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The Role of Dendrology in Analyzing Past Climatic and Historical

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The Role of Dendrology in Analyzing Past Climatic and Historical

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Abstract

The study of dendroclimatology uses tree growth responses to climate variables to reconstruct regional, national, and global chronologies from tree-rings (Speer, 2010). The species of focus was *Q. macrocarpa* (bur oak) located in Spring Creek Prairie because of its potential to hold a chronological history of environmental limitations and management practices in the area. The objective of this research is to: 1) determine the impact of available soil moisture on the annual growth of *Q. macrocarpa* in Wachiska Woods, 2) determine the effect of management practices on *Q. macrocarpa* annual growth in Wachiska Woods. Eight *Q. macrocarpa* specimens were identified; four specimens were selected in the unmaintained portion of the site and four specimens were selected in the thinned portion of the site. Measurements included diameter at breast height (DBH), crown spread, and height of tree and followed the protocols detailed in the *Timber Cruising Handbook* (FSH, 2012). General site characteristics were also recorded for each specimen. One increment core per tree was extracted then mounted, sanded and analyzed. The effects of available soil moisture on annual growth indicated mean basal area increment (BAI) is related to soil moisture, decreasing in drier years and increasing in wetter years. The mean DBH positively related to mean BAI and indicated that the trees sampled in the unmaintained site had greater values than the trees sampled in the thinned site when not accounting for age (Table 1; Figure 5). However, the model generated using linear regression accounts for age shows that trees sampled in the thinned site had a greater increase in annual BAI than trees in the unmaintained site (Table 2; Figure 6).

Introduction

Dendrochronology

The field of dendrochronology examines historical and environmental events recorded in annual tree-rings (Towner, 2002). Trees serve as long-term bioindicators with annual resolution, providing an accurate and precise non-documentary dating method available in researching past climatic events (Towner, 2002). Tree-ring analyses have allowed researchers to construct detailed chronologies, determining the age of the prehistoric ruins of Mesa Verde National Park found in the Southwestern United States through the sub-field of dendroarchaeology (Towner, 2002). The sub-field of dendrovolcanology dated the eruption of Mount Vesuvius located near the Bay of Naples in Italy, an event that buried the city of Pompeii and its inhabitants under millions of tons of volcanic ash (Luongo, et al., 2003).

Dendrochronology and the technique of cross-dating, where patterns of wide and narrow ring widths are matched to demonstrate dating between cores, was developed in the early 1900s by the American astronomer A.E. Douglass and is used to determine a variety of natural and human-caused changes to the environment (Speer, 2010). Applied dendrochronology requires trees that are responsive to environmental changes in selected sites where one environmental limiting factor varies dramatically year to year and directly or indirectly limits a process affecting growth to provide a full range of annual ring widths for comparison (Speer, 2010). The field instrument used in dendrochronology is referred to as an increment borer (Figure 1). An increment borer is a T-shaped precision tool designed to remove a core sample 3/16 of an inch in diameter, approximately the same as that of a number two pencil, without seriously harming living specimens (Stokes & Smiley, 1968). Large screw threads sit behind a sharp leading edge, drawing the instrument into the tree as pressure is applied and the shaft is turned clockwise by a rotating handle and produces samples up to 40 inches in length (Stokes and Smiley, 1996). When removing an increment borer, the handle must be turned counterclockwise (Speer, 2010). The height at which

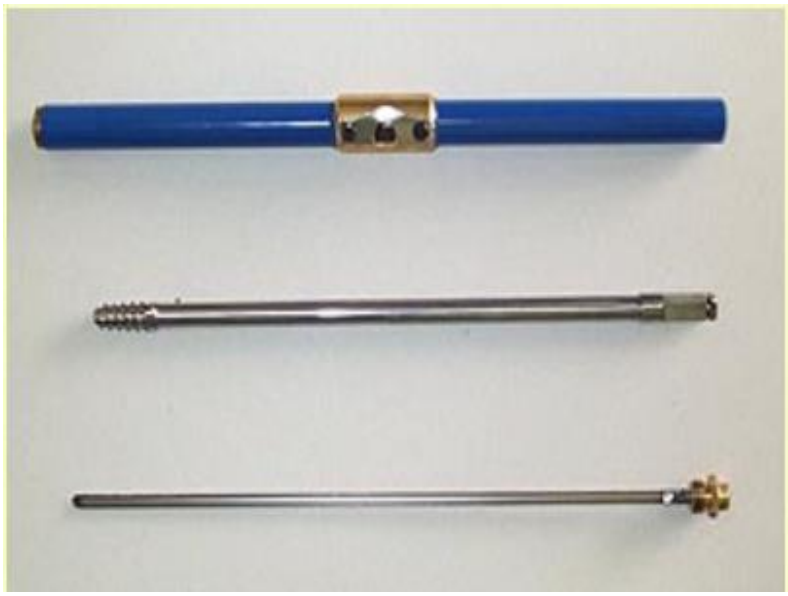

Figure 1. Dismantled increment borer showing all parts (Cardwell, 2004).

