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CLIMATE-GROWTH RELATIONSHIPS OF EASTERN HEMLOCK AND CHESTNUT OAK FROM BLACK ROCK FOREST IN THE HIGHLANDS OF SOUTHEASTERN NEW YORK

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ABSTRACT

Three eastern hemlock (*Tsuga canadensis* (L.) Carr.) and three chestnut oak (*Quercus prinus* L.) ring-width chronologies were constructed from old- and second-growth stands in the Black Rock Forest in Cornwall, New York, the first developed for the highlands of southeastern New York State. The longest hemlock chronology extends from 1780–1992 and the longest oak chronology from 1806–1994. The oldest trees sampled had minimum ages of 275 and 300 years for hemlock and chestnut oak, respectively. The tree-ring chronologies were compared to monthly temperature and precipitation data from nearby West

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Point, NY for the 1850s–1990s and to Palmer Drought Severity Indices for 1911–1990. The chronologies provide forest growth information for the period prior to the initiation of meteorological measurements, begun in 1824 at West Point. Black Rock Forest eastern hemlock growth correlates positively with current July and prior September precipitation, with February–March temperature and with prior September Palmer Drought Severity Indices. It correlates negatively with prior June temperature. Black Rock Forest chestnut oak growth correlates positively with current June–July and prior September and December precipitation, with January temperature, and with prior September–October and current June–July Palmer Drought Severity Indices. It correlates negatively with current June–July temperature. The Black Rock Forest tree-ring records and analyses yield useful information for climate reconstruction and for assessing the potential impact of anthropogenic change (*e.g.* CO_2-induced climate effects, CO_2 and N fertilization, acid deposition, changes in soil chemistry due to atmospheric pollution).

Keywords: Black Rock Forest, tree rings, dendrochronology, eastern hemlock, chestnut oak.

INTRODUCTION

The Black Rock Forest (BRF) is a 1,530 ha preserve located in the Hudson Highlands on the west bank of the Hudson River in Cornwall, New York, eighty kilometers north of New York City (Figure 1). The BRF was instituted as a research and demonstration forest in 1928, was part of the Harvard Forest system from 1949–1989, and has been operated by the Black Rock Forest Consortium (a group of New York area academic institutions) for the past decade (Tryon 1930; Mahar 2000). The BRF is located within the Highlands Physiographic Province, a 500,000-hectare region characterized by similar bedrock geology, soils, and plant communities. It retains many similarities to the pre-settlement forest ecosystems that once covered the entire region (Raup 1938; Maenza-Gmelch 1997; Barringer and Clemants 2000). The BRF is an oak-dominated forest, a type encompassing approximately half the forests in the northeastern United States (Braun 1967).

In this paper we present the first tree-ring width chronologies developed for the BRF and evaluate their relationships to climate. These chronologies are based on two widespread native species of the forests of eastern North America. Eastern hemlock is a shade-tolerant, evergreen conifer that prefers cool, moist conditions, whereas chestnut oak is a deciduous hardwood typically found on dry, upland sites (Burns and Honkala 1990). The nearest tree-ring records to those at the BRF are eastern hemlock and chestnut oak chronologies for the Shawangunk Mountains of southeastern New York State (Cook and Jacoby 1977); these chronologies extend to the mid 1600s.

Chronologies from the BRF broaden the coverage of tree-ring sites within the Hudson River Valley. Their responses to drought, insect disturbance, and other factors can be compared in future studies to those from additional sites and species in eastern North America. This may be especially important for eastern hemlock because it has been impacted severely throughout much of its range by an introduced insect, the hemlock wooly adelgid (*Adelgis tsugae* L.) (Orwig and Foster 1998; Mates-Muchin *et al.* 2000).

DATA AND ANALYSIS

Tree-core samples were collected from six stands in the BRF (Figure 1). The older stands most likely are remnants of pre-colonial forests, while the younger stands are second growth following deforestation in the early 1800s (Raup 1938). The older hemlock site was left uncut as local lore holds that Native Americans considered it sacred (J. Brady, personal communication). Tree-ring chronologies were constructed using conventional analytical techniques (Fritts 1976; Holmes 1983; Cook and Kairiukstis 1990). Cores were mounted and surfaced and each ring was measured to the nearest 0.001 mm. The wood samples were cross-dated using visual comparisons and the COFECHA quality control computer dating program (Holmes 1983). Standardization of ring-width measurements creates a mean-value series of indices for all samples for each year (Cook 1985). Smoothing splines, 66% of the series length, were used to reduce the effects of nonsynchronous suppression (narrow rings) and release

