysis of growth patterns. White oak, with an importance value (IV) of 32.8, was clearly the dominant species present in the tree stratum (stems $\geq$10 cm DBH), with tulip tree (*Liriodendron tulipifera*), sourwood (*Oxydendrum arboreum*) and beech (*Fagus grandifolia*) the most important associates. White oak was conspicuously absent form the small tree (stems <10 but $\geq$2.5 cm DBH) and sapling (stems <2.5 cm DBH but $\geq$1.0 m tall) strata but had a higher importance value than any other species in the seeding stratum. The oldest cored trees dated back to the 1770s. Analysis of growth patterns indicated that water availability (as precipitation) in current and prior growing seasons are the most important environmental factors affecting the growth of white oaks at this locality.

Key words: climate, dendroecology, environmental factors, forest ecology, Virginia Piedmont.

INTRODUCTION

"It is said to be the best-developed tract of its kind in the Piedmont" (M. Godfrey, author of *A Sierra Club Naturalist's Guide to the Piedmont*).

Remnant old-growth forests (with some trees >200 years old) are rare in eastern North America, where logging and other human activities carried out over the past four centuries have had a devastating impact upon the landscape. However, in certain localities where forests have been afforded a high degree of protection, small patches of old-growth do exist. These remnant old-growth forests give us an insight into the natural vegetation of the general area in which they occur. Moreover, tree-ring analysis can provide valuable information on just what environmental factors are responsible for patterns of growth during the lifetime of the trees present.

The old-growth remnant considered in the present study occurs on the campus of Sweet Briar College (37°33'26" N, 79°04'57"; elevation 255 m), a private women's college in Sweet Briar, Virginia. Sweet Briar College, which is located in Amherst County in the Virginia Piedmont, was established in 1901. The campus of the college is unusually large, extending over more than 13 km^2. A considerable portion of the campus is forested, but the old-growth remnant is less than 1.0 ha. Although widely known (see statement before the Introduction), this old-growth remnant had never been subjected to detailed study.

The objective the study reported herein was to obtain quantitative date on the structure and composition of the vegetation of the old-growth white oak forest on the campus of Sweet Briar College and then to extract increment growth cores from the largest (and presumably oldest) white oak trees present. These increment growth cores were analyzed to determine the environmental factors most responsible for growth patterns in these trees.

CLIMATE DATA

The nearest long-term weather station is in Lynchburg, Virginia. Long-term climate data for Lynchburg were obtained from the Global Historical Climate Network, version 2 (Vose et al. 1992; Peterson & Vose 1997). These data were used to generate the summary climate statistics used in the analysis of the relationships between climate and tree growth.

According to the Köppen climate classification system (Köppen 1936), Lynchburg has a humid subtropical (Cfa) climate. The humid subtropical climate zone covers most of the southeastern United States. Like all mid-latitude climates, weather can vary significantly both spatially and temporally. Humid subtropical climates are characterized by long, hot, humid summers and winters which, while often relatively mild, can bring cold, stormy weather. While droughts may occur, there is typically no dry season.

As is typical of humid subtropical climates, most of Lynchburg's annual climatic variability is restricted to average monthly temperatures, ranging from 1.7 °C in January to 24.3 °C in July (Figure 1). Mean monthly rainfall in Lynchburg ranges from 74.1 mm in April to 97.8 mm in July.

MATERIALS AND METHODS

Quantitative data on structure and composition of all strata of vegetation were collected using standard sampling methods (e.g., Stephenson & Adams 1986). All live trees (stems ≥2.5 cm diameter at breast height [1.37 m above ground level] and hereafter referred to as DBH) were measured and recorded by species in a single 20 m by 50 m (0.1 ha) quadrat in each of three study sites. Stems ≥10 cm DBH were considered to be trees, whereas stems <10 cm but ≥2.5 cm DBH were recorded as small trees. Quadrats were typically placed with their long axes parallel to the contour of the slope. Saplings (individuals of tree species <2.5 cm DBH but ≥1.0 m tall) were tallied by species in the same quadrat. Numbers of large seedlings (individuals of tree species <1.0 m but ≥10 cm tall), and shrubs (including woody vines) were recorded by species in four 5.0 by 5.0 m plots placed at regular intervals along a 50 m tape used to establish the centerline of the 0.1 ha quadrat. Numbers of small (germinal) seedlings (individuals of tree species <10 cm tall) and estimates of percent cover of herbaceous plants were recorded from ten 1.0 by 1.0 m plots placed at 5.0 m intervals along the same tape. All cover values were estimated using a cover class rating scale described by Daubenmire (1968).