the core sample is taken depends on the intended research of interest and c the various sub-fields of dendrochronology (Speer, 2010). However, in order to better understand how a tree-ring core can infer this kind of information with the described technique, a basic understanding of tree biology is necessary.

Roots

The impact of climate on root functions can cause variance in water and nutrient uptake, such as a lack of rainfall or reduced soil moisture which may impede growth of annual rings. On average a tree's roots penetrate no more than 2m below surface and are concentrated in the upper 60cm of the soil where it is the least compacted maximizing access to oxygen and water, and nutrients are readily available (Dobson, 1995). Tree roots uptake water and mineral nutrients from the surrounding soils during the growing season and act as a store for carbohydrates during the dormant seasons (Dobson, 1995). The spread of the roots is typically underestimated and reaches well beyond the crown spread; a widespread root base provides stability for the trunk and crown when faced with windy conditions or other forces exerted on the tree from the surrounding environment (Dobson, 1995). The variability of both environmental and soil conditions present obstacles and barriers that directly affect root growth and result in relatively unpredictable distribution of root-systems (Dobson, 1995).

Crown

The branches, twigs, and foliage form the tree crown. Tree crowns support the majority of photosynthesis. The vasculature in the leaves, twigs, and branches are the conduits for transportation of water and other nutrients. The growth pattern of individual branches is positively or negatively influenced by a complex interaction of environmental conditions and climatic events (Zimmerman & Brown, 1980). The leaves of the crown encompass a variety of discrete physical and chemical processes in order to conduct photosynthesis (Arthur & Strehler, 1956). The physical act of light absorption and the subsequent transformation of radiant energy into chemical energy comprises the first portion of photosynthesis. The second portion concerns the storage of chemical energy as carbohydrates and other nutrients used for growth (Arthur & Strehler, 1956). The rate at which photosynthesis is conducted is dependent on environmental factors such as light, temperature, and nutrient availability. The most influential being the intensity, duration and frequency of light exposure (Zimmermann & Brown, 1980). Reduced rainfall and increased temperatures for an extended period of time reduce the efficiency of photosynthesis and results in reduced tree growth that is recorded in the annual rings.

Trunk

The basic function of the trunk is to provide physical support and act as a conduit for transporting water and mineral nutrients from the roots to the leaves (Zimmermann & Brown, 1980). The layers of tissue found in the trunk of a tree include the pith, xylem, cambium, phloem, and outer bark. Each layer contributes differently to the structure and biological functions of the tree (Zimmermann & Brown, 1980). The pith of a tree is composed of parenchymal cells and appears as a minute discolored area at the biological, though not necessarily the geometric, center of the tree (Zimmermann & Brown, 1980). The effects of climate can be seen in the xylem (heartwood and sapwood layers) with variation in ring width inferring rainfall, temperature variations, soil moisture, and cloudy days (Speer, 2010). The primary function of heartwood is structural and is formed from inactive xylem tracheid or vessels as a tree ages. Sapwood's primary function is conducting water and nutrient transport through active xylem via tracheid or vessels (Brown, 1971). The cambium is a thin layer of actively growing tissue surrounding the sapwood that produces new cells from the outside edge of the sapwood inward ultimately forming the xylem and outward toward the bark forming the phloem (Brown, 1971). The phloem consists of living cells that transport sap containing sugar and other nutrients from source (leaves) to sink (roots and wood) tissues for growth, respiration, and storage (Asao & Ryan, 2014). The outer bark is made primarily of dead cells and serves as a protective layer against various environmental factors from dehydration of the xylem to fire protection (Zimmerman and Brown, 1980). Basic knowledge of tree structure allows detailed analysis of tree-rings and differentiating ring boundaries used in dendrochronology to better understand past events and the associated environmental impacts.

