Dendroecological analysis of a mature loblolly pine-mixed hardwood forest at the George Washington Birthplace National Monument, eastern Virginia

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ABRAMS, M. D., AND B. A. BLACK. (School of Forest Resources, Pennsylvania State University, University Park, PA 16802). Dendroecological analysis of a mature loblolly pine-mixed hardwood forest at the George Washington Birthplace National Monument, eastern Virginia. 127:139–148. 2000.—The composition, structure, and dendroecology of a mature pine-hardwood forest was studied at the George Washington Birthplace National Monument, eastern Virginia. Loblolly pine, sweetgum, holly, blackgum, and several oak species dominate the forest. Blackgum trees dominated recruitment from 1840 to 1900, based on current age structure. All other tree species are less than 100 years old. A compilation of major and moderate radial growth releases revealed multiple disturbance events in most decades from 1870 to 1990. A dramatic increase in the radial growth of blackgum occurred in the late 1880s, probably in response to selective logging of pine and hardwood timber species. A decline in blackgum recruitment occurred during the 20th century. The existing loblolly pine range in age from 64 to 105 years old, and this species stopped recruiting in 1935. The loblolly pine standardized (ARSTAN) chronology was positively correlated, and blackgum negatively correlated, with current and previous year temperatures. There were no correlations with Palmer drought severity index or precipitation. Seedlings and saplings of all species are scarce, with the exception of holly, a highly shade tolerant, understory tree species. Loblolly pine trees in the overstory may exhibit future declines due to their relatively short longevity, insect attack, and windthrow. Given current conditions, the future stand composition most certainly will contain less loblolly pine and more hardwoods, including sweetgum, blackgum, and holly.

Key words: tree-rings, age structure, disturbance, succession, Coastal Plain, oak.

Pine and oak species dominate many forests of the eastern United States (Braun 1950; Barnes 1991). Most pine and oak species are considered early to mid-successional, and it has been hypothesized that they developed and have been maintained by periodic, low intensity, understory burning (Garren 1943; Quaterman and Keeve 1962; Komarek 1974; Lorimer 1985; Abrams 1992). Historic ignition sources for fire in eastern U.S. forests include lightning strikes, Native American activity, and post-European settlement land-use practices, such as forest clearing, extensive timber cutting, and the charcoal iron industry (Komarek 1974; Abrams and Nowacki 1992; Ruffner and Abrams 1998a). Periodic low intensity fire, coupled with logging activities, would have allowed fire resistant, light demanding pine and oak species to recruit and persist (Abrams 1992). In addition, pine species invade old-fields after agricultural abandonment throughout much of the eastern U.S. (Oosting 1942; Quaterman and Keeve 1962; Orwig and Abrams 1994a). However, later successional, shade tolerant tree species readily invade and exhibit increasing dominance in most upland pine and oak forests in which fire and logging has been suppressed (Lorimer et al. 1994; Abrams 1992, 1998; Ruffner and Abrams 1998b).

Dendroecological techniques have become an important tool in the study of stand dynamics and ecological history (Fritts and Swetnam 1989; Abrams et al. 1995). Researchers studying tree-ring chronologies have been able to reconstruct species recruitment patterns, periodicity and intensity of disturbance factors, the impact of yearly climatic variation, extreme weather phenomena, population dynamics, and successional pathways (Canham 1985; Foster 1988; Prelich and Graumlich 1994; Abrams and Orwig 1995; Abrams et al. 1995). Analyzing radial growth variation in relation to age structure, land-use history, and climatic variation data has proven to be an important method for understanding long-term variation in forest dynamics (Foster 1988; Abrams and Orwig 1995; Abrams et al. 1998).

We report a 160-year history of species recruitment and dendroecology for a mature loblolly pine (Pinus taeda L.)-mixed hardwood forest at the George Washington Birthplace Na-
tional Monument (GWBNM) on the coastal plain of eastern Virginia. A number of old blackgum (*Nyssa sylvatica* Marsh.) and mature loblolly pine trees in the forest enabled us to establish a long-term dendrochronological history. This research represented a rare opportunity to study the historical development and dendroecology of a mature forest at this very important historical site. The specific objectives were to 1) quantify the present composition and structure of the forest, 2) report on the long-term patterns of species recruitment and radial growth variation, and 3) investigate the impacts of natural and anthropogenic disturbances on long-term forest dynamics. Results of this research will improve our understanding of forest dynamics and succession on the northern Coastal Plain of the eastern U.S. following European settlement.

