2018

Radial growth responses of upland oaks following recurrent restoration treatments in northern Mississippi

Kathryn R. Kidd
Stephen F Austin State University, kiddkr@sfasu.edu

J. Morgan Varner
U.S. Department of Agriculture Forest Service

J. Stephen Brewer
University of Mississippi

RADIAL GROWTH RESPONSES OF UPLAND OAKS FOLLOWING RECURRENT RESTORATION TREATMENTS IN NORTHERN MISSISSIPPI

Kathryn R. Kidd, J. Morgan Varner, and J. Stephen Brewer

Abstract—Fire exclusion over the past century has substantially altered composition, structure, and fuel dynamics in upland oak-hickory (*Quercus-Carya*) forests in the Southeastern United States. Numerous restoration efforts have been made to re-establish historical disturbance regimes into these altered forests. However, our understanding of the implications of restorative disturbances on stand dynamics has primarily been limited to shifts in species composition and post-disturbance regeneration. Therefore, we examined annual radial growth responses of dominant upland oaks following a combination of prescribed fires (2004, 2006, 2008, 2010, 2012, and 2014) and thinning (starting in 2004) treatments (thin+burn) in stands which had previously been unburned since the early 1900s. Radial stem growth rates were quantified using tree cores from 22 post oak (*Q. stellata*) and southern red oak (*Q. falcata*) in a 2.5-acre thin+burn and control stand at the Strawberry Plains Audubon Center in northern Mississippi. Radial growth rates were not significantly greater following repeated thinning and prescribed burning than prior to treatment initiation for either post oak or southern red oak. For the first 6 years after the initial thin, the annual ring width for southern red oak was identical in the thin+burn (1.9 ± 0.1 mm year^{-1}) and control (2.0 ± 0.2 mm year^{-1}) stands. However, in 2010 radial growth for southern red oak in the thin+burn increased such that the annual ring width for 2010 was 22 percent greater in the thin+burn than in the control stands. In contrast to the positive growth response in southern red oak (2 percent), post oak demonstrated a significantly different (p = 0.014) negative response (-19 percent) in the relative percent change in total radial growth for the 11-year period post-treatment initiation when compared to the 11-year period prior to treatment initiation. Radial growth for both species was negatively impacted by a severe drought in 2007 with southern red oak exhibiting the greatest decrease in radial growth. Results from this study highlight the underlying role of climatic factors and species life history characteristics in evaluating radial growth patterns following forest disturbances.

INTRODUCTION

Long-term fire exclusion coupled with the absence of significant harvesting disturbances has created contemporary forested conditions in upland oak-hickory (*Quercus-Carya*) forests in the Eastern (Nowacki and Abrams 2008) and Western United States (Cocking and others 2012). Such contemporary forests in the Southeastern United States are characterized by altered composition (i.e., an increase in frequency of fire-sensitive, shade-tolerant mesophytic species), forest stand structure (i.e., increased stem densities), and fuel dynamics (i.e., fuel beds less conducive to facilitating fire disturbances) (Cocking and others 2012, Kreye and others 2013, Nowacki and Abrams 2008). The reintroduction of disturbance into these now contemporary forested conditions leaves many questions unanswered relative to the impacts on forest structure and composition, radial stem growth, and forest health, particularly where there is strong potential for interactions with climatic factors (e.g., extreme fluctuations in temperature and precipitation).

Radial stem growth patterns recorded in tree-ring records can be analyzed to reflect environmental growth conditions and thus can be used to evaluate trees' responses to the reintroduction of disturbance along with climatic influences on growth (Fraver and White 2005, Fritts and Swetnam 1989, Rentch and others 2002). Annual radial stemwood growth (i.e., annual ring width) is restricted by the most limiting factor (Fritts 1976). For instance, increased competition from high stem densities can reduce light, water, and nutrient availability, thus reducing radial stemwood growth for the duration of such stressed conditions. When conditions improve (e.g., increased light, water, or nutrient levels), an increase in radial stemwood growth or a growth release will occur in response to the most limiting factor no longer limiting radial growth.

Author information: Kathryn R. Kidd, Assistant Professor, Arthur Temple College of Forestry and Agriculture, Stephen F. Austin State University, Nacogdoches, TX 75962; J. Morgan Varner, Team Leader and Research Scientist, Pacific Wildland Fire Sciences Laboratory, U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Seattle, WA 98103; J. Stephen Brewer, Professor, Department of Biology, University of Mississippi, University, MS 38677.

