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The use of witness trees as pyro-indicators for mapping past fire conditions

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ABSTRACT

Understanding and mapping presettlement fire regimes is vitally important for ecosystem restoration, helping ensure the proper placement of fire back into ecosystems that formerly burned. Witness trees can support this endeavor by serving as pyro-indicators of the past. We mapped fire-adapted traits across a landscape by categorizing trees into two classes, pyrophiles and pyrophobes, and applying this classification to a geospatial layer of witness-tree points centered on the Monongahela National Forest, West Virginia. A pyrophilic percentage was calculated for each point and spatially extrapolated via ordinary kriging to form a continuous geospatial cover. Regression analyses showed pyrophilic percentage was significantly related to a number of key environmental factors and changed along an elevation gradient from low, dry valleys (high pyrophilic percentage) to high, wet mountaintops (low pyrophilic percentage). This approach represents a significant advancement through the direct use of witness trees to depict past fire regimes applicable to both Public Land Survey and metes-and-bounds records.

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1. Introduction

Ecosystem restoration is predicated on documenting past compositions, structures, and spatial patterns within and across landscapes (SER, 2004). Even though vegetation characteristics are crucial for establishing reference conditions and restoration goals, the underlining disturbance regimes that profoundly shape ecosystems and vegetation expression are often overlooked. Indeed, re-establishing former disturbance regimes, i.e. returning natural flows/hydrologic pulses back to rivers (Postel and Richter, 2003) or fire back into pyrogenic ecosystems (Nowacki and Abrams, 2008), is vitally important. Since many terrestrial ecosystems are disturbance dependent and have been negatively affected by the disruption/discontinuance of former disturbances (Cowell, 1998; Whitney, 1987; Bond et al., 2004; Bowman et al., 2009), land managers have shifted towards emulating natural disturbance regimes for ecosystem restoration and sustainability (Seymour et al., 2002; North and Keeton, 2008; Long, 2009). By restoring fundamental disturbance processes, the evolutionary environment and basic ecological functions can be re-established, thus leading to the return of historic vegetation conditions.

Direct information for determining presettlement fire regimes in the eastern United States is scarce. Original forests have been greatly modified by European settlement activities, especially through exploitative logging, accidental and deliberate burning, land clearing, and pasturage (Williams, 1990; Whitney, 1994; MacCleery, 1996; Lewis, 1998). This transformation has been so complete that remaining "virgin" forests are few, scattered, and largely unrepresentative of past vegetation types (Nowacki and Trianosky, 1993). Likewise, older trees that may have recorded fire history in their rings are mostly gone. Moreover, even if they did exist, it is questionable whether past fire regimes of low to moderate intensity would be readily detectable through fire scars (McEwan et al., 2007). Vast opportunities exist with paleoecological data (stratigraphic charcoal), however their spatial distribution is geographically unbalanced (skewed to areas with high concentrations of lakes, ponds, and wetlands) with large voids across the east (see Fig. 1 of Hart and Buchanan, 2012). Moreover, charcoal interpretations are imperfect (Higuera et al., 2005) and the high resolution required from the charcoal record for concise fire regime reconstruction is usually not available (Clark, 1988), although there has been marked improvement in these regards (Power et al., 2008). Radiocarbon-dating of soil and cave-alluvial charcoal looks promising for reconstructing past fire regimes, but research is only in its infancy with few studies to date (Talon et al., 2005; Hart et al., 2008; Fesenmayer and Christensen, 2010; Springer et al., 2010). In the absence of such direct evidence, inferences from indirect information sources may be best for scientists and land managers seeking to understand past disturbance regimes.

The recognition that disturbance played a key role in determining past vegetation compositions, structures, and patterns has

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spurred efforts to map fire regimes for restoration purposes (Wright and Bailey, 1982; Pickett and White, 1985; Engstrom et al., 1999). In the United States, pioneering works by Frost (1998) and Schmidt et al. (2002) have been subsequently improved upon by others employing a variety of approaches (Guyette et al., 2005, 2012; Nowacki and Abrams, 2008). The need for higher resolution maps for land management have led to an increasingly sophisticated array of maps combining soils, topography, human history, remnant vegetation, landscape concepts, and local knowledge (Cleland et al., 2004; Schulte and Mladenoff, 2005; Bailey et al., 2007; Thomas-Van Gundy et al., 2007; Stambaugh and Guyette, 2008). This study represents a continuation of these recent advancements, specifically through the use of witness trees as pyro-indicators.

Although many historical datasets lend themselves to establishing reference conditions (Whitney, 1994; Egan and Howell, 2001), witness-tree databases are among the best. This is particularly so for Public Land Survey (PLS) records (Bourdo, 1956; Delcourt, 1976; Schwartz, 1994; Delcourt and Delcourt, 1996; He et al., 2000; Schulte and Mladenoff, 2001; Manies et al., 2001; Black et al., 2002; Bollinger et al., 2004; Anderson et al., 2006; Kronenfeld and Wang, 2007), which provide systematic and detailed witness-tree information (species, size, and distance) for reconstructing past compositions (species frequency) and structures (stand density and basal area). By coupling PLS information with more recent inventories, changes in vegetation conditions can be readily detected (Whitney, 1987; Iverson, 1988; Fralish et al., 1991; White and Mladenoff, 1994; Zhang et al., 2000; Rhemtulla et al., 2007). Although reconstructing historic disturbance regimes has been a minor focus of witness-tree research, literature has been progressively building (Lorimer, 1977; Canham and Loucks, 1984; Whitney, 1986; Seischab and Orwig, 1991; Zhang et al., 1999; Cleland et al., 2004; Schulte et al., 2004; Schulte and Mladenoff, 2005). Most efforts focus on line notes, which denote surveyor entry and exit of disturbed areas (primarily wind- and fire-based), to estimate disturbance attributes such as size, frequency, and return interval.