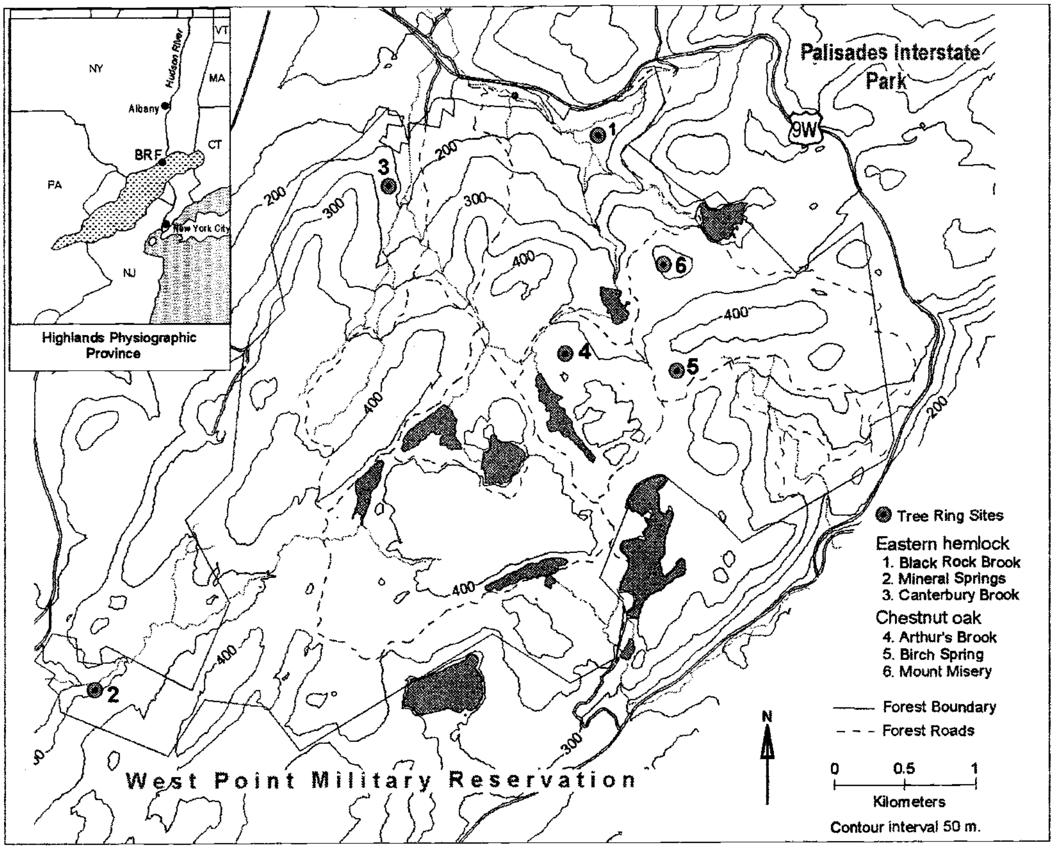

Figure 1. Map of the Black Rock Forest, New York, showing sampling locations of the three eastern hemlock and three chestnut oak chronologies (circles).

(wide rings) most likely related to competition and disturbance (*e.g.* Cook and Peters 1981; Graybill *et al.* 1982; Cook and Briffa 1990). The resulting standardized time series have a relatively stable mean and variance (Cook 1985).

All six chronologies were compared using correlation analysis to monthly total precipitation and mean temperatures at nearby West Point, NY (Figure 1) to identify which variables possibly affect the rate of radial growth. West Point features one of the longest meteorological data sets in the United States, with temperature and precipitation records extending to 1824 and 1850, respectively. We also compared the chronologies to the Palmer Drought Severity Index (PDSI) at West Point. The PDSI integrates potential evapotranspiration, precipitation, and soil moisture recharge and loss into estimated values of moisture deficiency or excess (Palmer 1965). PDSI values were constructed using the original method of Palmer (1965).