Field data from each study site were used to calculate absolute (N/ha) and relative (%) density and absolute (m^2/ha) and relative (%) basal area values for trees and small trees. Importance value (IV) indices were then calculated for all species in these two strata as one-half the sum of relative basal area and relative density (Curtis & McIntosh 1951). Only relative density values were derived for saplings, seedlings, germinal seedlings and shrubs. Relative cover and relative frequency were determined for herbaceous plants. Nomenclature follows Radford et al. (1968).

Tree-ring samples (cores) were obtained, prepared, and measured using standard tree-ring sampling techniques (Stokes & Smiley 1968; Fritts 1976). We cored nine of the largest trees, taking two cores from each tree at breast height. The computer program COFECHA (Holmes 1983) was used to statistically assess the accuracy of the dating and quality of the measurements.

Tree-ring chronologies were prepared using the program ARSTAN (Cook 1985). ARSTAN produces up to three types of chronologies from tree-ring series. The first is a standard chronology that does not take into account temporal persistence (autocorrelation) in tree-ring series. If serial autocorrelation is detected, then ARSTAN produces a residual chronology that has had the autocorrelation removed, and an ARSTAN chronology that adds the common persistence back to the residual chronology.

Response function analysis (Fritts et al. 1971, Fritts 1976) was used to evaluate the relationship between tree growth and climate. The residual chronology was compared to three monthly climate variables—mean maximum temperature, mean minimum temperature, and total precipitation—for a period of time beginning in May of the prior growing season and ending in September of the growing season in which a particular tree ring was produced. Response functions were calculated using principal components regression (Briffa & Cook 1990, Morzukh & Ruark 1991).

RESULTS

Vegetation data

White oak, with an importance value (IV) of 32.8, was clearly the dominant species present in the tree stratum, with tulip tree (*Liriodendron tulipifera*), sourwood (*Oxydendrum arboreum*) and beech (*Fagus grandifolia*) the most important associates (Table 1). White oak was conspicuously absent form the small tree and sapling strata but had a higher importance value than any other species in the two seedling strata (Tables 2 & 3).

Eleven taxa were recorded from the shrub stratum. Low-bush blueberry (*Vaccinium vacillans*) was the most important member of this stratum and represented 56.0% of all stems tallied. The other more important species were Virginia creeper (*Parthenocissus quinquefolia* [14.0%]), muscadine (*Vitis rotundifolia* [12.8%]), American bittersweet (*Celastrus scandens* [5.0%]), mountain laurel (*Kalmia latifolia* [3.3%]), sawbrier (*Smilax glauca* [2.2%]), and catbrier (*Smilax hispida* [2.2%]).

Table 1. Composition of the tree (stems ≥10 cm DBH) stratum.

Species	RD (%)	RBA (%)	IV
Quercus alba	14.0	51.5	32.8
Liriodendron tulipifera	17.0	13.3	15.2
Oxydendrum arboreum	22.0	4.7	13.4
Fagus grandifolia	12.0	8.3	10.2
Carya tomentosa	8.0	4.9	6.4
Quercus velutina	3.0	7.8	5.4
Acer rubrum	7.0	2.2	4.6
Nyssa sylvatica	5.0	2.7	3.9
Carya glabra	4.0	1.9	3.0
Quercus rubra	3.0	1.9	2.4
Betula lenta	2.0	0.3	1.1
Cornus florida	2.0	0.2	1.1
Fraxinus americana	1.0	0.3	0.7
Total	**100.0**	**100.0**	**100.0**

Table 2. Composition of the small tree (stems ≥2.5 cm but <10 cm DBH) stratum.

