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Stand dynamics of an oak woodland forest and effects of a restoration treatment on forest health

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ABSTRACT

Woodland restoration has been conducted in many countries, primarily in Mediterranean regions, but has only recently been attempted on publically and privately owned lands in the eastern United States. We reconstructed historical stand dynamics and tested the immediate effects of an oak (*Quercus*) woodland restoration treatment on forest health, inferred from tree-ring widths (TRW). The stands were upland white oak (*Q. alba*) and chestnut oak (*Q. prinus*) dominated and were located on the Cumberland Plateau of eastern Kentucky, USA. The stands regenerated primarily under a severe disturbance regime concurrent with peak industrial logging approximately 100 years ago. A relatively high percentage of trees (38 percent) recruited under large canopy gaps or clearings, indicative of a severe disturbance; however, gap-phase dynamics was also an important process in oak recruitment to the canopy. Primarily small (<31 cm DBH) and young (<110 years old) trees were removed during the restoration treatment, and mean DBH of residual trees was 13 cm larger than harvested trees. Residual trees were 22 years older than harvested trees, but this difference was not significant. The largest and oldest trees represented important legacy trees that could provide desirable forest biodiversity attributes. Residual trees had larger TRWs than harvested trees, beginning in the 1930s, and these differences increased over time. Residual trees also had larger TRW during two recent drought events (1986 and 1999), but recovery following drought was similar between residual and harvested trees. Managers can use well established silvicultural techniques to obtain desired stand structural conditions, while selecting healthy trees that have better response to stress factors such as drought. The oak woodland restoration treatment may help to maintain residual overstory trees until oak regeneration can be recruited to provide sustainability towards the next generation.

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1. Introduction

Forest restoration is a management goal for many public and private forest land owners throughout the world where long-term sustainability and resiliency are important targets (Stanturf, 2015). Restoration has been an evolving concept in which terminology and goals are sometimes debated, but it is generally agreed that forest restoration requires the implementation of silvicultural practices (Dumroese et al., 2015; Stanturf, 2015). Restored oak woodlands is a desired future condition in many southeastern forests of the U.S., with specific restoration goals and objectives included in Land and Resource Management Plans for national forests of the USDA Forest Service (2004a–c), for management coalitions involving Non-governmental Organizations (NGOs) such as the Nature Conservancy (USDA Forest Service, 2015), and for state agencies (Vander Yacht, 2013).

A woodland has been defined as having an oak dominated overstory, a sparse midstory and understory, and diverse ground flora (Dey et al., 2016). Open-structured oak woodlands were historically important throughout the world, particularly in Mediterranean climates (Roche et al., 2012; Selvi and Valleri, 2012; Schaich et al., 2015), but were also widespread in the temperate zone of the Midwest and Central Hardwood Region of the United States (Fralish et al., 2000; Dey et al., 2016). Oak woodlands in the US have been reduced in extent since European settlement, and fire was an important historical process in these ecosystems (Ryan et al., 2013). Fire alone will typically not restore open woodlands, however, if overstory tree density is relatively high (Arthur et al., 2015; Brose, 2014). The oak woodlands of the southern Appalachian region in the USA probably occurred on sites with specific

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edaphic qualities that limited available soil moisture, such as shallow, rocky soils, but the historical spatial and temporal extent of oak woodlands in the region is relatively unknown (Matlack, 2013).

Tree-ring analysis (i.e., dendrochronology) is a robust tool that can be used to understand current forest conditions, causes of degradation, and in development of realistic end points or targets for restoration. Dendrochronology augmented by field measurements can be used to test for desirable indicators of restoration, including a diverse stand age and size structure, tree growth, and diverse species composition (Hart et al., 2012; Anning et al., 2014; Haavik et al., 2015; Pach and Podlaski, 2015). Tree-ring growth rates can be used to infer overall forest health conditions because they correlate well to survival following stress events, such as drought or insect attacks (Pederson, 1998; Voelker et al., 2008; Haavik et al., 2015).

Silviculture, applied through commercial timber harvesting, can provide a cost-efficient and ecologically effective way to initiate the process of restoring oak woodland habitat by reducing stand density while retaining healthy oak trees (Dey, 2014). However, management effects of restoration treatments on desired ecological conditions, such as improved forest health, have gone relatively untested. While thinning or other silvicultural practices improve tree growth for timber (Gingrich, 1970), these same practices can be applied to meet restoration goals, such as improving resiliency or adaptability to impending threats such as insect attacks, drought, or climate change (Dumroese et al., 2015).