**Study Area.** This research was conducted within a 5 ha area of mature forest in the George Washington Birthplace National Monument (38° 12’ 31”N, 76° 55’ 29”W) in Westmoreland County, eastern Virginia. The study site is within the northern coastal plain between Pope’s Creek and the western bank of the Potomac River (Nicholson 1981). This floodplain site has an altitude of approximately 7 m asl. The climate of the region is humid maritime. The average daily summer and winter temperatures are 25 C and 3.5 C, respectively (Nicholson 1981). Average yearly precipitation is 102 cm, of which 55% falls between April and September. The average mid-afternoon relative humidity is 50%. Soils at the study site include Rumford sandy loam and Tetorus loam (Nicholson 1981). Both soils are deep, well-drained, and medium to strongly acid.

**Methods.** In May 1999, 20 fixed-area plots, located at 20 m intervals along transects through the forest interior, were used for vegetation and dendroecological sampling. Species, diameter, and crown class were recorded for all trees ≥10.0 cm dbh (diameter at breast height) that occurred within 0.02 ha circular plots at each point. Classification of tree crowns into four categories (dominant, codominant, intermediate, and overtopped) was based on the amount and direction of intercepted light (Smith 1986). For each tree species, a relative importance value was calculated as the average of the relative frequency (presence or absence in plots), relative density (number of individuals), and relative dominance (basal area) (Cottam and Curtis 1956). At each plot, two to four trees were cored at 0.5 m for age determination and radial growth analysis. Across all 20 plots we obtained cores from all the major stand species over a range of diameter classes. Saplings and seedlings were counted in nested circular plots of 9 m² and 5 m², respectively, located within each of the overstory plots. Saplings were classified as tree species ≥1.5 m in height but <10.0 cm in dbh and seedlings were <1.5 m in height. Nomenclature follows Fernald (1950).

**Radial-Growth Analysis.** All increment cores (n = 83) from the study area were dried, mounted, and sanded with increasingly finer sand paper (Phipps 1985). All cores were skeleton plotted to identify signature years for cross-dating to help identify missing, partial, or false rings (Stokes and Smiley 1996). After proper ages for all cores were verified by crossdating, 19 loblolly pine and 20 blackgum were measured for annual radial growth to the nearest 0.002 mm with the UniSlide “TA” Tree-Ring Measurement System (Velmax Inc. Bloomfield, N.Y.). Crossdating accuracy was verified using the program COFECHA in the International Tree-Ring Data Bank Program Library (ITRDBL) Version 2.1 (Cook et al. 1997).

For dendroclimatological analysis, 20 blackgum and 19 loblolly pine cores were detrended with a negative exponential curve or simple linear regression, which ever provided a better fit, using the ARSTAN program available in the ITRDBL Version 2.1 (Cook et al. 1997). Detrending removes the effects of tree age and microsite and allows trees of different growth rates to be combined into a single chronology (Fritts 1976). The detrended chronologies were averaged to create separate master chronologies for blackgum and loblolly pine. A modified version of the No wacki and Abrams (1997) method for determining overstory releases was used with the raw ring-width data. A growth increase of greater than 25% sustained for 10 years was identified as a moderate overstory release and a growth increase of greater than 50% sustained for 10 years was classified as a major overstory release. We examined all 39 cores for release dates.

For the dendroclimatology analysis, the ARSTAN blackgum and loblolly pine chronologies were calculated to reveal the strongest climatic signal possible (Cook et al. 1997). Residuals from autoregressive modeling of the detrended measurement series were averaged to produce a residual chronology. The pooled model of au-
Table 1. Results of the overstory tree survey at George Washington Birth Place National Monument, eastern Virginia.