Dendroclimatology

The focus of this paper is on the study of dendroclimatology, which has used tree growth responses to climate variables in order to reconstruct regional, national, and global chronologies from tree-rings (Speer, 2010). As trees respond to environmental changes, they record climatic events such as temperature variations, rainfall, soil moisture, cloudy days and even wind stress; implying that climate is the main controlling factor of tree-ring growth in various scales (Speer, 2010). The application of tree-ring analysis to environmental and climatic problems have informed scientists of anomalies in atmospheric circulations for the Northern Hemisphere since 1700 A.D. and can provide valuable information of future climatic predictions (Fritts, 1971).

Study Area

Spring Creek Prairie is located approximately 20 minutes southwest of Lincoln, Nebraska on the site of the former O'Brien Ranch. This area totals approximately 850-acres of native tallgrass prairie, wetlands and ponds, wildflowers and grasses (Spring Creek Prairie Audobon Center, n.d.). Specific management techniques, including prescribed burns, have been implemented to control woody vegetation, invasive species, and to stimulate native plant growth to maintain the tallgrass prairie ecosystem (Spring Creek Prairie Audobon Center, n.d.). The trees species of interest was Q*uercus macrocarpa*, that inhabit thinned and unmaintained Wachiska Woods area within Spring Creek Prairie. *Q. macrocarpa* tolerates cold, a wide range of soil conditions and moisture regimes, and is a dominant savanna or woodland species in the Great Plains region (U.S.F.S. & U.S.D.A., 2019). The objective of this research is to: 1) determine the impact of available soil moisture on the annual growth of *Q. macrocarpa* in Wachiska Woods, 2) determine the extent of evidence the effect of management practices have had on *Q. macrocarpa* annual growth of tree-rings since being implemented in Wachiska Woods.

Methods

The study area is approximately 30 acres of publicly-managed woodlands located in Wachiska Woods within in Spring Creek Prairie 20 miles southwest of Lincoln, NE, USA. Spring Creek Prairie is managed by Nebraska Game and Parks in cooperation with the National Audubon Society. The eastern section of the woodlands was the only portion of the study area that was thinned between July, 2012 and October, 2013 (Figure 2).

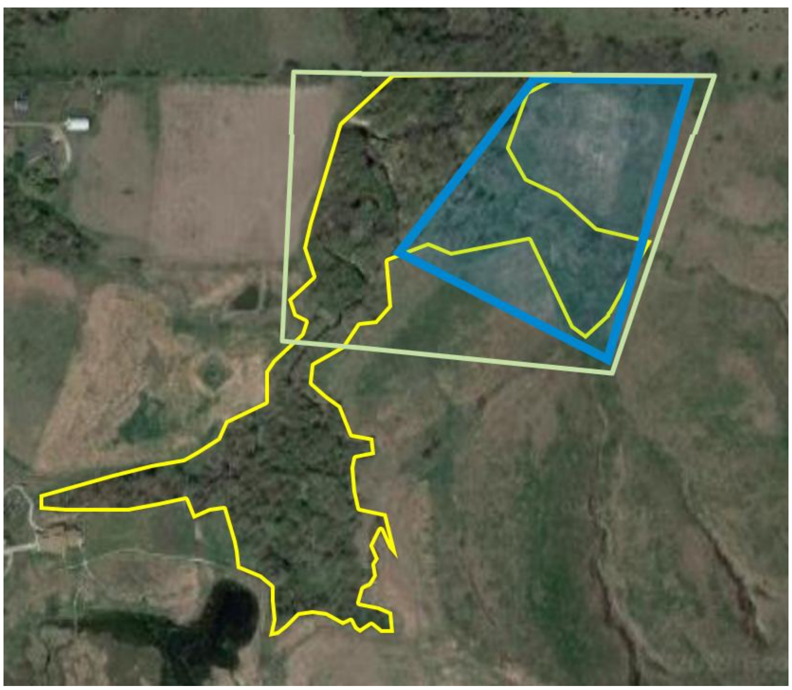

Figure 2. The yellow outline represents Spring Creek Prairie Woodlands. The green outline shows the beginning of Wachiska Woods and where selected Q. macrocarpa stand. The blue outline shows the area that has been thinned by management (Betz, 2019).

The species of interest was *Q. macrocarpa* (bur oak) because of its potential to hold a chronological history of environmental limitations and management practices in the area. Eight *Q. macrocarpa* specimens were identified, flagged and their GPS coordinates recorded. Four specimens were selected in the unmaintained portion of the site and four specimens were selected in the thinned portion of the site. DBH, crown spread, height of tree, and general site characteristics were recorded for each specimen that followed the protocols stated in the *Timber Cruising Handbook* (FSH, 2012). All measurements were recorded using the metric system unless otherwise specified in their description.