Kirschman, Julia E., comp. 2018. Proceedings of the 19th biennial southern silvicultural research conference. e-Gen. Tech. Rep. SRS-234. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 444 p.

In 2003, an oak woodland restoration project was established at the Strawberry Plains Audubon Center (SPAC) in northern Mississippi (Brewer 2014). Recurrent thinning and prescribed burning treatments were implemented to restore historic oak woodland conditions in a long-undisturbed (since early 1900s) upland oak-hickory forest dominated by southern red oak (*Q. falcata*) and post oak (*Q. stellata*). Restoration treatments were designed to increase light availability by decreasing overstory and midstory stem densities and to promote regeneration by more shade-intolerant, fire-tolerant species by reducing the competition from more fire-sensitive, shade-tolerant mesophytic species. The reintroduction of disturbance into this long-disturbed contemporary forest provided the opportunity to examine radial stemwood growth responses to the recurrent disturbances. Therefore, the objectives of this study were to 1) determine if southern red oak and post oak demonstrated a radial stemwood growth response to repeated thinning and prescribed fire treatments and 2) determine if radial stem growth responses differed between the two upland oak species.

MATERIALS AND METHODS

Study Area

This study was conducted at the SPAC in northern Mississippi. Specifically, the SPAC is located in Marshall County, MS, approximately 10 km north of Holly Springs, MS and 80 km southeast of Memphis, TN (34°49' N, 89°28' W). The study site consisted of two adjacent 2.5-acre upland oak-hickory stands situated on a Providence silt loam soil. From the mid-1800s to the early 1900s the area was intensively managed for cotton but since, these upland oak-hickory stands have not been burned or received any significant disturbance (Surrette and others 2008). Upland sites in this region were characterized as oak woodlands before conversion for agriculture (Brewer 2001, Surrette and others 2008). However, since previous agricultural use, long-term effects of fire exclusion and absence of harvesting disturbance created contemporary conditions which were no longer conducive to frequent, low-intensity disturbance (Nowacki and Abrams 2008).

Treatments

The two adjacent stands represented a paired design; one stand was designated as a control (no treatment) and one as a thin+burn (recurrent thinning and burning). This pair of oak-hickory stands was part of a larger study established in 2003 aimed at restoring historic oak woodland conditions (Brewer 2014, Brewer and Menzel 2009). The original study included a total of two replicated pairs (one control and one treatment stand). Our current study utilized only one of the pairs due to differences in species composition, soils, and site hydrology between the pairs. In 2003, all stems with a diameter at breast height (DBH, 4.5 feet above ground) >4 inches were tagged and inventoried. The overstory in both the control and thin+burn stand was initially dominated by post oak and southern red oak. In 2004, an initial thinning was conducted in the thin+burn treatment stand. A combination of girdling via Pathway® (picloram and 2,4-D) and felling techniques were used to primarily target the fire-sensitive, mesophytic non-oak species such as red maple (*Acer rubrum)*, sweetgum (*Liquidambar styraciflua)*, winged elm (*Ulmus alata)*, blackgum (*Nyssa sylvatica)*, and dogwood (*Cornus florida)*. To further increase canopy gaps and amount of light reaching the forest floor, both of which are characteristics of fire-prone oak woodlands, smaller-scale thinning disturbances were implemented in 2008, 2010, and 2012 in which an additional 10 percent of the canopy cover was thinned via girdling (Brewer 2014). By 2015, the basal area decreased from 110 to 75 square feet per acre and stand density decreased from 123 to 54 stems per acre in the thin+burn. Post oak and southern red oak composed the majority of the overstory with mockernut hickory (*Carya tomentosa*) as a minor component. In combination with thinning disturbances, prescribed fires were conducted in September 2004, October 2006, July 2008, April 2010, March 2012, and March 2014 to aid in reducing competition from more fire-sensitive species and to promote native grasses and fuel dynamics associated with historic oak woodland conditions. In the absence of thinning and burning disturbances, the control stand was representative of a typical eastern deciduous contemporary forest, in which the midstory composition consisted of mesic shade-tolerant, fire-intolerant species with little to no seedlings or shrubs (Nowacki and Abrams 2008). In the control stand, basal area increased from 100 to 110 square feet per acre and stand density increased from 122 to 143 stems per acre between 2003 and 2015. Thus, in 2016, when our sampling occurred, the control stand was characterized by a greater component of red maple, sweetgum, winged elm, blackgum, and dogwood in the mid- and overstory strata than in the thin+burn stand. In contrast, the thin+burn stand contained more shade-intolerant and fire-tolerant species (i.e., *Quercus* spp.) in the midstory and seedling regeneration layers.

