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Growth of Red Oaks in the Bottomland Hardwood Forests and Response to the Potential Climatic Conditions in Arkansas

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Abstract

Bottomland hardwood (BLH) forests have shown high potential for producing climate-smart commodities including C sequestration and storage, wood products, wildlife, and other ecosystem services. Among the most important tree species in BLHs are red oaks, which provide abundant food for wildlife, and lumber and veneer for the production of high-quality furniture, flooring, wine barrels, and other products. Mast production of bottomland oaks is desired by managers for enhancing wildlife habitat and high-quality wood. In addition, as natural and primary hardwood forests become increasingly scarce and are protected for conservation purposes, a dominant amount of hardwood timber has come from second growth and plantations. Plantations will become increasingly important in timber supply and producing other climate-smart commodities/services (i.e., C sequestration) in the near future. This calls for the exploration of forest growth models that help estimate, with high accuracy, the growth and stem profile of BLH plantations, as well as to test their capacity to adapt to the projected climate conditions. Our main findings revealed that there was no significant difference in diameter at breast height for trees within plantations in our study, whereas a significant difference was observed in total height, wood density, and stem profile. Red oak species are also well suited to implement more conservation/restoration practices (i.e., tree planting) to conserve the BLH forests even with the possibly increasing temperature and precipitation.

Keywords:
Red Oaks; Cherry bark Oak; Nuttall Oak; Shumard Oak; Mississippi Alluvial Valley; Climate Change

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Introduction

Bottomland hardwoods (BLH), also known as floodplain forests, are predominantly found in the southeastern United States, with the Mississippi Alluvial Valley (MAV) historically containing the highest concentration of BLH [1]. BLH forests are composed of various species of Gum (*Nyssa sp*.), Oak (*Quercus sp*.), and Bald Cypress (*Taxodium distichum*) and exhibit distinct characteristics that foster high levels of productivity and ecological diversity [2,3]. The significance of these forests extends beyond their intrinsic ecological value, providing valuable ecosystem services, such as carbon sequestration, water quality regulation, flood mitigation, provision of habitat for numerous plant and animal species, timber production, and recreational opportunities. BLH ecosystems face various challenges, including habitat fragmentation, land-use changes, and altered hydrological regimes due to human activities and climate change.

BLH forest once occupied almost 25 million acres of the MAV but declined to 6.6 million acres by the 1980s; in Arkansas, BLH acreage suffered a 65% decline [4,5]. Since then, numerous governmental policies have been implemented to restore BLH forests through reforestation such as the Conservation Reserve Program and the Wetland Reserve Easement (previously known as the Wetland Reserve Program) [6]. Oaks represented 78% percent of all planted species particularly, the red oaks species were part of typical reforestation projects [7,8]. Red oaks, such as Cherrybark oak (*Quercus pagoda Raf*), Shumard oak (*Quercus shumardii Buckl*), and Nuttall oak (*Quercus texana Buckley*), hold significant ecological and economic importance. They were given priority during planting because of their importance for wildlife species (e.g., waterfowl, deer, and turkey), especially as a food source via mast production, as well as possessing high timber value [9].

The impact of climate change on forests is ongoing and will continue to persist [10]. In the U.S. South, the evidence of climate change consists of warmer winters, dryer summers, and increasing droughts [11]. In Arkansas, specifically, climate change threats to forest resources encompass various aspects, such as potentially affecting adaptability to change, carbon sequestration capacity, forest regeneration, and vulnerability to catastrophic wildfires [12].

Efficient conservation and management strategies are essential to protect and sustainably utilize red oaks. Tree growth modeling has been explored as means to improve the understanding of red oak species' projected development and climate change resilience [13-15]. Tree growth models serve multiple purposes, with predicting and forecasting the development of forest stands over time, informing forest management decisions, and assessing the potential impacts of climate change on forest ecosystems being among the most prevalent applications. However, the availability of precise growth and yield models for oak trees is restricted when compared to other species, such as pine [16]. There is also a lack of information concerning the development of young oak stands, such as those prevalent in restoration sites. Further, modeling stem profiles can enhance the precision of growth and yield estimates, all the while offering valuable insights into the attributes of individual trees and entire forests. These limitations have hindered the advancement of effective strategies for BLH restoration and management, especially when climate change considerations are not considered.

This short communication aims to summarize the findings of three studies conducted by Mhotsha, Tian et al., and Choi et al. to estimate tree growth models, stem profile models, and growth response to climatic conditions of red oak species in Arkansas [13-15].