Measurements

The diameter at breast height (DBH) was the location for core sample 1 and taken on the high ground side of the tree 4.5 feet off the forest floor using a diameter tape. If no obvious high side was present the measurement was taken from the north side of the tree. If the tree forked below 4.5 feet the DBH was measured just below the fork under any bulge that may occur on the trunk. If the tree presented any abnormalities (canker, swell, catface) the DBH was measured above and below the abnormalities and an average measurement was calculated. If the tree could not be measured above and below the abnormalities, it was measured above and a taper calculation was applied from comparable trees of the same species.

The height of the tree was recorded with a clinometer by using the law of sines and the baseline distance, elevation angle, and depression angle measurements. This was taken using an uphill or ground level point of view; taking the measurement from a downhill point of view was avoided in order to produce accurate measurements.

The average crown spread of each tree was calculated by measuring the distance from the trunk of the farthest and shortest length of the crown and adding them together. General site characteristics were recorded in order to describe the environment the trees inhabit.

One increment core per tree was taken from the side tangential to the slope of the tree 4.5 feet off the forest floor. Cores collected were marked with a unique code that correlated to the tree the sample was taken from. Cores were dried, mounted, and sanded with progressively finer sandpaper up to 400 grit in order to yield a flat, smooth surface. A Velmex Tree-Ring measurement system and the software J2X was used to measure individual tree-rings to the nearest 0.001mm. Annual tree growth was calculated as basal area increment (BAI) from the tree-ring measurement using R (R Core Team, 2016) with the dplR package (Bunn, 2010). BAI is the cross-sectional surface area of a standing tree's trunk measured at breast height (Mercker, 2006). The BAI is used in tree growth and modeling studies because it offers an accurate quantification of wood production due to a consistently increasing diameter of a growing tree (Rubino & McMarthy, 2000). BAI for all visible years of annual tree growth was used in the analysis. The Palmer Drought Severity Index (PDSI) for the east central region (National Centers for Environmental Information., 2019) of Nebraska (Figure 3) was used to correlate available soil moisture with tree-ring widths to determine the impact of drought on the annual growth (April to October) of *Q. macrocarpa* (Figure 1). The average PDSI during the growing indicates that significantly drier than average years (< -1.99) occurred during 1918, 1928, 1934-1940, 1956, 1989, 2000, 2002, and 2012 (Figure 3) resulting in reduced availability of soil moisture in the central eastern region of Nebraska.

