

THE CLIMATE SENSITIVITY OF TALUS SLOPE TREES BEHIND THE DAIRY KING

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ABSTRACT

To compare the climate response of five different tree species growing on the same site we selected a mixed species stand on a steep, south-facing, well-drained talus slope in eastern West Virginia. We extracted 2 cores of 8 to 10 of the potentially oldest Virginia pine, white pine, eastern hemlock, chestnut oak, and red oak trees using an increment borer. We developed a crossdated standard chronology of each species using standard dendrochronological techniques. In general – with the exception of white pine - trees growing on the well-drained slope showed the expected response to May through July precipitation of the current growing season. Conifers responded positively to March mean temperature, possibly indicating a differential advantage of evergreen tree species.

INTRODUCTION

The geologic, hydrologic, and physiographic features of the Appalachian Mountains in northeastern West Virginia combine to offer notable opportunities to explore a variety of pressing ecological and environmental issues. Here, we report the results of a dendrochronological and dendroclimatological study of tree growth and tree dynamics in this special environment.

This investigation was specifically designed to answer the following two questions:

- a). To what degree are paleo-temperature and/or precipitation signals preserved in tree-ring chronologies of endemic species?
- b). Are the tree-ring chronologies of distinct, mature hardwood and conifer species in this environment more or less sensitive to climatic signals?

A secondary objective for this study was formulated during field activities when opportunities afforded by the diversity of local tree species and geohydrological site conditions became apparent. The latitude of the study area corresponds to a regional ecotone boundary that separates temperate deciduous forests from warm temperate forests. A second study question formulated to take advantage of these spatial and physical features was,

- c). Are there any apparent trends among the tree ring chronologies of mature site species that would suggest a shift in the regional ecotone boundary common to the latitude of this study area?

STUDY AREA

The study area, which is referred to in this report as the Dairy King study site, is located adjacent to Mill Creek approximately 0.5 miles upstream of the South Branch Potomac River. The junction of these water bodies is referred to as Hinkle Gap on the U.S. Forest Service, Monongahela National Forest, North Half, West Virginia map. This small water gap is incised through a narrow but extensive exposure of the Silurian/Devonian Tuscarora Formation, which coincides with the west slope of North Fork Mountain. The formation is distinctive and currently develops cliffs along a narrow, roughly 20 foot section of a quartzite formation member. Relatively steep, 21-degree slopes of sandstone fall away from the ridge crest. The slopes have very poor soil development and are covered by scree. Field sampling was restricted to the floodplain of Mill Creek and about 500 feet upslope to elevations of roughly 2800 feet.

Soil, talus and slope conditions result in the development of intermittent first-order streams on the ridge slopes. Mill Creek was less than one foot deep during the June 7, 1999 field portion of the study. Channel deposits are dominated by cobbles and gravel.

Soil and bedrock fracture characteristics of the site lead to minimal soil moisture capacity and rapid vertical drainage of local groundwater recharge. It is likely that conditions can not support a water table much above the stage of Mill Creek. The ridge slopes therefore are dry and suitable for vegetation that is adapted to xeric conditions. The region has a mean annual temperature of 52 F (11.2 C) and mean total annual precipitation of 35 inches (891 mm).

Tree species in the study area are dominated by *Quercus prinus*, *Quercus rubra*, and *Pinus virginiana*. Other species, which were more abundant at the lower elevations include: *Pinus strobus*, *Tsuga canadensis*, *Acer saccharum*, *Carya ovata*, *Sassafras albidum*, and *Prunus serotina*. Tree species occurring on the quartzite cliff rock are dominated by Virginia and Table Mountain pine.

METHODS

Sampling Design

A specific tree-ring sampling plan was developed to address the research questions mentioned above. In an attempt to reduce between tree variability and optimize the climate signal in the tree-ring data, all sampling was restricted to well-drained south facing slopes. With the exception of *Tsuga*, which was only abundant on the lower slopes and floodplains, all tree sampling was also restricted to mature individuals that occurred on scree slopes. In combination this approach should desensitize the influence of insolation on canopy tree basal area growth while maximizing the influence of temperature and precipitation. An analysis of species response to historical environmental or other conditions was accomplished by sampling tree-rings from mature individuals of *Pinus virginiana*, *Pinus strobus*, *Quercus prinus*, *Quercus rubra*, and *Tsuga canadensis*. More specific aspects of the sampling protocol are addressed in the following sections of this report when appropriate .

Core preparation

Cores were mounted with masking tape on wood mounts and allowed to dry overnight. After drying, the cores were permanently mounted and sanded using a series of progressively finer grit sand paper (up to 400 grit).