A landscape-scale (approximately 1300 ha) study was implemented in eastern Kentucky, USA in 2004, under the auspices of the 2003 Healthy Forest Restoration Act, as part of the Daniel Boone National Forest Management Plan (USDA Forest Service, 2004a). The study was designed to examine how various silvicultural treatments may enhance resiliency of oak dominated forests to impending forest health concerns, including oak decline and threats from exotic invasive pests (Schweitzer et al., 2014). One of the silvicultural treatments in this study included restoration of putatively degraded closed-canopy forests to open oak woodland habitat using commercial timber harvest followed by prescribed fire. Early field data indicated that the initiation (i.e., commercial timber harvest) of the woodland restoration treatment increased oak dominance and crown vigor, but questions remain about the health and potential resiliency of residual trees once prescribed burn treatments are implemented.

In this study, we reconstructed stand history and examined effects on forest structure and tree health due to an oak woodland restoration treatment using the dominant canopy species, white oak (*Q. alba* L.) and chestnut oak (*Q. prinus* L.). This forest has not yet been impacted by exotic insects, but other disturbances that affect forest health have occurred, including drought. The objectives of our study were to (1) reconstruct historical temporal dynamics of white oak species using dendrochronology to better understand forest development and conditions prior to the restoration treatment, and, (2) to determine the immediate impact of the oak woodland restoration treatment on indicators of forest resiliency and adaptability. For objective two, we compared and contrasted harvested and residual trees for differences in (a) age and size structural attributes, and (b) health inferred from past tree-ring growth.

2. Methods

2.1. Study site

The study took place on the Daniel Boone National Forest, London Ranger District, Kentucky, and the oak woodland restoration treatment was replicated in 6, 10 ha stands throughout the forest as previously described in Schweitzer et al. (2014). The oak woodland restoration treatment was initiated in 2007 by commercially harvesting 40–60 percent of trees $\geqslant$13 cm diameter at breast height (DBH) to obtain a residual basal area of 10–16 $m^2\ ha^{-1}$. Non-commercial trees <13 cm DBH were felled using chainsaws. White oak and chestnut oaks were favored as residual trees, and an objective of the treatment was spatial and vertical heterogeneity. The harvesting treatment was to be followed by prescribed burning every three years beginning in 2010. We randomly selected 5 of the original 20 circular vegetation plots (0.01 ha) described in Schweitzer et al. (2014) from each stand to conduct our data collection.

2.2. Data collection

Prior to restoration treatment in winter 2005, we measured diameter at breast height (DBH) of all white oak (n = 71) and chestnut oak (n = 65) $\geqslant$ 13 cm DBH on each plot in each stand. Each tree was permanently tagged. Cores were collected from each tree using increment borers at breast height (~1.4 m) prior to treatment. Only one core per tree was collected. One year after woodland restoration treatments were implemented (2008), but prior to the first prescribed burn, we tallied residual and harvested trees. Tree cores were not collected following the treatment.

We processed (i.e., mounted and sanded) cores using standard techniques (Stokes and Smiley, 1996), and visually dated each core under a stereo-zoom microscope. We measured annual tree-ring widths (TRW) to the nearest 0.001 mm using a Velmex stage micrometer and MeasureJ2X software. We used COFECHA software for quality control of dating to ensure each ring was dating to the exact calendar year (Grissino-Mayer, 2001). If the pith was not visible, we used graphical techniques to estimate the pith date (Clark and Hallgren, 2004). If visible estimation of the pith was not possible, we used linear regression to predict age from DBH using SAS software (SAS, 2012; Clark and Hallgren, 2004).

2.3. Release chronology development

We excluded 33 cores from tree-ring analysis due to rot, damage, or exceptionally suppressed growth that made tree-ring measurements impractical, for a total of 59 white oak cores and 44 chestnut oak cores used in this study. We identified canopy releases across both species using the radial growth averaging technique, a proven method to detect canopy disturbances in oak species (Nowacki and Abrams, 1997; Rentch et al., 2002). A previous study found a 1:1 relationship between canopy release and percent growth change in ring-width in 55 year old trees (Rentch et al., 2002). We identified a release when the percent growth change between the running TRW mean of the previous and the subsequent 10 years exceeded a certain threshold, but older trees have been found to be less sensitive to release detection (Nowacki and Abrams, 1997; McEwan et al., 2014). Therefore, we lowered the threshold for release detection based on examination of linear regression equations to predict positive percent growth change by age. Although positive percent growth change was not well explained by age, the relationship was statistically significant ($R^2 = 0.01$, $P < 0.0001$),

$$y = 35.70 - 0.21 \times (0.00001 \times Age^3)$$

We used the maximum predicted value for young trees (1–100 years old), and older trees in 50 year age classes to set our lower threshold for detecting minor release events (Table 1).

Major release events were identified as releases with twice the value of the minimum threshold value (Nowacki and Abrams,