The tree-ring and meteorological data were prewhitened to remove the effects of persistence and to simplify statistical tests of significance (Box *et al.* 1994). Variables are considered significant at the 95% level using two-tailed tests. Dendroclimatic years (Fritts 1976) beginning in April of the prior growth year and extending through September of current growth were used to analyze tree-ring chronologies and climatic data. This eighteen-month interval encompasses two radial growth seasons and the intervening winter months. Prior climate and other influences can impact growth in the current year due to preconditioning effects (*e.g.* Cook and Jacoby 1977). The West Point monthly temperature and precipitation station data for these analyses were obtained from the Global

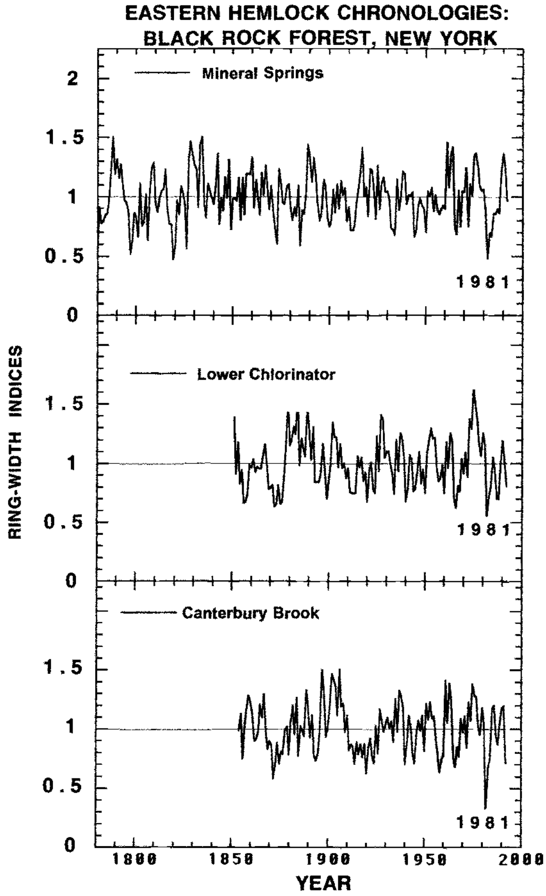

Figure 2. Three Black Rock Forest hemlock chronologies, extending to 1992, beginning in 1780 at the oldest site (Mineral Springs). The oldest eastern hemlock sampled had a minimum age of at least 275 years. Chronologies from Lower Chlorinator and Canterbury Brook being in 1851 and 1854, respectively. Due to low sample size we truncated the earliest decades of some of the chronologies. Reduced growth in 1981 is delineated. These are the residual chronologies from the ARSTAN process, which emphasize high-frequency variation (Cook 1985).

Historical Climatology Network, which is screened for quality control (Vose *et al.* 1992).

RESULTS AND DISCUSSION

Eastern Hemlock

A time-series plot (1780–1992) of the three BRF eastern hemlock chronologies is presented in Figure 2. Significant positive correlations were identified with current July and prior September precipitation. Canterbury Brook just misses 95% significance for September, and shows a significant correlation with November precipitation (Figure 3A). This precipitation response for BRF hemlock is similar to that of trees on well-drained sites in the nearby Shawangunk Mountains and other locations in northeastern North America (Cook and Cole 1991). BRF hemlock growth also correlates positively with March temperature (Figure 3B). Above average temperatures in March would be expected to melt snow cover and promote photosynthesis before the actual onset of radial growth. BRF hemlock shows a negative response to prior summer temperature, especially in prior June, possibly indicating a lagged response to increasing evapotranspiration associated with increasing temperature (Cook and Cole 1991). These correlations with temperature are similar to those of eastern hemlock in the Shawangunk Mountains and at sites throughout its range in eastern North America, suggesting that temperature responses of this species are relatively site-independent (Cook and Cole 1991).

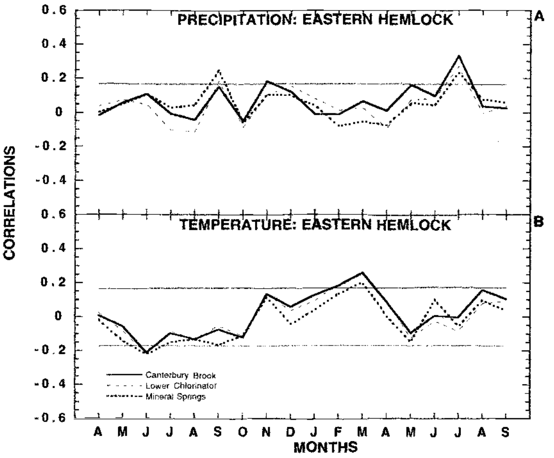

Figure 3. Correlation plots for eastern hemlock chronologies and West Point monthly precipitation (A) and temperature (B) for common period from 1851–1992 based on prewhitened tree-ring and climate data. 95% significance levels indicated by dashed horizontal lines.