Crossdating

We assumed the outer complete ring was 1998 and then counted back towards the pith recording narrow signature years. Signature years were checked across all series for high agreement. Signature years were recorded and then cross-referenced across the other series within species (Table 1).

Measuring

Tree ring series were measured using a Velmex measuring system and the PJK measuring interface program for a Macintosh computer. Measurements were made to an accuracy of 0.001 mm.

COFECHA

Cross dating of individual series were checked using the computer program COFECHA. The default settings of the program were used to compare the high-frequency variation within the series. Problem series found using COFECHA were visually re-checked and the dating corrected.

Standardization

Standardization of the cores was performed on the ARSTAN program. The conifers were detrended with a negative exponential curve or a negative linear regression (Figure 1). We standardized the red oak with a 30-year spline and the chestnut oak with a 40-year spline (Figure 2). From the ARSTAN output we extracted the span of chronology, mean ring width, standard deviation, mean sensitivity, all-series mean correlation, serial correlation, joint persistence of the autoregressive variance and the percent variance explained (Table 2).

To examine the frequency and amplitude of releases and suppressions, we calculated outlier years for each series. Outliers were defined as years with greater than 3 standard deviations from the mean. We summed the series results for each species and calculated the fraction of series that showed a common release year.

RESULTS

Crossdating

Cross dating of cores produced variable degrees of success both within and between species (Table 1). *Pinus virginiana* cross dated the most reliably having signature years in almost every decade. Hemlock was also easily cross dated having several years in common between series. *Pinus strobus* was more difficult to cross date than the above species having only three signature years. *Quercus rubra* and *Quercus prinus* were the most difficult to cross date having very few reliable indicator years. *Quercus* spp. did not have signature years but several years together appeared to be common in some of the series.

Chronology comparisons

The chronologies ranged from 157 to 109 years in length. The average ring width was widest in hemlock (1.797) and narrowest in chestnut oak (1.163). The standard deviation of the chronologies was highest in red oak (0.985) and lowest in chestnut oak (0.169) (Table 2).

The common periods of similar response in all the species master chronologies were focused near 1920 and 1930 (Figure a-e). In each chronology there was higher growth beginning around 1920 and persisting for several years. This increased growth seen in the ring-width indices may be the result of selective logging which occurred in the area during that time. Cut stumps were seen at the study site.

All chronologies have a period of decreased growth after 1930. In most species this decreased growth persisted for several years, however, *Pinus strobus* experienced decreased growth for as much as 40 years (Figure 3a). This may be due to the high degree of serial correlation (0.637) in the growth of *Pinus strobus*. The cause of the decreased growth in all the species around 1930 may be due to drought conditions which occurred in this region at that time. Mean sensitivity is traditionally viewed as a predictor of climate sensitivity in trees (Table 2). Species with the highest values should show the strongest climate signal. The rank of species from most sensitive to least sensitive is: hemlock, Virginia pine, white pine, chestnut oak, and red oak.

The all-series mean correlation takes all possible pairs of series and calculates correlation coefficients for the common span of years. All of these correlations are averaged to calculate a single value representing the strength of the common signal within a species. The Virginia pine are most strongly correlated to each other, thus indicating all series followed similar growth patterns throughout the stand (Table 2). The other four species were less well self-correlated.

The serial correlation identifies the persistence or degree of autocorrelation present in a species; the higher the serial correlation value the longer a disturbance event will influence radial growth. White pine

has the longest persistence (0.637) and Virginia pine the shortest (0.267) (Table 2). The oaks and hemlock showed intermediate persistence. The joint persistence autoregressive variance values show the number of years a signal influences radial growth. White pine and Virginia pine have a two year lag and the other species show a one year lag (Table 2). However, the percent variance explained by white pine (0.427) as compared to the other four species indicates that prior growth is very important to radial growth.

Outliers

The two oak species showed more frequent and higher amplitude release and suppression years (Figure d and e). The strongest release period for the oaks and hemlock was the early 1920s: chestnut oak experienced releases in 35% of its series; red oak had releases in 25%; and hemlock in 20%. In contrast, the white pine showed releases in 5% (Figure 4a) of its series and Virginia pine showed no releases during this period (Figure 4b).

PRECON analysis

We used the standard chronology and regional monthly temperature and precipitation data to examine relationships between ring width and variation in climate. Response function analysis using the default options provided by the PRECON program for cutoff of number of principal components retained in the analysis. Response function analysis enabled to include also ring width of three previous years as variables into the models.

All species showed a significant relationship with climate (Figure 5a-e). Response function analysis indicated that the strength of the relationship varied between species. Climate explained ~ 40 % of the variance in ring width of Virginia pine (Figure 5b) and eastern hemlock (Figure 5c), whereas it explained only ~ 28 % for white pine (Figure 5a), chestnut oak (Figure 5e), and red oak (Figure 5d).