Study Site

The majority of Arkansas' forest is comprised of hardwoods, with BLH forests covering 16% of the state’s forestland area [17], primarily in the MAV [12]. Mhotsha, Tian et al., and Choi et al. calculated growth estimates using red oak trees from a 30-acre BLH plantation site located in the MAV (Figure 1) [13-15]. The plantation was established in 2004 with three species: Cherry bark oak (*Quercus pagoda Raf*), Shumard oak (*Quercus shumardii Buckl*), and Nuttall oak (*Quercus texana Buckley*). The site consisted of a retired soybean agricultural land enrolled in the Conservation Reserve Program.

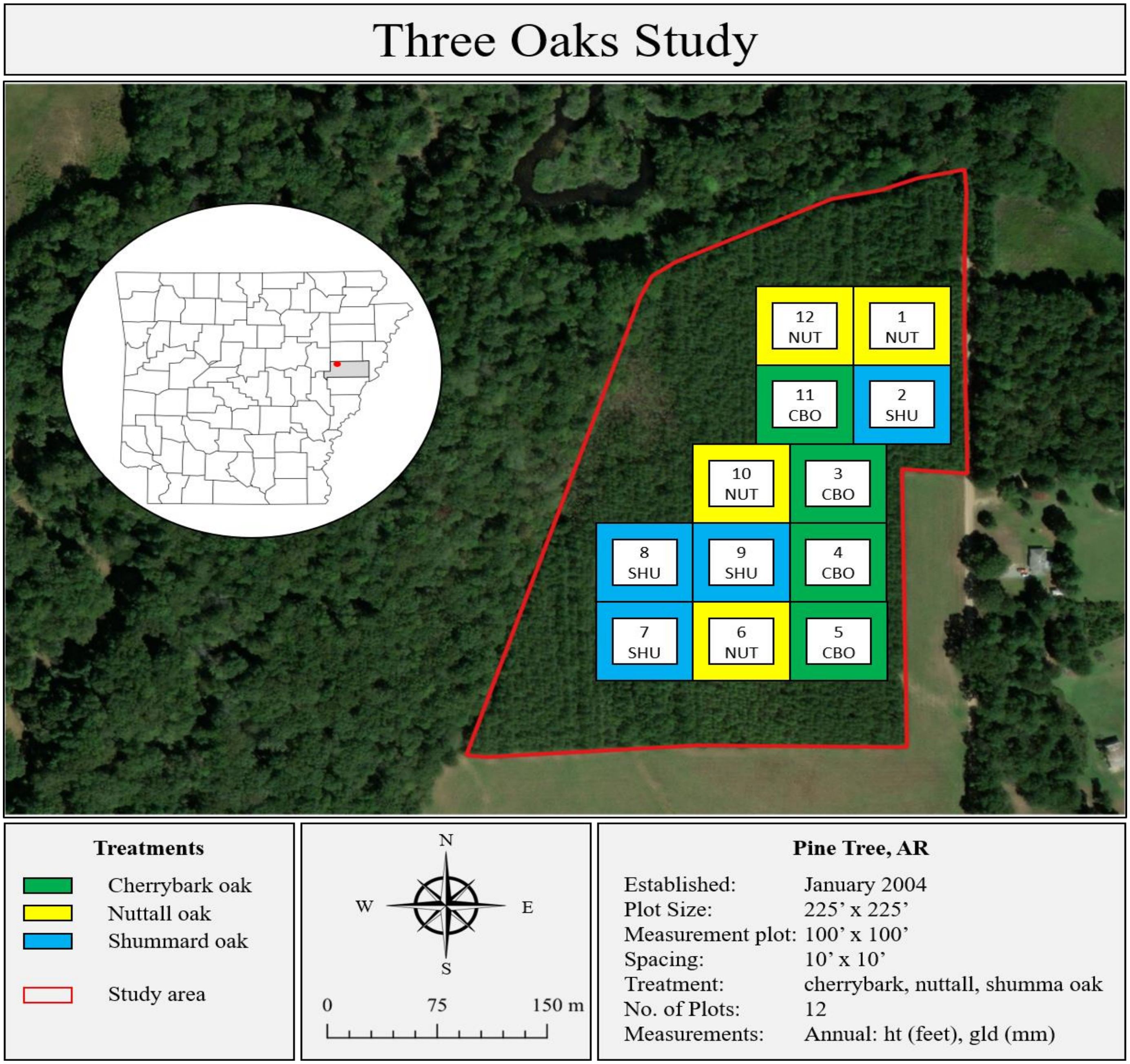

Figure 1: The study site location and the layout of the measurement plots with all three oak species (CBO – Cherry bark oak, NUT – Nuttall oak, SHU – Shumard oak) located in the Division of Agriculture Pine Tree Research Station (AgPTRS) in the Arkansas Delta.