Field Methods

During the summer of 2016, 11 southern red oak and post oak trees were selected within each of the 2.5-acre thin+burn and control stands. Two tree cores were extracted from each selected tree at DBH using a manual increment borer. Cores were taken 90° apart from each other around the circumference of the tree. Two cores were collected rather than one to reduce within-tree variation (Copenheaver and others 2009). Trees located at stand boundaries were not selected in order to avoid potential edge effects. Trees that displayed wounds or broken tops were omitted.

Laboratory Methods

Tree cores were air dried and glued to wooden mounts. Progressively finer sand paper was used to surface cores until cellular structures became visible in the cross-sectional view under magnification (Phipps 1985). Two tree-ring chronologies were developed: 1) southern red oak and 2) post oak. Each chronology was developed using all 22 trees (44 cores) from across both stands (5 acres). This was done to ensure the standard minimum of 20 trees was used to develop each chronology (Copenheaver and others 2009). Prior to treatment implementation there was no significant disturbance in either stand, therefore the trees should have been exposed to the same environmental conditions during the formation of the majority of annual growth rings. Cores were visually cross-dated using the list method in which narrow growth rings common among samples were identified and used as signature years to ensure proper alignment of dating (Yamaguchi 1991). Annual tree-ring widths were measured under stereoscopic magnification to the nearest 0.01 mm using the Velmex Measuring System and J2X software (v.3.2.1, 2004). Dated tree-ring width measurement values were verified to ensure quality of visual cross-dating using COFECHA software (Holmes 1983). Dating errors detected by COFECHA were corrected.

Data Analysis

To determine if changes in radial stem growth occurred following implementation of recurrent thinning and burning treatments, mean annual ring width and total radial growth increment for the 11 years prior to and following treatments were compared. Comparisons were made between pre- and post-treatment values (mean ring width and total 11-year radial growth) for each individual species using Wilcoxon-Mann-Whitney tests within the NPAR1WAY procedure in SAS 9.3 (SAS 2012). To determine if radial growth responses differed between species, the relative percent growth change in total 11-year radial growth increment from pre- to post-treatment implementation was calculated for southern red oak and post oak (adapted from Nowacki and Abrams 1997). Relative percent change in growth was compared between southern red oak and post oak in both the control and thin+burn stands using a Wilcoxon-Mann-Whitney test. All tests were performed at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Tree-Ring Chronologies

The southern red oak tree-ring chronology included years of 1910 to 2015 (mean length of series = 68.4 years) while the post oak chronology spanned from 1853 to 2015 (mean length of series = 110.5 years). Series intercorrelation values were 0.700 for the southern red oak and 0.669 for the post oak chronologies indicating a relatively strong degree of correlation (ranging from 0-weak to 1-strong) for interannual ring widths and thus cross-dating among samples (series). Mean sensitivity values, which provide a year-to-year measure of variability in ring width, were 0.207 for southern red oak and 0.205 for post oak indicating little variability in ring width for the length of the chronologies.

