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Historic log structures as ecological archives: A case study from eastern North America

Kristen K. de Graauw

Montane Forest Dynamics Laboratory, Department of Geology and Geography, West Virginia University, Morgantown, WV 26505, USA

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ABSTRACT

Forests of eastern North America have undergone abrupt transformations over the last several centuries due to changing land use and climate. Researchers look to pre-settlement forests as a guide for forest restoration, though much of our understanding of composition and dynamics in pre-settlement forests is based on spatially restricted sediment records, few and fragmented old-growth stands in a narrow range of site types, and potentially biased historical documentation. Logs from historic structures hold information that may be useful to forest ecology in eastern North America, but before these records can be used, we must first establish where the logs originated, why they were selected over other trees, and what they can and cannot tell us about past forest ecology. Using a case study approach, I collected data from fifteen log structures in the central Appalachian region to compare construction site locations, species used, and mean diameter of logs through time to determine the ecological biases associated with human behavior in log structure construction. Construction site locations changed from valleys to mountains through time and the species used in construction shifted from *Quercus alba* to a mix of *Quercus alba*, *Liriodendron tulipifera*, *Pinus strobus*, and *Castanea dentata* over time. The diameter of logs used in construction were generally consistent through time, with an average basal diameter of 31.3 cm ($\pm$ 4.7). Mean age of logs increased through time for *Quercus* species, regardless of log diameter. These results suggest the species used for structural logs were selected by their abundance at the location of construction but that as construction site locations and resource availability changed through time, the species used in construction changed as well. While there are biases and limitations of dendroecological data from historic structures, the results presented here demonstrate that structural log data provide greater replication during the early European immigration period, representation of upland (valley) forest sites, and establishment of chronologies for species that are not well represented in current tree-ring chronologies (e.g. *Castanea dentata, Liriodendron tulipifera*). These results suggest structural logs can benefit ecological research by filling the temporal, spatial, and species gaps in tree-ring chronologies not only for the central Appalachian region, but also for other areas in eastern North America.

1. Introduction

Forests of eastern North America have undergone major transformations over the last several centuries due to changing climate and land use. Managers and researchers look to pre-settlement forests as a guide for restoration in modern forests. Thus, it is important to understand forest composition and dynamics prior to extensive human impacts. Much of our understanding of pre-settlement forests is based on sediment records, old-growth forests, and historical documentation (Williams, 1989; Abrams et al., 1995; Foster et al., 1996; Nowacki and Abrams, 1997; Ruffner and Abrams, 1998). While these paleo-environmental sources aid investigations of past processes and interactions between trees, forests, climate, and people (Berglund, 2003; Wick et al., 2003; Marlon et al., 2008; Buntgen et al., 2011), each data source presents unique challenges. Pollen and macrofossils from sediment cores provide long records about shifts in vegetation composition due to climatic and anthropogenic effects at watershed and regional levels (Webb, 1981; Davis, 1983; Delcourt and Delcourt, 1997), but these records are spatially limited to areas with glacial lakes, bogs, and hollows, are taxonomically deficient, and are at best limited to decadal resolution. Tree rings provide annual records of forest disturbance but are often temporally limited by the fading record problem (Bowman, 2007) which is particularly problematic in humid environments where wood decays rapidly. Further, remaining old-growth forests that provide relatively long records of forest change are spatially restricted to steep, often southwest facing, dry, and rocky slopes because of past logging and habitat restrictions of long-lived trees (Stahle and Chaney, 1994; Therrell and Stahle, 1998). Early land survey records and

E-mail address: kkdegraauw@mix.wvu.edu.

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travelers' diaries provide accounts of forest composition, including tree density, dominant species, and disturbance events in pre-settlement forests. However, these contain biases such as misidentification of species, falsified information by surveyors, and preference for witness trees of particular species (Bourdo, 1956; Black and Abrams, 2001; Dyer, 2001; Schulte and Mladenoff, 2001; Bouldin, 2008). When and where they are available, combinations of sediment, old-growth tree, and historical records can provide detailed evidence of past forest composition and dynamics (Spurr, 1951; Howell and Kucera, 1956; Webb, 1981; Davis, 1983; Loeb, 1987; Mikan et al., 1994; Rentch and Hicks, 2005; Wang, 2007), but because these records are spatially and temporally limited, additional sources of pre-settlement forest composition and dynamics could improve ecological understanding in areas under-represented by paleo-environmental data.

The central Appalachian region is one such area in eastern North America that lacks spatially and temporally homogenous ecological data sources. This region is located within the largest contiguous area of temperate broadleaf trees in the world (Hicks, 1998), and is part of the mixed mesophytic Appalachian oak forest, dominated by *Quercus* species such as *Quercus alba*, *Quercus rubra*, *Quercus velutina*, *Quercus coccinea*, and *Quercus montana* (Braun, 1950; Dyer, 2006). With 162 tree species, the mixed mesophytic forest is the most diverse of all forested regions in North America (Dyer, 2006). *Quercus alba*, *Fagus grandifolia*, and to a lesser extent, *Pinus strobus* are found in upland valleys, while *Acer* species, *Fagus grandifolia*, *Tsuga canadensis*, *Prunus serotina*, *Quercus montana*, and *Picea rubens* dominate higher, drier, mountainous areas (Braun, 1950; Thomas-Van Gundy and Nowacki, 2013). Species such as *Liriodendron tulipifera*, *Tilia americana*, *Quercus rubra*, *Pinus strobus*, and *Fraxinus americana* are commonly found in the transitional areas between valleys and mountains. However, modern forests here may be significantly different from the pre-settlement forests that once covered the region, in both species composition and tree density (Abrams, 2001, 2003; Rentch and Hicks, 2005; McEwan et al., 2011). Natural and anthropogenic events have altered forest species composition and density, disturbance regimes, and stand productivity throughout the region over the last several centuries (Stephenson, 1986; Feng, 1999; Brose et al., 2001; McEwan et al., 2011; Pederson et al., 2014a). Current tree-ring chronologies representing the central Appalachian region are both geographically skewed to the south and temporally restricted by a focus on just a few species that reliably reach great ages, making it difficult to study the effects of these changes. An additional data source would improve interpretations of forest change at both the local and regional scale.