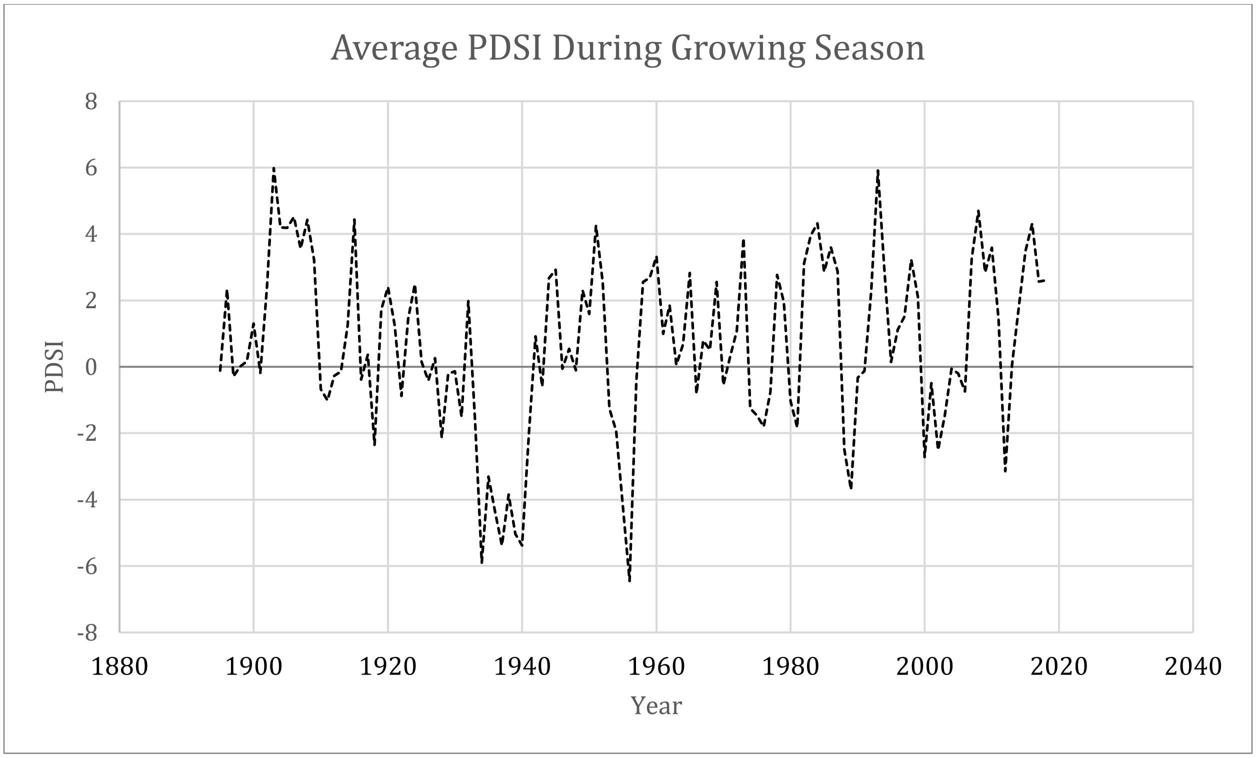

Figure 3. The average growing season (April to October) PDSI (National Centers for Environmental Information., 2019).

The most recent year of growth was recorded as 2018 for all samples where bark was present and was used as a reasonable approximation of age. The R (R Core Team, 2016) and dplR package (Bunn, 2010) were used to generate a linear regression model and BAI formula that calculates average growth during growing season and age of specimen with the respective standards deviations.

Results

The specimens located in the unmaintained site had a higher mean DBH and age than the trees in the thinned portion (Table 1). The unmaintained standard deviation for age was significantly less than the specimens in the thinned site, while the thinned site resulted in significantly less standard deviation in average DBH (Table 1). The height of the trees in the unmaintained and thinned sites did not practically vary (Table 1).

Table 1. Sample size and descriptive statistics of readable increment core by location.

species	site	DBH (cm)	age	height	n
Q. macrocarpa	unmaintained	76.3 (20.5)	117.5 (6.4)	55.4 (11.5)	4
Q. macrocarpa	thinned	51.7 (10.4)	79.8 (20.5)	54.8 (15.0)	4
Q. macrocarpa	combined	64.0 (19.9)	98.8 (24.7)	55 (12.3)	8

Note: Standard deviation is shown in parenthesis.

The calculated mean BAI for all sample trees shows an upward growth trend over the study period (Figure 4).