All three BRF hemlock chronologies show low index values for 1981 (Figure 2). According to West Point data, the previous summer (1980) was exceptionally dry and relatively hot during August and September. It seems reasonable that these prior-year conditions account for some of the reduced growth in 1981. However, a severe gypsy moth outbreak in 1981, which affected the hemlocks in addition to deciduous species, might also account for the low indices (Nowacki and Abrams 1997). More than 5 million hectares of forest in the eastern United States were defoliated by gypsy moth in 1981 (Heinrichs 1982). Accounts of infestation at BRF indicate nearly complete defoliations in late spring of 1981 (J. Karnig, personal communication; unpublished forest records).

Chestnut Oak

A time series plot (1806–1994) of the three BRF chestnut oak chronologies is presented in Figure 4. BRF chestnut oak growth at all three sites correlates positively with June and July precipitation during the current growing season (Figure 5A). Despite the drought tolerance and deep-rooting habit of chestnut oak (Abrams 1990), growth apparently can be greatly affected by summer moisture, particularly since the species often becomes established on upland sites and areas with shallow soils (Burns and Honkala 1990). A corresponding inverse relationship with current June–July temperatures strengthens this contention. As for BRF hemlock, a significant positive correlation was found with prior September precipitation. Above-average moisture during early fall may promote storage of carbohydrates and bud formation, thus enhancing growth in the following year (Fritts 1976; Kozlowski *et al.* 1991). Correlations with prior December precipitation and January temperatures are positive and significant, although the reasons for these linkages are not apparent (Figure 5B). One possible explanation might be that these correlations represent relationships to snowpack and its subsequent effect on soil moisture.

BRF hemlock growth correlates positively (albeit weakly) with prior September PDSI, PDSI being a variable that integrates the combined effects of temperature and moisture (Figure 6A). BRF chestnut oak growth correlates positively and significantly with prior September–October and current summer (June–July) PDSI (Figure 6B).

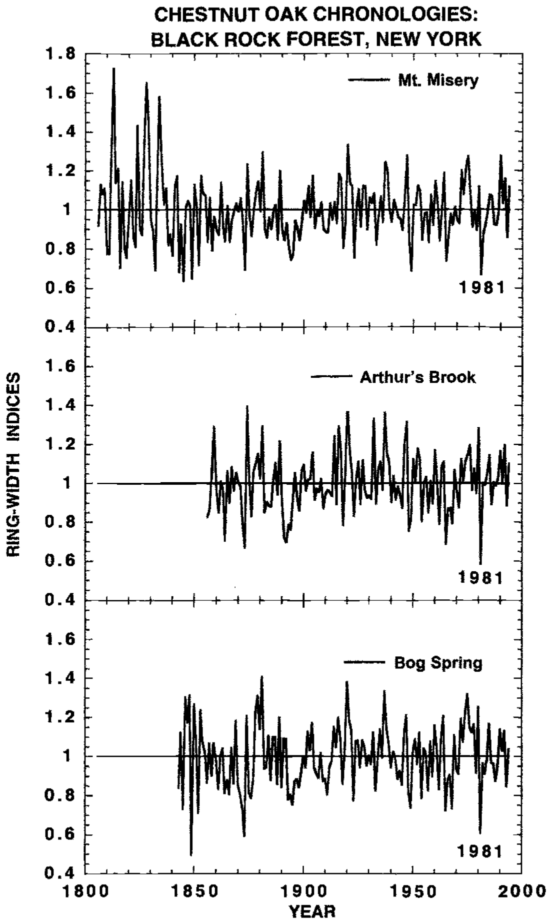

Figure 4. Three Black Rock Forest chestnut oak chronologies, extending to 1993, beginning in 1806 at the oldest site (Mt. Misery). The oldest chestnut oak had a minimum age of 300 years. Chronologies from Aurthur's Brook begin in 1860 and from Bog Spring in 1843, as in Figure 2.

As for hemlock, 1981 was a year of below-average growth for chestnut oak (Figure 4), following hot, dry conditions during late summer of the previous year. These trees almost certainly were completely defoliated by gypsy moths in 1981. Yet the reduction in ring widths is less severe and shorter-lived than during periods of reduced growth in the 1890s and during the severe drought of the 1960s.