<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency (20 plots)</th>
<th>Density (stems/ha)</th>
<th>Dominance (m²/ha)</th>
<th>Relative density</th>
<th>Relative frequency</th>
<th>Relative dominance</th>
<th>Relative importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquidambar styraciflua</td>
<td>16</td>
<td>201.4</td>
<td>14.7</td>
<td>30.7</td>
<td>22.5</td>
<td>27.5</td>
<td>26.9</td>
</tr>
<tr>
<td>Pinus taeda</td>
<td>17</td>
<td>97.5</td>
<td>20.6</td>
<td>14.9</td>
<td>23.9</td>
<td>38.4</td>
<td>25.7</td>
</tr>
<tr>
<td>Ilex opaca</td>
<td>18</td>
<td>237.2</td>
<td>4.6</td>
<td>36.1</td>
<td>25.4</td>
<td>8.5</td>
<td>23.3</td>
</tr>
<tr>
<td>Quercus falcata var. falcata</td>
<td>7</td>
<td>42.2</td>
<td>4.2</td>
<td>6.4</td>
<td>9.9</td>
<td>7.9</td>
<td>8.1</td>
</tr>
<tr>
<td>Nyssa sylvatica</td>
<td>5</td>
<td>45.5</td>
<td>4.4</td>
<td>6.9</td>
<td>7.0</td>
<td>8.2</td>
<td>7.4</td>
</tr>
<tr>
<td>Quercus phellos</td>
<td>2</td>
<td>9.7</td>
<td>1.4</td>
<td>1.5</td>
<td>2.8</td>
<td>2.6</td>
<td>2.3</td>
</tr>
<tr>
<td>Quercus alba</td>
<td>1</td>
<td>6.5</td>
<td>2.3</td>
<td>1.0</td>
<td>1.4</td>
<td>4.2</td>
<td>2.2</td>
</tr>
<tr>
<td>Pinus virginiana</td>
<td>2</td>
<td>6.5</td>
<td>1.1</td>
<td>1.0</td>
<td>2.8</td>
<td>2.0</td>
<td>1.9</td>
</tr>
<tr>
<td>Acer rubran</td>
<td>2</td>
<td>6.5</td>
<td>0.3</td>
<td>1.0</td>
<td>2.8</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Juniperus virginiana</td>
<td>1</td>
<td>3.2</td>
<td>0.1</td>
<td>0.5</td>
<td>1.4</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>Totals</td>
<td>71</td>
<td>656.3</td>
<td>53.6</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

toregression was reincorporated into the residual model to generate the ARSTAN chronology (Cook et al. 1997). Pearson Product-moment correlation was used to analyze the relationship between the ARSTAN standardized chronologies and climatic variables dating from 1895 to 1998 (NOAA 1999). Climatic variables included total precipitation, mean temperature and mean Palmer Drought Severity Index (PDSI) for each year and season. One year spanned January through December, and for each season, winter encompassed January through March, spring: April through June, summer: July through September, and fall: October through December. The ARSTAN chronology for each species was also correlated with climate from the previous year.

Results. The forest contains ten tree species and is dominated by American holly (Ilex opaca Ait.), sweetgum (Liquidambar styraciflua L.), loblolly pine, southern red oak (Quercus falcata var. falcata Michx.), and blackgum (Table 1). American holly tends to be a small understory tree, but has the highest importance value in the forest due to its high density. The high importance value of sweetgum is due to very high density, coupled with a high dominance (basal area) value. The highest dominance value is obtained by loblolly pine due to the large size of most individual trees (Table 1, Fig. 1). The total basal area of all trees in the forest is 53.6 m² per ha. The diameter distribution of all measured trees approximates an inverse-J distribution, typical of an uneven-aged forest (Fig. 1, Smith 1986). The smaller diameter classes are dominated by holly and sweetgum, followed by southern red oak and blackgum. Loblolly pine, sweetgum, blackgum and oak dominate the middle and larger diameter classes. The dominant canopy class mainly comprises loblolly pine, sweetgum, and oak (Fig. 2). Sweetgum is most important among codominant trees. Holly and sweetgum dominate the intermediate and overtopped canopy classes. Tree reproduction is very scarce within the forest and is primarily holly (500 seedlings and 778 saplings per ha), red maple (100 seedlings per ha) and willow oak (Q. phellos L.; 55 saplings per ha).

The forest is distinctly uneven-aged, and blackgum represented nearly all of the trees that established prior to 1900; it had a maximum age of 158 years (Fig. 3). Recruitment of this species continued through the 20th century, albeit at a lower frequency than in the 19th century. Loblolly pine dominated recruitment during the early 1900s, followed by a moderate amount of recruitment for sweetgum, holly, southern red oak, and willow oak. The oldest trees of loblolly pine and oak recruited in the 1890s. The Master tree-ring chronology for blackgum indicated a period of generally low growth between 1850 and 1880, followed by a dramatic growth increase (indicative of a major stand-wide disturbance) in the late-1880s (Fig. 3). Radial growth for blackgum was nearly average (RWI = 1) for most years between 1900 and 1958, but was substantially above average from 1960 to 1976. The Master tree-ring chronology for loblolly pine showed protracted periods of below average growth in the early 1960s and early 1980s, periods of above average growth in the 1940s and 1950s, and maximum values between 1988 and 1998.

