Forest Ecology and Management 329 (2014) 158–165

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Climate-growth relationships for yellow-poplar across structural and site quality gradients in the southern Appalachian Mountains

Tara L. Keyser [a,*], Peter M. Brown [b,1]

[a] USDA Forest Service, Southern Research Station, Bent Creek Experimental Forest, 1577 Brevard Rd., Asheville, NC 28806, United States
[b] Rocky Mountain Tree Ring Research, Inc., 2901 Moore Ln., Fort Collins, CO 80526, United States

ARTICLE INFO

Article history:
Received 9 April 2014
Received in revised form 12 June 2014
Accepted 13 June 2014

Keywords:
Basal area increment
Palmer Drought Severity Index
Dendroecology
Forest thinning
Liriodendron tulipifera

ABSTRACT

Forecasted changes in climate across the southeastern US include an increase in temperature along with more variable precipitation patterns, including an increase in the severity and frequency of drought events. As such, the management of forests for increased resistance or resilience to the direct and indirect effects of climate change, including decreased tree- and stand-level productivity, is of interest to natural resource practitioners. Because the sensitivity of tree growth to climate can be moderated by competition, manipulating stand density through silvicultural activities may mitigate the negative effects climate change may have on tree growth and productivity. In this paper, we utilized dendrochronology data, along with long-term forest inventory data, from 134 plots established and subsequently thinned between 1960 and 1963 to analyze the effects of climate on annual tree growth for yellow-poplar (*Liriodendron tulipifera* L.) across a broad stand structural and site productivity gradient in the southern Appalachian Mountains.

Annual basal area increment (BAI) was most related to the Palmer Drought Severity Index (PDSI) during the months of May, June, and July ($\mathrm{PDSI_{MJJ}}$) relative to that of the annual or growing season when structural and site productivity variables were included in the analysis. Annual BAI of trees growing in stands of lower density responded to increases in $\mathrm{PDSI_{MJJ}}$ at a faster rate than trees growing in stands of greater density. Conversely, those same trees experienced proportionally greater decreases in BAI at lower values of $\mathrm{PDSI_{MJJ}}$ compared to trees in stands of greater density. Annual BAI was positivity related to site productivity, as quantified by site index, with BAI more sensitive to changes in $\mathrm{PDSI_{MJJ}}$ on plots of progressively higher site index. Results suggest stand structure as well as measures of productivity should be considered when quantifying climate-growth relationships for forest tree species. Such information could not only aid in the identification of stands most susceptible to reduced growth, but also be used to develop site- or stand-specific silvicultural prescriptions focused on promoting resilience or resistance under a changing climate.

1. Introduction

The southern Appalachian Mountains encompasses ~14.97 million hectares in the southeastern US (Southern Appalachian Man and Biosphere, 1996) and contain some of the most productive and diverse temperate forests in North America. Forecasted changes in climate across the southeastern US include an increase in temperature along with more variable precipitation patterns, including an increase in the severity and frequency of drought events (McNulty et al., 2013). More frequent and extreme weather events have the potential to affect forest productivity through a variety of mechanisms, including increasing tree mortality (Klos et al., 2009; Allen et al., 2010), reducing tree- and stand-level growth (Elliott and Swank, 1994; Boisvenue and Running, 2006; D'Amato et al., 2013), and amplifying complex insect and/or disease interactions (Lawrence et al., 2002; Negrón et al., 2009; Vose et al., 2012). The specific response of tree- and stand-level growth to climate varies across species (Pan et al., 1997), tree size (Mérian and Lebourgeois, 2011), age (Copenheaver et al., 2011), stand structures (Linares et al., 2010; D'Amato et al., 2013), edaphic or productivity gradients (Orwig and Abrams, 1997; Leonelli et al., 2008), and genetic variability across populations (McLane et al., 2011). Because the sensitivity of tree growth to climate has been shown, for some species, to be moderated by intra- (Piutti and Cescatti, 1997; Cescatti and Piutti, 1998; Linares et al., 2010) and

---

* Corresponding author. Tel.: +1 828 667 5261x102; fax: +1 828 667 9097.
E-mail addresses: tkeyser@fs.fed.us (T.L. Keyser), pmb@rmtrr.org (P.M. Brown).
[1] Tel.: +1 970 229 9557.

http://dx.doi.org/10.1016/j.foreco.2014.06.015
0378-1127/Published by Elsevier B.V.

inter-specific competition (Lebourgeois et al., 2013; Forrester, 2014), manipulating stand density and/or species composition through silvicultural activities may prove a useful strategy that mitigates some of the negative effects climate change may have on growth and productivity.

Thinning has been suggested as a potential management activity that may increase the resilience of individual trees, stands, and forests to the direct and indirect effects of a changing climate, including potential decreases in growth and productivity (Bréda and Badeau, 2008; Klos et al., 2009; Vose et al., 2012). Reductions in stand density via thinning increases growing space and may result in decreased competition for water, nutrients, and light among residual trees (Martín-Benito et al. 2010). Soil moisture availability is also indirectly increased through decreased rainfall interception and reduced stand-level transpiration (Morikawa et al., 1986; Stogsdill et al., 1989; Bréda and Granier, 1996; Bréda et al., 1996), with the degree of increase varying with stand density (Della-Bianca and Dils, 1960; Butcher, 1977; Mitchell et al., 1993). Due to the interaction among density and soil moisture, tree-level response to periods of soil moisture deficit can vary with stand structure. For example, Misson et al. (2003a,b) report growth of plantation-origin Norway spruce (*Picea abies* (L.) Karst.) in heavily thinned stands was less affected by drought than in higher density stands. Likewise, D'Amato et al., (2013) report stand density, as modified through repeated thinnings, altered the climate-growth relationships of plantation-origin red pine (*Pinus resinosa* Ait.), with trees in high density stands more susceptible to reductions in growing season precipitation than trees in low density stands. Although information related to how stand structure interacts with climate to modify tree growth for naturally-regenerated, deciduous tree species is less abundant, similar effects have been observed. For example, both increased temperature and increased moisture deficit were found to decrease growth of European beech (*Fagus sylvatica* L.) to a greater extent in high density than low density stands (Piutti and Cescatti, 1997).