Species	RD (%)	RBA (%)	IV
Cornus florida	31.9	27.2	29.5
Acer rubrum	18.4	15.4	16.9
Liriodendron tulipifera	9.7	11.8	10.8
Fagus grandifolia	11.1	9.2	10.1
Oxydendrum arboreum	6.3	11.2	8.7
Nyssa sylvatica	7.7	7.3	7.5
Betula lenta	2.4	6.9	4.6
Carya tomentosa	3.9	2.7	3.3
Carya glabra	2.9	1.9	2.4
Sassafras albidum	1.5	2.4	1.9
Quercus rubra	1.5	2.0	1.7
Fraxinus americana	1.5	0.9	1.2
Cercis canadensis	1.0	1.0	1.0
Juniperus virginiana	0.5	0.2	0.3
Total	**100.0**	**100.0**	**100.0**

Table 3. Composition of the sapling (<2.5 cm DBH but ≥1.0 m tall), large seedling (<1.0 m but ≥10 cm tall), and small seedling (<10 cm tall) strata. Values are relative density.
Note: SAP = saplings, LSE = large seedlings, and SSE = small seedlings.

Species	SAP (%)	LSE (%)	SSE (%)
Fagus grandifolia	36.9	7.4	1.2
Cornus florida	22.3	8.8	5.8
Acer rubrum	19.1	12.5	31.4
Liriodendrum tulipifera	9.4	9.1	11.0
Magnolia tulipifera	3.4	2.6	
Oxydendrum arboreum	2.9	0.3	
Fraxinus americana	1.7	6.0	0.6
Carya glabra	0.6	2.0	0.6
Sassafras albidum	0.6	8.0	2.3
Carya tomentosa	0.3	10.8	4.1
Quercus alba		15.6	36.6
Prunus serotina		4.0	4.7
Quercus velutina		3.1	1.2
Other species	2.8	9.6	0.5
Total	**100.0**	**100.0**	**100.0**

Table 4. Summary statistics for the Sweet Briar College old-growth white oak chronology.

Number of dated series	17
Master dating series (1749-1998)	250 years
Total rings in all series	2995
Total dated rings	2980
Correlation among series	0.551
Mean measurement (mm)	1.29
Maximum measurement (mm)	3.72
Mean serial autocorrelation	0.703
Mean standard deviation	0.385
Mean sensitivity	0.164

Table 5. Comparison of Sweet Briar College (SBC) chronology statistics to those from Virginia (VA) tree-ring chronologies as well as those from other white oak (QUAL) chronologies archived in the International Tree-Ring Data Bank.

Chronology Statistic	SBC Data	VA Mean	VA SD	QUAL Mean
Correlation among series	0.551	0.582	0.068	0.65
Mean serial autocorrelation	0.703	0.718	0.107	0.69
Mean standard deviation	0.385	0.540	0.200	—
Mean sensitivity	0.164	0.274	0.123	0.22