Ring width of two prior growth rings was significantly related to the current years ring width of the pine species. In all other species only one year of prior growth influenced ring width significantly. These findings corresponded well with the order of the pooled autoregressive models fitted to the tree ring series.

All species (except white pine) showed similar response to climatic variations for the current growing season, favoring relatively wet and cool conditions in May – July. This response was expected since we deliberately had chosen a dry site to maximize climate response. Precipitation reaches a maximum in the growing season. The tree species on our site appear to rely on rainfall during this period on soils with low water holding capacity; if precipitation is below normal during the growing season water stress will lead to a reduced ring width. Eastern hemlock and white pine responded strongly to previous growing season precipitation. Response of white pine differed very much from the other species' response, since there was no response to current growing season precipitation. Ring width of all conifers was positively related to March mean temperatures, which is probably related to an early start of the growing season. Only the evergreen species appear to be able to take advantage of warm springs.

Of the five species on our site eastern hemlock appears to be best suited for climate reconstruction, because it shows a strong relationship with both, previous and current years' growing season precipitation. Virginia pine is short lived, therefore, its potential is limited.

Considering results of previous studies, the relatively low climate information contained in our oak chronologies was surprising. We attribute this to stand dynamic effects, most likely release after (partial) logging in the 1920's. This is indicated in the outlier analysis, which displayed a high number of abnormally large rings in the oak tree ring series. The need to fit a 40-year spline to the data for detrending may have also removed part of the climate information. In addition, trees may not record

climate variation well right after a release. Competition may affect climate response as recent studies suggest that response.

DISCUSSION

The study site consisted of a mixed, even-age forest as evidenced by a similar range in first year chronologies (Table 2). Classic secondary successional theory suggests that forest regeneration is initiated after a disturbance by pioneer species such as pines which are eventually displaced by hardwood species. The concurrent establishment of mixed evergreen and deciduous life forms may have been the result of a disturbance in the mid to late 1800's.

Disturbance effects such as those exhibited by the oak species in the early 1920's may have confounded our dendroclimatic reconstructions. It is clear from our results that there are multiple interacting factors contributing to the growth and dynamics of this mixed deciduous and evergreen forest.

The sensitivity of all species towards cool and wet summers during the current growing season suggests that under warmer and drier climate conditions, growth and productivity may decrease. This inference is supported by generally depressed ring indices. In addition, seasonal dendroclimatological reconstructions corroborate the functional and chronological analyses with an extended warm period and generally lower than normal summer precipitation during this time.

Our results suggest that under appropriate environmental conditions and disturbance regimes, factors that may contribute to a competitive advantage of either coniferous or deciduous species may be outweighed by offsetting interactions. Although there are no climate trends evident over the past 100 years, the current state of linked biogeography and ecosystem models forced by future climate scenarios suggest that the current vegetation structure may be replaced by either southern conifer/broadleaf evergreen or savanna systems. In addition, climate effects on the current generation of plant population and ecosystem-type models generally do not incorporate lagged effects of climate or 'memory' of current and past climate conditions. It is clear from the autoregressive and impulse response function analyses that the mixed forest species sampled in this study exhibit variable lagged response (3-8 years; Table 2, Figure 6).

In general, climate change scenarios predict overall increases in temperature and decreased precipitation, thereby driving a northern migration of southern pines and broadleaf species into the region surrounding West Virginia. Our results imply that changes in the distribution and seasonality of precipitation and temperature may be more important. In addition, scenarios of climate impacts should be interpreted with caution as pollen studies suggest that the current community structure in West Virginia arose from spatially widely divergent populations through migration processes. While the climate system may contribute to biologic inertia or altered community structure, there may be indirect climatic impacts on future communities through migration and the subsequent establishment of 'foreign' species that are perhaps better adapted to a new climate regime.

CONCLUSIONS

Our study clearly demonstrates the strength of dendrochronological and dendroclimatological analyses on interpreting forest response to climate. It appears that important links exist between the dendrochronological community and the forest/ecosystem modeling communities. There are current activities underway to attempt a translation between tree-ring analyses and a biological response that may pave a productive interaction between the two communities. For instance, an appropriate translation between dendroclimatological analyses and ecosystem models could provide insight into tree-ring response to abiotic forcing factors such as increased atmospheric CO₂ concentrations and nitrogen deposition.

In summary, careful interpretation of the dendroclimatic reconstructions can provide a useful tool towards enhanced forest stand/growth and ecosystem model development. Likewise, improved ecosystem and biogeography models can aid dendrochronologists in teasing out confounding variables such as pollution and our changing physical and chemical climate and their impacts on forest growth.