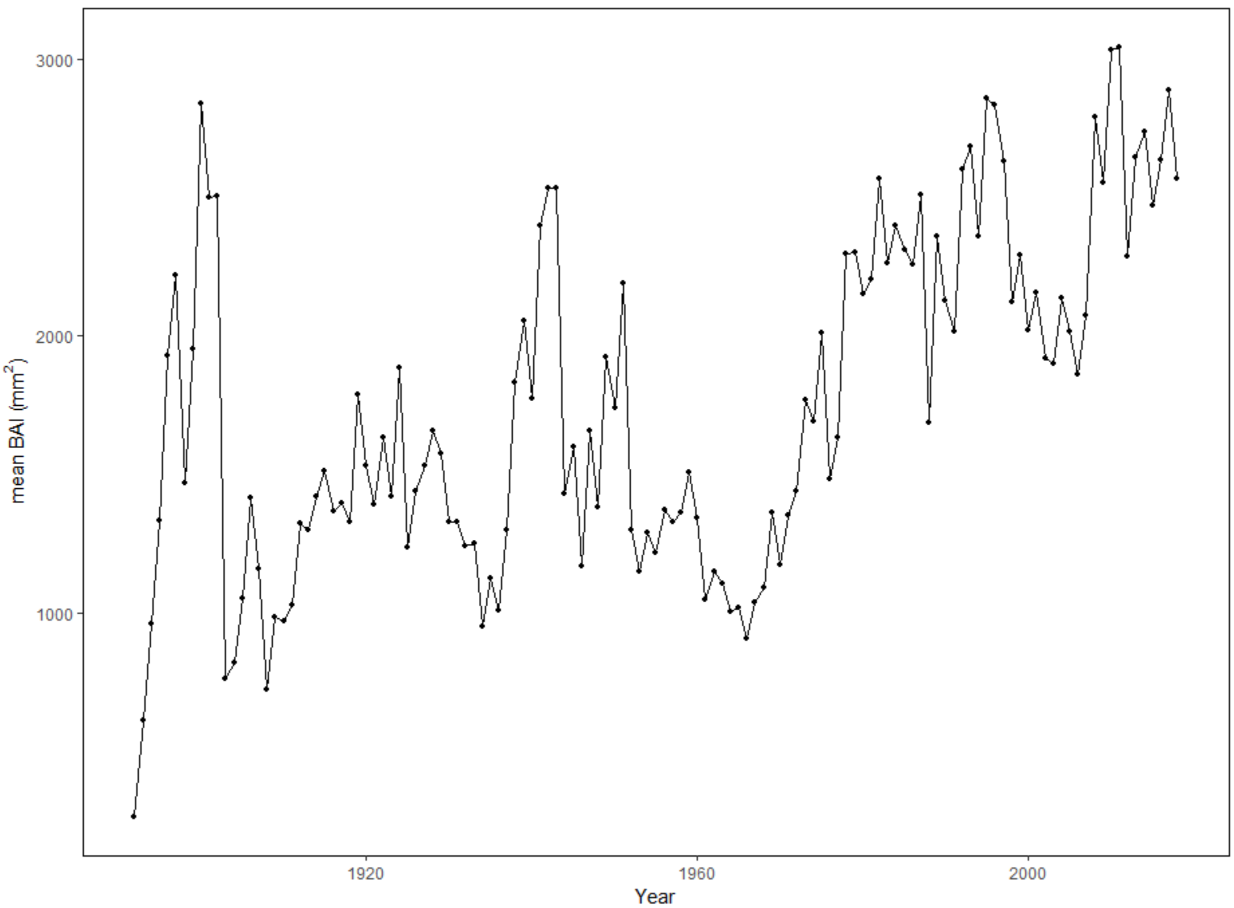

Figure 4. Growth trends in basal area increment (BAI) over the study period.

A comparison of mean BAI between sites shows that the unmaintained specimens had a greater average BAI than those growing in the thinned site when age was not taken into consideration (Figure 5).

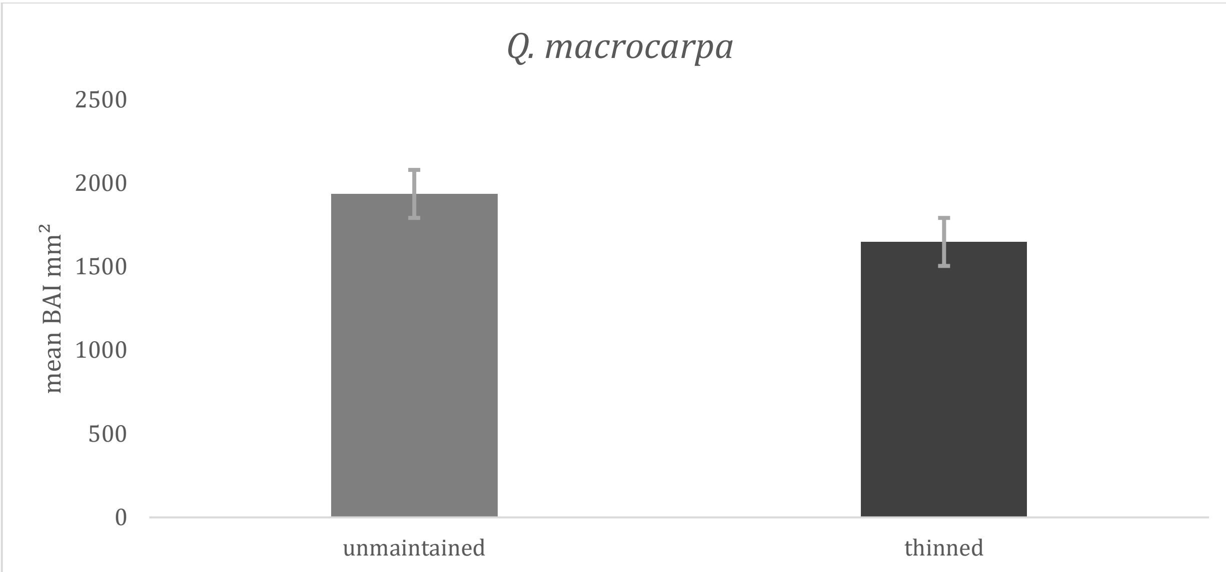

Figure 5. Comparisons of modeled basal area increment (BAI) by site. Error bars indicated one standard error. The graph was generated assuming the last visible ring represented the first year of growth for all samples.

The effects of PDSI on mean BAI were statistically significant ($p < 0.00352$), with mean BAI decreasing in drier than average years and increasing in wetter than average years (Figure 6). Mean BAI increased or decreased by approximately 46 mm^2 for every one unit change in PDSI and mean BAI increased by approximately 16 mm^2 for each year of growth (Table 2). Tree age had a positive effect on mean DBH and mean BAI (Table 1; Table 2). Approximately 18.65% of the variation in the mean BAI is explained by PDSI and tree age (Table 2).