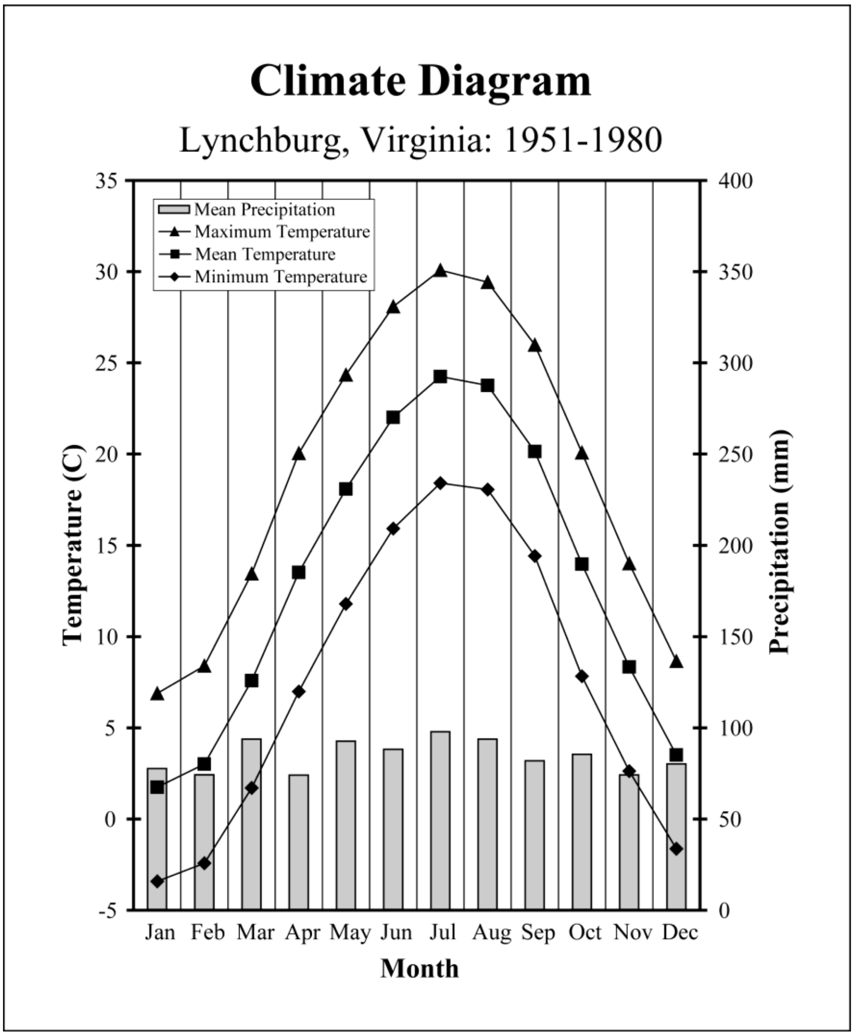

Fig. 1. Climate diagram for Lynchburg, Virginia, based on data from 1951-1980. Gray bars are mean monthly precipitation in mm. The line series are all mean monthly temperature data in degrees centigrade. The top series (triangles) is mean daily maximum, or high, temperature. The middle series (squares) is mean daily average temperature. The bottom series (diamonds) is mean daily minimum, or low, temperature.

Taxa recorded in the plots used to sample the herbaceous stratum were beggar's lice (*Desmodium* spp. [56.0%]), sedges (*Carex* spp. [13.3%]), wild yam (*Dioscorea villosa* [10.4%]), wild licorice (*Galium circaezans* [8.7%]), whorled milkweed (*Asclepias quadrifolia* [2.9%]), hog peanut (*Amphicarpa bracteata* [2.9%]), solomon's seal (*Polygonatum biflorum* [2.9%]), and violets (*Viola* spp. [2.9%]). Other species observed but not present in these plots were black cohosh (*Cimicifuga racemosa*), Indian pipe (*Monotropha uniflora*), Christmas fern (*Polystichum acrostichoides*), and false solomon's seal (*Smilacina racemosa*).

Tree-ring data

Seventeen of the tree cores obtained were included in the final chronologies (Figure 2; Table 4). The master dating series was 250 years long; It begins in 1749 and ends in 1998 (Table 4). Of that, only the first 14 years were based on a single sample, and only the first 32 years were based on five or fewer samples. The correlation among the 17 series (series intercorrelation) is 0.551. Other summary statistics include a mean autocorrelation (serial autocorrelation) of 0.703; mean standard deviation of 0.385; and mean sensitivity of 0.164.

Response function analysis revealed statistically significant relationships ($p < 0.05$) with five monthly climate variables (Figure 3). These were negative correlations with current growing season July maximum temperature (-0.412) and prior growing season May minimum temperature (-0.392), and positive correlations with prior December minimum temperature (0.456), prior October precipitation (0.442), and current June precipitation (0.410).

Other correlations of note (i.e., $p < 0.1$) include negative responses to prior October maximum temperature and current June maximum temperature, and positive responses prior July precipitation and current May precipitation.