Tree data collection was conducted via the destructive sampling approach. Sixty randomly selected oak trees, 20 per species, were harvested from the study site in 2020. Pre-felling tree measurements included height and diameter at breast height (DBH). Post-felling tree measurements consisted of diameter-outside-bark (DOB) and diameter-inside-bark (DIB). The felled stems were cut into 6 feet cross-sections, and DOB and DIB were recorded at the lower and upper end of each section. Disks of 1-2 inches in thickness were also extracted from both ends and used for further laboratory analysis to determine wood density and tree age (count of rings).

Growth Models Fitting

To examine the variations in DBH, total height, and wood density among three oak species, Tian et al. utilized the ANOVA analysis and found that there was no significant difference in DBH, while a significant difference was observed in terms of total height and wood density [14]. Specifically, Cherry bark oak exhibited greater height and higher wood density compared to Shumard and Nuttall oaks [13,14].

Mhotsha employed a series of individual-tree growth models to determine the best fit to predict the relationship among tree age, diameter, and height [13]. These models included the Chapman-Richard model, the Power model, and the Exponential model. The modeling outcomes indicated that the Chapman-Richards model exhibited the best fit for diameter growth across all species, while the Power model demonstrated the best fit for height growth [13].

Stem profile modeling using taper equations is a common procedure to describe changes in stem diameter with height. Several taper functions exist, including simple, variable, and segmented polynomial models along with their derived sub-models and form-class models, each with its advantages and disadvantages (discussed in [14]).Segmented polynomial profile models have been used particularly to effectively fit hardwood species stem profiles [18,19].

Tian et al. [14] fitted and compared seven taper models which covered the segmented-profile model, form-class profile model, and second-and third-order polynomial model for the three red oak species collected from the hardwood plantation using destructive data analysis. The models ran included those proposed by Max and Burkhart [20], Cao [21], and Clark et al. [22], and the estimated parameters were DOB and DIB. A comparison of the seven models indicated that their performance varies based on the tree species. Among the different models considered, the segmented polynomial model of Clark et al. [22] exhibited the best fit for both Cherry Bark and Nuttall Oaks. However, when it came to Shumard oak, particularly in terms of DIB, the form-class model of the third-order polynomial provided the best fit. As previously noted, the species of the trees may play a significant role in the variation in stem form and modeling performance.

Growth Response to Climatic Conditions

To estimate red oak's response to current and future climatic conditions, Choi et al. retrieved historical (years 2005-2018) and projected (years 2020-2099) climate data of temperature and precipitation from the NOAA'S Applied Climate Information System (ACIS) using the corresponding coordinates of the study site. Climate information generated included monthly average, maximum, and minimum temperature and total monthly precipitation.

Using log-linear regression analysis, Choi et al. [15] examined the relationship between the annual radial growth rate of tree rings and climatic variables and concluded that despite the anticipated climate change, all three red oak species appear to be well adapted to the region. The growth response to climatic conditions is better explained using different critical time windows when the measures of temperature (e.g., average, maximum, and minimum) and precipitation affect tree growth the most. The authors identified four critical windows and their expected correlation to the radial growth rate. For instance, increases in the average temperature during October and minimum temperature between December and January promotes a radial growth rate. On the other hand, the increase in the maximum temperature between January and August and the increase in the total precipitation between April and July reduce the tree's radial growth rate. Overall, the projected climate change in terms of temperature and precipitation is likely to create slightly more favorable climatic conditions for the three red oak species in this bottomland hardwood region. Therefore, the findings included in this study suggested that red oak species are well suited for the study region to implement more restoration/conservation practices (such as oak tree planting) to conserve the BLH forests, especially with a future changing temperature and precipitation.

Management Implications

BLH forests in the United States are critical ecosystems that provide a wide range of ecological, biodiversity, and socioeconomic benefits. Addressing conservation challenges and implementing sustainable management practices are paramount for preserving their functionality. This summary contributes to the understanding of appropriate growth models to estimate the growth rate and stem profile of young oak trees in the MAV, as well as to provide light on the suitability and resilience capacity to the projected climatic conditions. Of note, considering that data collected for the studies summarized above comes from an even-aged plantation within a single geographical site, heterogeneity in terms of tree age and site conditions is not accounted for. Therefore, extrapolation of results should be conducted with caution.

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