Table 2. Model coefficients and statistical significance.

Variable	Coefficient
intercept	1035.512 (79.772) ***
age	15.763 (1.323) ***
PDSI	45.661 (15.596) **
unmaintained	-63.721 (86.78)
adjusted R-squared value	0.186

Note: Standard deviation is shown in parenthesis.
Significance codes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

The mean BAI response to growing season mean PDSI shows a higher average in annual increase of BAI in the thinned site controlling for tree age (Figure 6).

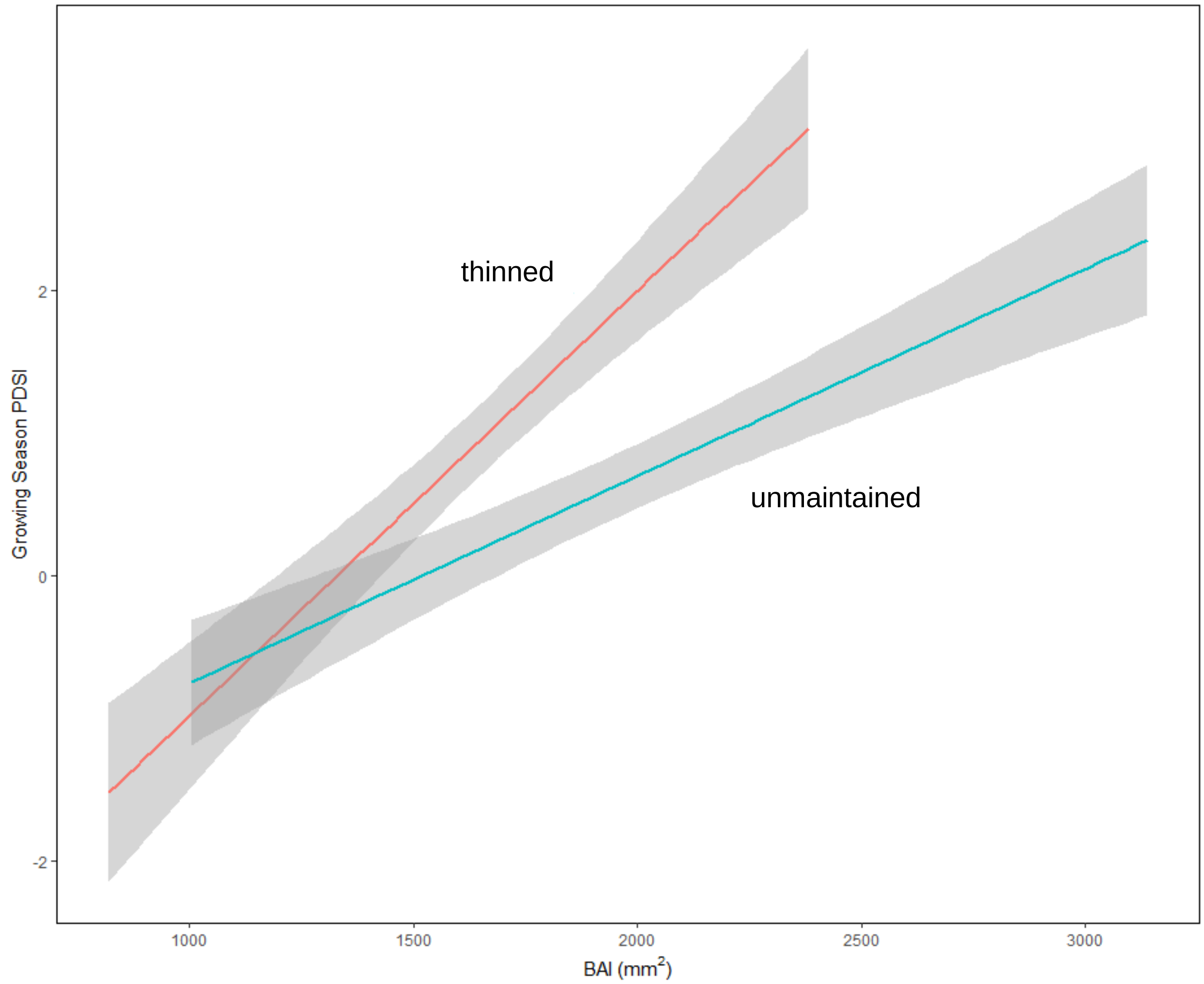

Figure 6: Mean BAI response to growing season mean PSDI in thinned versus unmaintained sites when considering the age of the sample trees. The blue line represents the trees in the unmaintained site, the red line represents the trees in the thinned site. Note: confidence interval is shown in grey.