Although stand structure can influence the effects of climate on tree growth, other factors such as site productivity can interact with climate to further affect growth. For example, studies suggest trees growing on mesic high-quality sites often experience proportionally greater growth reductions during periods of reduced soil moisture availability than trees growing on xeric, low quality sites (Fekedulegn et al., 2003; Orwig and Abrams, 1997). Dendrochronological climate-growth relationships have been developed for many eastern US tree species, including oak (*Quercus*) and hickory (*Carya*) species (Orwig and Abrams, 1997; Speer et al., 2009; LeBlanc and Terrell, 2011; White et al., 2011) and a subset of the prominent mixed-mesophytic species [e.g., yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.)] (Orwig and Abrams, 1997; Pan et al., 1997; Fekedulegn et al., 2003). Lacking, however, is information about how competition and site quality interact with climate to influence tree growth for some of these ecologically and economically important tree species.

Yellow-poplar is a mesophytic species common to moderate to highly productive sites throughout the southern Appalachian region and is the most abundant individual tree species (in terms of volume) in the southern Appalachian Mountains (Thompson, 1998; Schweitzer, 1999; Brown, 2003). Although yellow-poplar is most often found in areas of relatively high soil moisture holding capacity where moisture does not generally limit growth (Beck and Della-Bianca, 1981), yellow-poplar is susceptible to decreased growth and increased mortality during drought events (Elliott and Swank, 1994; Orwig and Abrams, 1997; Klos et al., 2009). Past studies linking tree growth with climate for eastern US tree species have often failed to consider the interacting effects competition and site quality may have with variations in tree growth affected by annual changes in climate. This likely over-simplifies climate-growth relationships and the potential effect of climate change on both tree- and stand-level productivity. The primary goal of this study was to examine the effect of climate on the growth of a prominent tree species in the southern Appalachians, yellow-poplar, across broad structural and site quality gradients. Specifically, based on the literature, we hypothesize the negative effects of reduced soil moisture availability on annual tree growth will be exacerbated as stand density, site quality, and tree size increase. Such quantitative information regarding climate-growth relationships under varying stand structures and across environmental gradients will (1) determine if altering the competitive environment via silvicultural thinning does, in fact, mitigate some of the deleterious effects of climate on tree growth, and (2) provide information that will aid in the identification of stands most susceptible to drought-induced reductions in growth.

2. Materials and methods

2.1. Study area

This study was conducted in the Blue Ridge Mountains and Northern Ridge and Valley Physiographic provinces of the southern Appalachian Mountains. Study sites were located in northern Georgia, western North Carolina, and southwestern Virginia. Soils were either ultisols or inceptisols, and encompassed six major soil series (Tusquitee, Brevard, Ashe, Haywood, Watuga, and Porters), indicating a range of site productivity. Soils were well-drained, coarse or fine-loamy in texture. Temperatures in the intermountain basin of Asheville, NC, which is centrally located within the geographic study area, ranged from 2.3 °C in January to 22.3 °C in July (McNab et al., 2004). Elevations of the study sites range from approximately 340–1150 m. Average annual precipitation, which increases with elevation, is evenly distributed throughout the year and ranges from 1000 mm to 1500 mm (but can be as high as 2500 mm in some areas) across the study sites (McNab, 2011). As a reference, in the Asheville Basin, which is approximately 600 m elevation, annual precipitation averages 1200 mm (McNab et al., 2004).

2.2. Experimental design and data collection

Between 1960 and 1963, 141 – 0.1 ha permanent plots were established in yellow-poplar stands throughout the study area. This study utilized 133 of the original 141 plots, as some plots were mistakenly harvested. All plots were established in naturally regenerated, even-aged stands in which yellow-poplar comprised >75% of the overstory basal area. Plots were located on north and east aspects and ecologically mapped as primarily rich cove forests (Simon et al., 2005). Rich cove forests possess high levels of biodiversity (tree and herbaceous layers) and are located on protected landscapes characterized by gentle slopes (Simon et al., 2005). At the time of plot establishment, all live trees greater than 11.4 cm in diameter at breast height (DBH; 1.37 m above ground line) within each plot were tagged, and species, DBH (cm), and total height (m) were recorded. Increment cores were extracted from five of the most dominant trees on each plot. Using age data obtained from the increment cores and height data, site index (base-age 50) was calculated for each of the five trees per plot (Beck, 1962), with site index (SI; m) calculated as the average SI of the five sample trees.

Within a one to two months following the initial inventory (1960–1963), plots were thinned to a randomly assigned basal area (BA; m^2 ha^{-1}). Post-thinning BA corresponded to residual relative densities (RD) ranging from 12% to 56% calculated as plot-level