Radial growth patterns and release dates for individual blackgum and loblolly pine trees are shown in figure 4. Blackgum growth ranged from a low of 0.2 mm per year to high of 4.9
mm per year (Figs. 4 A and E). Blackgum exhibited a relatively high number of major and moderate releases, the timing of which varied among individual trees. Eight of the nine oldest blackgum analyzed exhibited a significant radial growth increase in the 1880s as demonstrated in Figures 4 C and E. Loblolly pine trees tended to show a pattern of high early growth and then declining radial growth with increasing age, excluding major releases in 1984 and 1987 (Figs. 4 B and F). Loblolly pine trees had, on average, a much higher growth rate, and fewer major or moderate releases compared to blackgum (Figs. 4 and 5). Radial growth releases were recorded in blackgum and loblolly pine trees for most decades from 1860 to 1990 (Fig. 5). The decades of 1870 and 1910 had a relatively large number of trees (40–50%) exhibiting releases compared to the over-all average of about 20% per decade. Drought (Palmer Drought Severity Index <1.0) occurred in most decades during the 20th century in eastern Virginia (Fig. 6). The loblolly pine ARSTAN chronology (data not shown) was positively correlated with average annual temperature ($p = 0.006; r = 0.27$), winter temperature ($p = 0.001; r = 0.38$), and previous year's average annual ($p < 0.000; r = 0.403$), winter ($p < 0.000; r = 0.419$), and spring temperatures ($p < 0.000; r = 0.310$). The ARSTAN chronology for blackgum was somewhat negatively correlated with mean annual temperature ($p = 0.057; r = -0.19$), spring temperature ($p = 0.057; r = -0.19$), and previous year's annual ($p = 0.001; r = 0.324$), winter ($p = 0.005; r = 0.279$), and spring temperatures ($p = 0.002; r = 0.279$). There were no significant correlations with Palmer drought severity index or precipitation. The severe and prolonged drought and cool temperatures of the early 1960s appears to have negatively affected the growth of loblolly pine, but not blackgum (Figs. 4 and 6). The relatively high growth in loblolly pine between 1988 and 1998 may be due in part to the generally warm and wet climate during that period.

**Discussion.** A cultural landscape study of the George Washington Birthplace National Monument (GWBNM) reported the site was occupied by the Algonquin Indians of the Powhatan Confederacy from the Late Woodland period (ca. 1300 AD), and possibly as early as 200 AD until arrival of English at about 1650 (OCULUS
The majority of the park was first patented to an Englishman, Henry Brooks, in 1657. By 1664, George Washington’s great-great uncle, John Washington, acquired a 50 ha parcel, on which he constructed a home and a farmstead. By George Washington’s birth in 1732, the site was a well-developed plantation. In 1813, most of the Washington family estate was sold to another family (John Gray). The birthplace site and family burial ground were deeded to the Commonwealth of Virginia in 1858 and to the U.S. Government in 1882. The property was unmanaged from 1858 until the 1930s, when it was acquired by the National Park Service.

The stand used in this study was reported to have been used as agricultural fields, pastures, and agricultural drainage ditches from time of Indian occupation until 1846 (OCULUS 1998). Between 1846 and 1923, the site was listed as agricultural drainage ditches despite the absence of active management; it was reported to have converted to woodlands between 1923 and 1932 (OCULUS 1998). However, the results of our research contradict reported conclusions about land cover, at least in part. We believe that forest succession started at the study site at least several decades prior to 1840 (date of the oldest blackgum trees), possibly around 1813 when the Washington family sold their holdings to John Gray. Blackgum is a shade-tolerant, late successional tree species, which usually does not invade old-fields. Loblolly pine is the overwhelming dominant pioneer tree species in old-field succession on the coastal plain of Virginia (Monette and Ware 1983). Sweetgum and oak species typically invade several decades after loblolly pine. It seems likely that the study site was invaded by loblolly pine after agricultural abandonment in the early 1800s; sweetgum, oak, and blackgum then followed.