Discussion

The mean DBH positively related to mean BAI and indicated that the trees sampled in the unmaintained site had greater values than the trees sampled in the thinned site when not accounting for age (Table 1; Figure 5). However, the model generated using linear regression accounts for age as a variable affecting annual growth and shows that the trees sampled in the thinned site had a greater increase in annual BAI than trees in the unmaintained site (Table 2; Figure 6). BAI may be influenced when the balance of competition for resources is interrupted in a site with a higher density of vegetation and may result in reduced availability of essential nutrients, lower annual BAI growth and limited carbon sequestration.

The calculated BAI suggests that trees in an unmaintained site will show a decrease in annual BAI growth and implementing management techniques can positively impact tree growth. This is reflected in the study done by S.F. Gingrich (1971) which found that oak stands tend to have sufficient stocking but are deficient in high-quality trees and thinning such stands may increase the quality and enhance net BAI growth. The decision to thin or not depends on the quality and density desired for a given stand (Gingrich, 1971). A thinned stand with reduced canopy coverage increases the amount of sunlight that reaches the forest floor and stimulates the growth of herbs, forbs, legumes and other herbaceous plants used by wildlife (Forestry, 2019). Thinning also increases the amount of available browse, produces temporary nesting cover from the tops of cut trees, and increases potential mast production providing essential nutrients for wildlife (Forestry, 2019). The purpose of Wachiska Woods is to provide high-quality habitat for wildlife and implementing forest management practices such as thinning has the potential to provide various benefits to wildlife and stand health.

The effects of available soil moisture on annual growth of *Q. macrocarpa* in Wachiska Woods indicated that mean BAI is directly related to mean PDSI, decreasing in drier than average years and increasing in wetter than average years (Figure 3). The Great Plains region experienced a decrease in precipitation from the late 1800's through the dust bowl years of the mid 1930's (Andresen, Hilberg, & Kunkel, 2012) and is reflected in the core samples collected in Wachiska Woods. The fluctuation in precipitation directly impacted the average BAI of sampled trees within Wachiska Woods. The study of dendroclimatology can use this information to construct regional chronologies of climatic events and potentially provide valuable information for future climatic predictions (Fritts, 1971).

The limitations of this study are that only one environmentally limiting factor affecting annual tree growth was taken into consideration with approximately 18.5% of the variation in mean BAI being explained by PDSI and tree age (Table 2). Environmental factors such as temperature, available sunlight and soil composition have the potential to impact annual tree growth and are impacted by competition for resources. A reduction in photosynthesis due to structural deformities below ground may also hinder a trees ability to uptake nutrients and decrease annual tree growth. In order to increase the accuracy of the study recording more measurements and site observations may provide information on other contributing variables affecting average annual growth (i.e. trunk flare, height to lowest branch, second core sample, ground cover, proximity of surround trees).

Conclusion

The objectives of this research were 1) to determine the impact of available soil moisture on the annual growth of Q. macrocarpa in Wachiska Woods, 2) determine the extent the effect of management practices have had on *Q. macrocarpa* annual growth. This study indicated that available soil moisture directly impacts mean BAI in the Wachiska Woods study area (Figure 6). These results are consistent with current understanding of tree biology and are reflected in the results found by Heilman et al. (2017) showing that tree growth is strongly linked to summer drought severity which can negatively impact tree-ring growth.

In calculating mean BAI, the trees located in the unmaintained site showed greater values than those in the thinned site (Table 1; Figure 5). However, when accounting for age as a variable the trees in the thinned site had greater mean BAI than those in the unmaintained site

(Table 2; Figure 6) indicating that management practices have an impact on mean BAI. These results are consistent with current understanding of tree biology and are reflected in the study done by S.F. Gingrich (1971) which found that oak stands tend to have sufficient stocking but are deficient in high-quality trees and thinning such stands may increase the quality and enhance net BAI growth.

If future research were to be conducted in Wachiska Woods a greater sample size would help to further understanding the impact of climate on annual tree growth. It is important to note that carry capacities are unique to individual ecosystems and management objectives should address the potential impact of drought stress on tree growth to determine an appropriate thinning regime that will reduce stand density and competition for resources and essential nutrients. Implementing this technique has the potential to increase annual BAI and improve environmental quality by maximizing carbon sequestration.

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