In the far eastern United States (original 13 colonies), witness-tree data were recorded via the metes-and-bounds system of land measurement. Unfortunately, the manner in which witness-tree data were derived greatly limits their ecological use (Kronenfeld and Wang, 2007). Thus, alternatives are needed to characterize past disturbance regimes using witness trees from metes-and-bounds surveys. To overcome inherent limitations of this survey method, we offer a novel solution where witness tree species are classified by fire relations (pyrophilic or pyrophobic) based on ecological literature. From this classification, a pyrophilic percentage is calculated at each witness-tree point and these percentages spatially extrapolated via ordinary kriging to form a continuous surface. From this pyrophilic percentage cover, we created a new fire adaptation map and compared it a previously published rule-based model (Thomas-Van Gundy et al., 2007).

2. Methods

2.1. Study area

The spatial extent of this study spans the proclamation boundary for the Monongahela National Forest, which covers about 710,000 ha (Fig. 1). National Forest System lands comprise about 371,000 ha of this area; the remainder is held in State, private, or other federal ownership. The study area includes portions of two ecological sections with different geomorphologies and climates: the Allegheny Mountains and Northern Ridge and Valley (Cleland et al., 2005), with most of the study area lying in the former section.

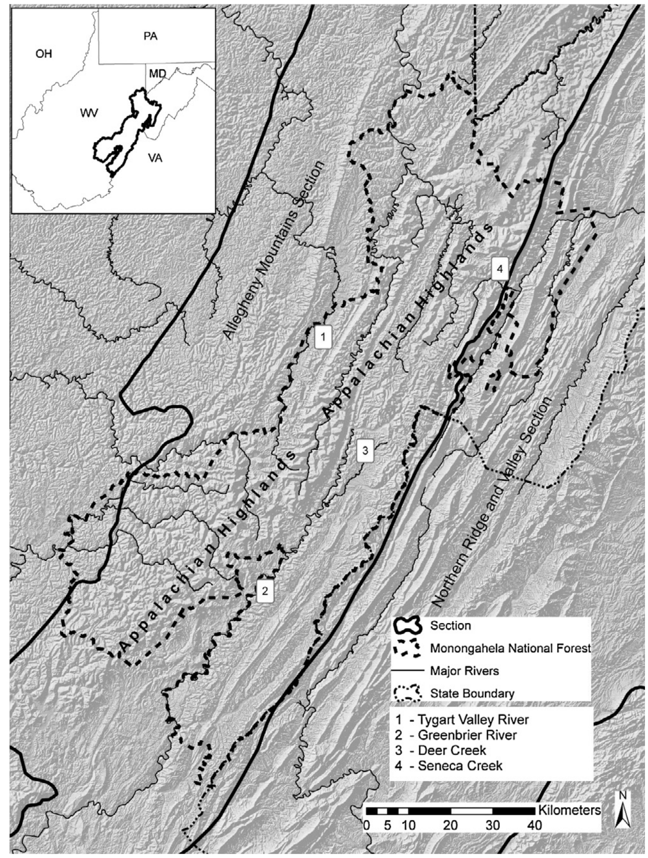

Fig. 1. Study area location showing ecological sections, major rivers, and selected reference points mentioned in the text.

The Allegheny Mountains Section has a wet and cool climate, with 100–138 cm of precipitation per year (about 20% as snow; 30% at higher elevations), an annual average temperature of 8–11 °C, an average annual maximum temperature of 14.5–17 °C, an average annual minimum temperature of 2–4 °C, and a growing season of 126–155 days in the study area (Cleland et al., 2005). The vegetation of the Allegheny Mountains is strongly influenced by elevation, forming four broad zones: oak, mixed mesophytic, northern hardwoods, and red spruce. The lowest elevations (valleys and foothills) are dominated by oaks, which associate with sycamore (*Platanus occidentalis* L.), river birch (*Betula nigra* L.), and various mesophytes along riparian corridors and in floodplains. Upslope, the vegetation transitions into mixed mesophytic forests, which include yellow-poplar (*Liriodendron tulipifera* L.), basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), sugar maple (*Acer saccharum* Marsh.) and northern red oak (*Quercus rubra* L.). The rich, mesic cove hardwoods are diagnostic of this group. The northern hardwood group is found on upper slopes and ridge tops and features sugar maple, yellow birch (*Betula alleghaniensis* Britt.), American beech (*Fagus grandifolia* Ehrh.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and black cherry (*Prunus serotina* Ehrh.). Red spruce (*Picea rubens* Sarg.) forests occur at the highest elevations (above 1000 m) often mixing with northern hardwoods.

Much of the Northern Ridge and Valley Section lies in the rain shadow of the Allegheny Mountains and supports vegetation reflective of drier conditions (Abrams and McCay, 1996; McCay et al., 1997). Annual precipitation ranges from 100–107 cm, although it may be as high as 152 cm near the Allegheny Plateau (Cleland et al., 2005). Annual temperature ranges from 10–12 °C, with an average annual maximum temperature of 17–19 °C, an