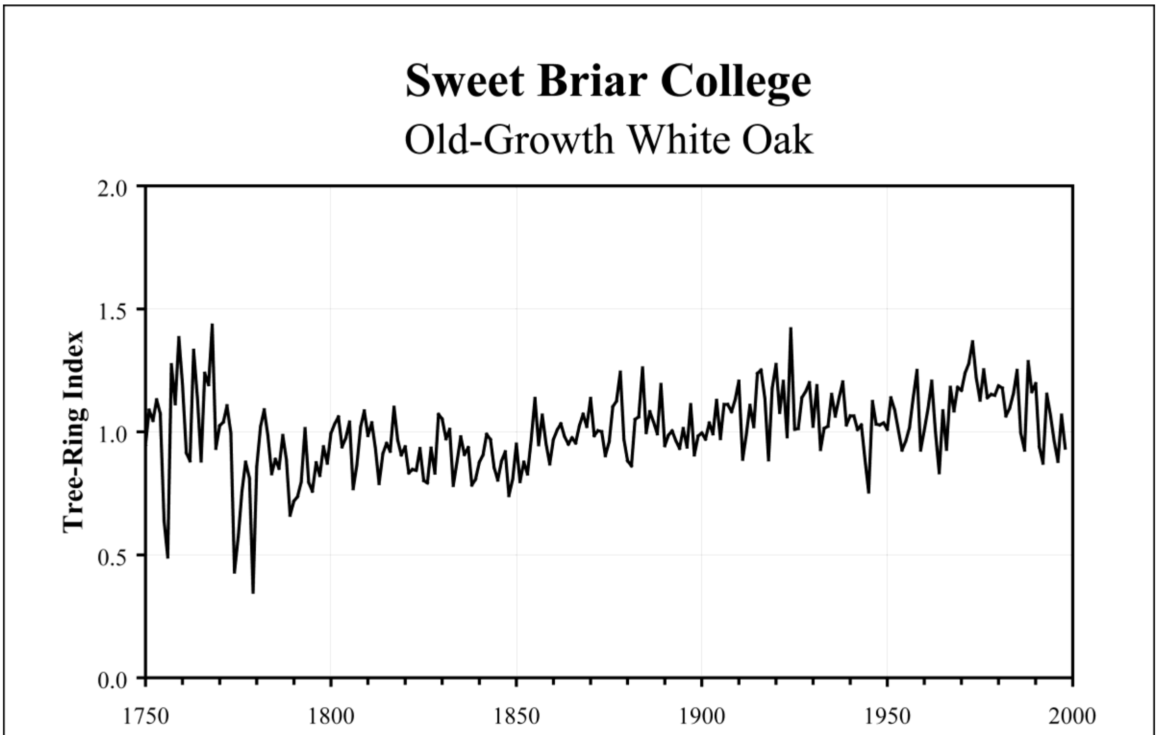

Fig. 2. ARSTAN chronology of Sweet Briar College old-growth white oak tree-ring data.

DISCUSSION

The composition of the forest we sampled is consistent with the data reported for oak-dominated forests in the mid-Appalachian region of the United States (e.g., Stephenson et al. 1993; Lawrence et al. 1997, 1999). All of the species recorded in the tree, small tree, sapling, and seeding strata commonly occur in these forests. The main dominant (lowbush blueberry [*Vaccinium vacillans*]) in the shrub stratum also would be expected, but the presence of Virginia creeper (*Parthenocissus quinquefolia*) suggests some degree of disturbance. The herbaceous stratum was sparse, but that is typical for oak-dominated forests on xeric sites. Because sampling was carried out in September, many of the plants in this stratum had died back to the extent that identification to species was not possible.