During the 1880s, the site may have been logged for commercially valuable trees of loblolly pine, oak, and sweetgum. The absence of these species in the 1800s, despite the fact that they can live over 100 years (Loehle 1988; Pederson et al. 1997), suggests that they were selectively removed from the forest. Blackgum has little value as a timber species and was generally avoided by early loggers in the mid-Atlantic region (Nowacki and Abrams 1994; Orwig and Abrams 1994b). The dramatic rise in the black-
Fig. 3. (a) Age-diameter relationships for all cored trees and the mean standardized ring width index for the oldest twenty (b) *Nyssa sylvatica* and nineteen (c) *Pinus taeda* in a mature loblolly pine-mixed hardwood forest at the George Washington Birthplace National Monument, eastern Virginia.
Fig. 4. Individual tree-ring chronologies and release dates for three selected *Nyssa sylvatica* (panels a, c, and e) and three *Pinus taeda* (panels b, d and f) cores in a mature loblolly pine-mixed hardwood forest at the George Washington Birthplace National Monument, eastern Virginia. * = moderate release dates; arrows = major release dates (criteria from Nowacki and Abrams 1997).

Gum ring width index provides further evidence of a major stand-wide disturbance in the late 1880s. Based on current age structure, this disturbance initially promoted the recruitment of blackgum, probably the release of advance regeneration, followed by the reinvasion of loblolly pine, sweetgum, and oak after 1900.

Fire caused by humans and lightning has been a recurring factor in the eastern coastal plain (Garren 1943; Oosting 1944; Quartersman and Keever 1962; Patterson and Sassaman 1988). Fire has been important in maintaining pine-dominated communities and retarding the invasion of later successional hardwoods (Komarek 1974; Monette and Ware 1983). Indeed, slash and burn agriculture and selective burning of woodlands were probably common at GWBNM during the period of Indian habitation (OCULUS 1998). However, there is no mention in the cultural landscape report that the park vegetation burned after European settlement due to the high level of cultivation (OCULUS 1998). Frequent occurrence of blackgum, a fire sensitive species, in the 19th century suggests a lack of fire during
that time. Recruitment of several other fire sensitive hardwoods (e.g., sweetgum and holly) during the 20th century also indicates a lack of burning during that period.

Forest succession on the eastern coastal plain typically involves pine, followed by early successional hardwoods, and then later-successional hardwoods (Oosting 1944; Quarterman and Keever 1962; Komarek 1974; Hartnett and Krofta 1989). It appears that the forest at GWBNM is in transition from pine to hardwood domination. Loblolly pine recruitment started in 1895 and ended about 1935. Many of the older pine are now dying from southern pine bark beetle infestation and windthrow (MDA, personal observation). Loblolly pine age can exceed 200 years, but its typical longevity ranges from 100–150 years (Loehle 1988; Pederson et al. 1997). Oosting (1942) states that loblolly pine is overmature and starts to thin out at 70–80 years.

Death of loblolly pine at the study site, and the probable decrease in competition, coupled with warmer and wetter climate, may be responsible for the recent radial growth increases in the remaining loblolly pine and blackgum. Sweetgum and holly dominate the intermediate and overtopped trees in the forest understory and subcanopy. Holly is very shade tolerant, but is typically a relatively small understory tree. In contrast, sweetgum is classified as shade intolerant but can grow to be a canopy dominant tree (Barnes 1991). Despite its reputation as an early
succession species, sweetgum will likely remain a codominant in the study forest at GWBNM and will probably attain increasing dominance with the continued decline of loblolly pine. A decline in loblolly pine and an increase in sweetgum was reported for an old-growth bottomland forest in South Carolina (Battaglia et al. 1999).

In the absence of disturbance, tree species of low shade tolerance will continue to be replaced by tolerant species. Holly will maintain dominance in the understory and subcanopy and blackgum will likely continue to codominate the overstory in the GWBNM forest based on their high shade tolerance (Orwig and Abrams 1994a; Mikal et al. 1994). Reduction in blackgum recruitment during the 20th century may be due to its slow growth and tendency to be easily over-topped by more opportunistic, faster growing tree species following disturbance (Nowacki and Abrams 1994; Orwig and Abrams 1994b).

Southern red oak and willow oak tend to have low to intermediate understory tolerance (Burns and Honkala 1990), and these species will probably not recruit in the future unless they capture gaps created by the death of loblolly pine. However, regeneration numbers are currently very low to nonexistent for all tree species, except holly. The lack of tree regeneration is probably due to a combination of deep shade, thick organic layer at the forest floor due to the absence of periodic burning, and deer browsing (MDA, personal observation). Given current conditions, we anticipate a large reduction of overstory loblolly pine over the next 50 years, coupled with increasing hardwood domination, which will include sweetgum, blackgum, and holly.

Literature cited


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