Pre- and Post-Treatment Radial Growth Responses Compared

Prior to implementation of recurrent thinning and burning treatments, mean annual ring width for southern red oak for the time period 1992 to 2003 was similar ($p = 0.922$) between the thin+burn (2.2 ± 0.1 mm year^{-1}; mean ± SE) and control (2.3 ± 0.3 mm year^{-1}) stands (fig. 1). Radial growth rates for post oak were also relatively similar ($p = 0.309$) in the thin+ burn (1.2 ± 0.2 mm year^{-1}) and control (1.5 ± 0.2 mm year^{-1}) stands prior to treatments (1992 to 2003). An increase in post oak radial growth occurred in the control stand around 2001, after which the mean annual ring width was approximately 25 percent greater for post oak in the control than in the thin+burn stand. For the first six years (2004 to 2009) after the initial heavy thin, the mean ring width for southern red oak remained nearly identical in the thin+burn (1.9 ± 0.1 mm year^{-1}) and control (2.0 ± 0.2 mm year^{-1}) stands despite the additional 10 percent basal area thinning in 2008 and prescribed fires in 2004, 2006, and 2008. However, in 2010 radial growth for southern red oak in the thin+burn increased such that the mean annual ring width for 2010 was 22 percent greater in the thin+burn than in the control stands. Radial growth rates for southern red oak continued to be greater ($p = 0.140$) in the thin+burn (2.6 ± 0.2 mm year^{-1}) than in the control (2.0 ± 0.2 mm year^{-1}) from 2010 through 2013. Post oak radial growth was consistently greater ($p = 0.033$) in the control (1.4 ± 0.2 mm year^{-1}) than in the thin+burn (1.0 ± 0.1 mm year^{-1}) stand during the 2004 to 2015 time period (fig. 1). The relative percent change in the total radial growth for the 11-year period prior to (1992 to 2003) and following (2004 to 2015) initiation of treatments was not significantly different between the control and thin+burn stands for southern red oak ($p = 0.224$) or post oak ($p = 0.053$) (fig. 2).

Although changes occurred in radial stemwood growth, we were unable to detect statistically significant growth responses for southern red oak or post oak through analysis of mean annual ring width or total radial growth increments between pre- and post-initiation of thinning and burning treatments. The most likely reason for the lack of significant response to treatment is the underlying role of climate on radial growth responses. Radial growth is limited by the most limiting factor, and in our study this may have been water availability rather than light. Climate records indicate a severe drought occurred in 2007 (NOAA 2017). Coincidentally, annual ring width decreased in both the thin+burn and control stands likely masking any immediate growth response in the

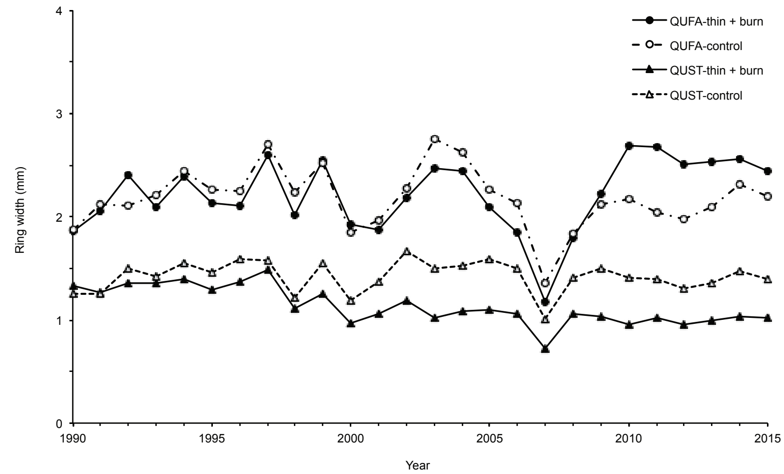

Figure 1—Mean annual tree-ring width (mm) for southern red oak (QUFA) and post oak (QUST) within the thin+burn and control stands for the 1990 to 2015 time period at the Strawberry Plains Audubon Center in northern Mississippi. Twenty-two QUFA and QUST tree cores (11 trees) were analyzed from within each stand. Recurrent thinning and prescribed fire treatments in the thin+burn were initiated in 2004.