The importance of moisture availability to growth has been demonstrated in other tree-ring chronologies of eastern hemlock and chestnut oak, as well as for other tree species from eastern North America (Cook and Jacoby 1977; Cook and Cole 1991). There are similar patterns of climate response in the BRF chronologies relative to those

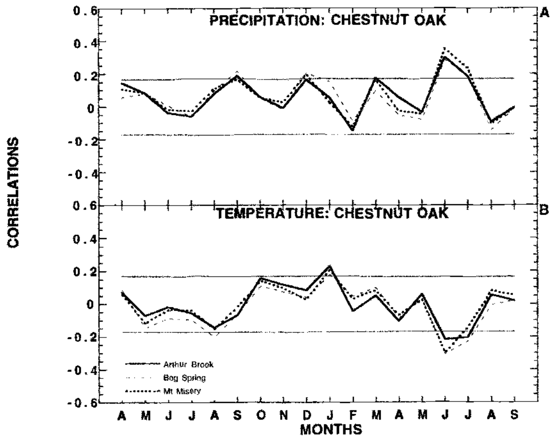

Figure 5. Correlation plots for chestnut oak chronologies and West Point monthly precipitation (A) and temperature (B) for the common period from 1856–1992 based on prewhitened tree-ring and climate data, as in Figure 3. 95% significance levels indicated.

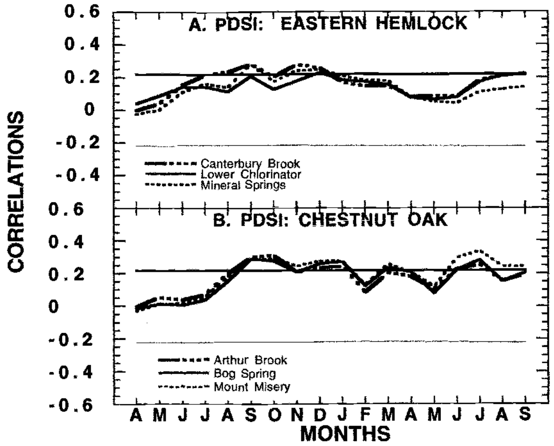

Figure 6. Correlation plots for eastern hemlock chronologies and monthly West Point PDSI (A), and chestnut oak chronologies and PDSI (B) for 1911–1990. 95% significance levels indicated.

described elsewhere for these species (*e.g.* Nowacki and Abrams 1997). The general agreement in climate response among the individual chronologies developed for each of the two species at the BRF allows us to conclude that microsite factors, although probably present, are not highly significant in influencing growth at these sites. There are also similarities in climate response between the two species (the average of the chronologies for hemlock and oak correlate at r = 0.4 for the common period from 1856–1992). This correspondence is reflected in the similar response to several extreme events including the 1960's drought (Cook and Jacoby 1977). Growth indices averaged separately for the BRF hemlock and oak sites during the 1965 and 1966 drought years are below the mean: 0.57 and 0.81 for hemlock, and 0.72 and 0.87 for oak (relative to a mean of 1.0). Despite this response, formal reconstructions were not developed, as the correlations with climate, although statistically significant in some cases, were insufficient for this purpose (Cook and Kairiukstis 1990).

CONCLUSIONS

Six tree-ring width chronologies for two tree species have been presented for the Black Rock Forest, New York. The chronologies provide climatic and other environmental information for the period prior to temperature and precipitation measurements. Both species show significant ring-width correlations with climate, especially with precipitation in the current summer and prior fall. For BRF chestnut oak, current June–July, prior September and December precipitation, and prior June temperatures are the most significant factors for growth. These results are in general agreement with other studies from the region (Cook and Jacoby 1977). For BRF hemlock, current July and prior September precipitation and March temperatures appear to be the most important climatic variables for growth. This response is similar to that found in previous studies of hemlock in New York State using shorter meteorological records (Cook and Cole 1991). This response to March temperatures in hemlock but not in chestnut oak from the same locality may be due to the ability of evergreen hemlocks to begin photosynthesis earlier in years when conditions are favorable. Thus, when ring-width indices differ between the two species, it could indicate particularly warm early spring temperatures in that year.

The tree-ring chronologies of both species provide a background history of tree growth and climate-growth relationships for the BRF ecosystem that can be placed in the context of other sites of these species across their range in eastern North

America. These records may prove of value for use in future climate reconstructions (incorporating additional tree-ring data to reconstruct regional climate), for studies of the impact of introduced organisms (*e.g.* the hemlock wooly adelgid), and for examinations of environmental change related to increasing greenhouse gases or contaminants in the atmosphere including air pollution.

The chronologies yield valuable information on tree growth and climate variations at the Black Rock Forest spanning the last three centuries. These records should prove useful in evaluation of forest growth patterns and response to biotic and climatic changes.

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