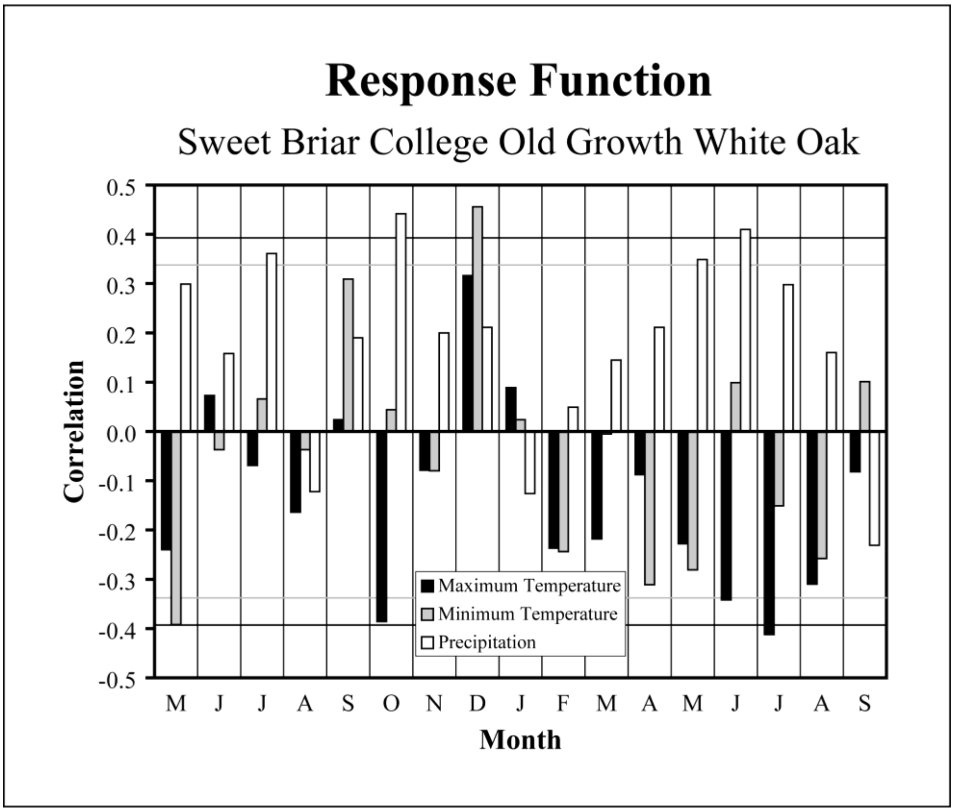

Fig. 3. Results of the response function analysis of the relationships between tree growth and the following monthly climatic variables: mean maximum temperature (Black bars), mean minimum temperature (gray bars), and total precipitation average (white bars).

The number of trees samples was less than ideal, but our concentration on old-growth limited the number of suitable samples. The results of the quality control analysis of the tree-ring measurements revealed that quality of the dataset did not suffer from the low sampling density. A comparison of the chronology statistics to those from other Virginia chronologies archived in the International Tree-Ring Data Bank (Grissino-Mayer & Fritts 1997, World Data Center for Paleoclimatology 2006a) reveal that the Sweet Briar chronology values are well within one standard deviation unit from Virginia values, and within the normal range of other white oak chronology values (World Data Center for Paleoclimatology 2006b).

The negative response to prior May minimum temperature is difficult to interpret. High temperatures prior to or early in the prior growing season might herald drought or excessive loss of primary production because of photorespiration, increased herbivory, or some other factors. The positive response to December minimum temperature is less difficult to interpret, although interpretation likewise requires speculation. It is possible that warmer December minimum temperatures herald shorter winters; They may also indicate warmer winters, thus less time required for spring thaw.

The positive response to October precipitation may represent conditions that favor recharge of groundwater (i.e., a significant amount of precipitation, after the peak heat of the growing season). This water percolates into the ground instead of being lost back to the atmosphere as evapotranspiration, thus is available in the soil when tree growth resumes the following spring.

None of the prior season growth responses are surprising, as conditions in prior years affect both the timing of and the amount of internal and external resources available for tree growth when it resumes in the spring (Fritts 1971, 1976; Kramer & Kozlowski 1979; Fritts & Swetnam 1989; Kozlowski et al., 1991). Current season growth responses are pretty clear. Growth responds positively to June precipitation, and negatively to July maximum temperatures. Both are likely two sides of the same coin in that June precipitation determines the amount of water available early in the summer, while July maximum temperatures help set the evapotranspiration demand, hence water losses, later in the summer. Water affects ring growth in a number of ways, such as in the extent that xylem cells – the cells of the woody part of the stem – expand during the growing season (Fritts 1971, 1976; Kramer and Kozlowski 1979; Fritts and Swetnam 1989; Kozlowski et al., 1991).

While not statistically significant at the p = 0.05 level, the other noted responses—positive response to prior June precipitation, negative response to October maximum temperature, positive response to current June precipitation, and negative response to current July maximum temperature – all reinforce the notion that water availability in current and prior growing seasons are important environmental factors limiting the growth of mature white oaks at Sweet Briar College.

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