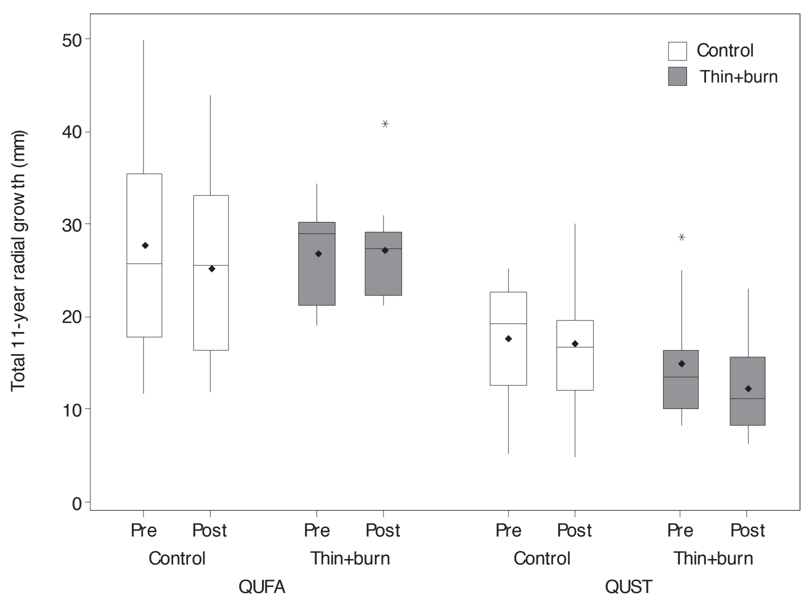

Figure 2—Boxplot of total radial growth (mm) for southern red oak (QUFA) and post oak (QUST) within the thin+burn and control stands for each 11-year period prior to (Pre; 1992 to 2003) and following (Post; 2004 to 2015) implementation of recurrent thinning and prescribed fire treatments at the Strawberry Plains Audubon Center in northern Mississippi. Twenty-two QUFA and QUST tree cores (11 trees) were analyzed within the thin+burn and control stands. Diamond markers indicate mean values.

thin+burn stand. In 2007, the monthly Palmer Drought Severity Index was -3.34 for May, -3.24 for June, -2.35 for July, and -2.93 for August on a scale of +6 (extreme wet spell) to -6 (extreme drought) (NOAA 2017). Another reason for the lack of significant growth responses could be related to changes in physiology as trees mature in age and increase in diameter. Such changes in physiology may make mature trees more resistant to short-term alterations in environmental conditions than younger trees (Liñán and others 2012, Voelker 2011). Further, the relatively low intensity and spatial pattern (asynchronous) of the additional 10 percent thinning treatments in 2008 and 2010 may have contributed to the lack of a significant radial growth response following initiation of restoration treatments. Gap sizes adjacent to selected trees were measured; however, data was not analyzed in this preliminary report.

Radial Growth Responses Compared Between Species
The relative percent growth change in total radial growth for the 11-year period prior (1992 to 2003) compared to following treatment initiation was significantly different (*p* = 0.014) between southern red oak (increased by 2 percent) and post oak (decreased by 19 percent) in the thin+burn stand (fig. 2). In the control stand, total radial growth during 2004 to 2015 decreased for both (*p* = 0.450) southern red oak (6 percent) and post oak (2 percent) when compared to the total radial growth during 1992 to 2003.

Southern red oak exhibited a slightly positive radial growth response in the thin+burn stand whereas post oak demonstrated a negative growth response. Southern red oak also demonstrated a greater growth response to the 2007 drought (fig. 1). Post oak appeared to be more resistant to thinning, burning, and climatic disturbances in our study. Differences in growth responses are most likely attributed to species' life history strategies and characteristics. Longevity has been shown to be approximately twice as long (320 years) for post oak than southern red oak (150 years) (Guyette and others 2004). Other researchers have identified slower growth rates as tradeoffs to ensure longevity in post oak (Guyette and others 2004). Differences in species responses could have also been due to physiological effects of tree age and size. On average, post oaks analyzed in this study were older and larger in diameter than the southern red oaks. The increased age and size of post oak may have reduced the radial growth response identified. Ring widths were not standardized prior to analysis in our current study, as we were directly comparing the 11 years of growth prior to and following treatment implementation and the percent change in growth between the two time periods (adapted from Nowacki and Abrams 1997). Further, standardization of radial growth may have decreased the tree-level response and thus we may have reduced the variation to the point where possible responses were not detected. To account for diameter size-related growth trends in future analyses, we will use the basal area increment, which takes into account the diameter rather than only changes in raw ring width and 11-year radial growth increments.

CONCLUSION

Identifying growth releases following known disturbances will aid future use of radial growth patterns to detect the occurrences and impacts of canopy disturbances, particularly smaller-scale disturbances. Our study recognizes the role that stand disturbances (e.g., repeated thinning and burning), climate, tree age and size, and species life history strategies play in influencing radial growth responses.