Dendroclimatologists often use non-living sources of tree-ring data to study long-term climate variability, including wood from archaeological structures (Zhang et al., 2003; Cook et al., 2004; Buntgen et al., 2011), ancient dead wood in arid regions (LaMarche, 1973; Grissino-Mayer, 1996; Pederson et al., 2014b), and submerged subfossil wood (Stambaugh et al., 2011; Wilson et al., 2011). By combining living and dead sources, tree-ring chronologies have been extended by thousands of years, providing some of the longest tree-ring records of annually resolved climate variability in the world (LaMarche and Stockton, 1974; Briffa, 2000; Esper et al., 2002). While ancient dead wood and submerged subfossil wood are less abundant in eastern North America, there are countless sources of archaeological wood on the landscape in the form of historic log structures. Dendroarchaeological dating of log structures, though relatively new to eastern North America, has resulted in large collections of chronologies (e.g. Stahle, 1979; Bortolot et al., 2001; Wight and Grissino-Mayer, 2004; Grissino-Mayer and van de Gevel, 2007; Robichaud and Laroque, 2008; Henderson et al., 2009; Querrec et al., 2009; Garland et al., 2012; Barclay and Rayburn, 2014). As of yet, these collections have had little application outside of archaeological dating and extending chronologies for climate reconstructions (but see Pederson et al., 2014a).

Structural logs may hold ecological information useful to studies of forest ecology in eastern North America, including records of once prevalent species (*e.g. Castanea dentata*), and could cover a larger temporal and spatial domain than living old-growth trees alone. Further, the trees used for structural logs are unique in that many of them lived and died prior to the Industrial Revolution and contain information about tree growth that is unaffected by the increase in atmospheric CO_2 during the modern period. However, structural logs were likely selected from a forest population limited by the site of construction, the dominant species available at the construction site, and the size (diameter and height) and physiological characteristics of the available trees at that site. Before ecological information can be derived from historic structures, we must assess the potential biases associated with human behavior and why certain trees were chosen for construction.

During early European immigration in eastern North America people selected trees for log structures that were located on or near the construction site (Williams, 1989; Rehder, 2004). Construction sites were often on level terrain and near water sources (e.g. rivers, creeks, springs), as water was the most important resource required by early immigrants when choosing their home site (McRaven, 1994; Caruso, 2003; Rehder, 2004). As populations grew, construction sites were located further from the early settlement nucleus and/or logs were extracted further from the construction site (Williams, 1989; McRaven, 1994). In the central Appalachian region, this often translated into migration from river valleys to higher elevations (Williams, 2001; Caruso, 2003). Logs of similar diameter were particularly important to build level structures (Mackie, 1972). Many structures were constructed so that larger (or denser) logs were on lower levels and smaller logs were on higher levels. This technique was advantageous during a time with minimal construction technology. The most common species used for structural logs in eastern North America were *Quercus* species, though there were exceptions dependent upon the location of the structure and the dominant forest species in that area (Table 1). *Castanea dentata*, once found throughout the Appalachian region (Fig. 1), was frequently used in construction as well (Wigginton, 1972; McRaven, 1994). Over time the availability of species for construction changed as resources were used (Rehder, 2004). Human behavior greatly influenced the ecological information that is now archived in historic log structures.

Here I test three important assumptions about the reliability of ecological information in historic log structures using a group of fifteen structures from southeastern West Virginia. I ask the following questions: 1) What are the human behavior-related biases of log structure construction? 2) How will these biases limit or affect ecological information held within historic logs? 3) What types of ecological studies might historic logs serve? The goal of this case study is to carefully consider associated biases and limitations of structural log data and to provide a framework for further use of historic logs in ecological studies.

2. Study area, history, and materials

Southeastern West Virginia (Fig. 2) is located at the convergence of the Appalachian Plateau, Allegheny Mountain, and Ridge and Valley physiographic provinces. Pre-settlement forests of West Virginia were estimated to cover 15.5 million acres, and by the early 1900's only 1.5 million acres of uncut forests remained (Brooks, 1911). Modern forests of West Virginia are smaller, have different spatial coverage, and have lost dominant species and individuals due to pathogens and changing species composition (e.g. *Castanea dentata, Quercus alba*) (Braun, 1950; Woods and Shanks, 1959; Russell, 1987; Abrams and McCay, 1996; Abrams, 2003; Rentch and Hicks, 2005; McEwan et al., 2011). I selected this region for a case study because it provided a) numerous log structures from the early immigration period to the cessation of log built structures (approximately 1750 − 1900) that had not been previously tree-ring dated, b) a location that, while heavily forested during the early immigration period, has undergone extensive land