ACKNOWLEDGMENTS

This study was funded by Joint Fire Science Program project #13-1-04-49, the McIntire-Stennis Cooperative Forestry Research Program, and Stephen F. Austin State University. We would also like to thank the Audubon Society and staff at the Strawberry Plains Audubon Center for their cooperation and permission to continue this long-term study.

LITERATURE CITED

Brewer, J.S. 2001. Current and presettlement tree species composition of some upland forests in northern Mississippi. The Journal of the Torrey Botanical Society. 128(4): 332–349.

Brewer, J.S. 2014. Effects of oak woodland restoration treatments on sapling survival and tree recruitment of oaks in an upland mesic oak-dominated forest. Ecological Restoration. 32(2): 127–130.

Brewer, J.S.; Menzel, T. 2009. A method for evaluating outcomes of restoration when no reference sites exist. Restoration Ecology. 17(1): 4–11.

Cocking, M.I.; Varner, J.M.; Sherriff, R.L. 2012. California black oak responses to fire severity and native conifer encroachment in the Klamath Mountains. Forest Ecology and Management. 270 (1): 25–34.

Copenheaver, C.A.; Black, B.A.; Stine, M.B. [and others]. 2009. Identifying dendroecological growth releases in American beech, jack pine, and white oak: within-tree sampling strategy. Forest Ecology and Management. 257(11): 2235–2240.

Fraver, S.; White, A.S. 2005. Identifying growth releases in dendrochronological studies of forest disturbance. Canadian Journal of Forest Research. 35(7): 1648–1656.

Fritts, H.C. 1976. Tree Rings and Climate. Academic Press, New York, New York. 582p.

Fritts, H.C.; Swetnam, T.W. 1989. Dendroecology: a tool for evaluating variations in past and present forest environments. Advances in Ecological Research. 19: 111–188.

Guyette, R.P; Muzika, R.; Kabrick, J.; Stambaugh, M.C. 2004. A perspective on Quercus life history characteristics and forest disturbance. In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station: 138–142.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bulletin. 43: 69–78.

Kreye, J.K.; Varner, J.M.; Hiers, J.K.; Mola, J. 2013. Toward a mechanism for eastern North American forest mesophication: the role of litter drying. Ecological Applications. 23(8): 1976–1986.

Liñán, I.D.; Gutiérrez, I.H.; Andreu-Hayles, L. [and others]. 2012. Age effects and climate response in trees: a multi-proxy tree-ring test in old-growth life stages. European Journal of Forest Research. 131(4): 933–944.

NOAA, National Climatic Data Center. 2017. Division Data. https://www7.ncdc.noaa.gov/CDO/CDODivisionalSelect.jsp#. [Date accessed: February 16, 2017].

Nowacki, G.J.; Abrams, M.D. 1997. Radial-growth averaging criteria for reconstructing disturbance histories from presettlement-origin oaks. Ecological Monographs. 67(2): 225–249.

Nowacki, G.J.; Abrams, M.D. 2008. The demise of fire and “mesophication” of forests in the eastern United States. BioScience. 58(2): 123–138.

Phipps, R. L. 1985. Collecting, preparing, crossdating, and measuring tree increment cores. Water-Resource Investigations Report 85-4148. Reston, VA: U.S. Geological Survey, Water Resources Division. 48p.

Rentch, J.S.; Desta, F.; Miller, G.W. 2002. Climate, canopy disturbance, and radial growth averaging in a second-growth mixed-oak forest in West Virginia, U.S.A. Canadian Journal of Forest Research. 32(6): 915–927.

SAS. 2012. SAS/STAT 9.3 user’s guide: the NPAR1WAY procedure. SAS Institute, Inc. Cary, NC.

Surrette, S.B.; Aquilani, S.M.; Brewer, J.S. 2008. Current and historical composition and size structure of upland forests across a soil gradient in north Mississippi. Southeastern Naturalist. 7(1): 27–48.

Voelker, S.L. 2011. Age-dependent changes in environmental influences on tree growth and their implications for forest responses to climate change. In: Meinzer, F.C.; Lachenbruch, B.; Dawson, T.E., eds. Size- and age- related changes in tree structure and function. Tree Physiology: 4. New York: Springer: 455–479.

Yamaguchi, D.K. 1991. A simple method for cross-dating increment cores from living trees. Canadian Journal of Forest Research. 21(3): 414–416.