Wildfire Hazard and the Role of Tree-Ring Research

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1 Introduction

In February 2009, wildfires raged across 3,900 km^2 in southern Victoria near Melbourne in southeastern Australia, killing over 200 people and destroying more than 1,800 homes, the worst wildfire tragedy in the country's history and worst ever natural disaster (Callinan 2009). Wildfires in Australia are in fact common. The vegetation of the region is well-adapted to frequent fire, suggesting a long history of fires that stretches back for millennia, well before human presence, but the severity with which these series of wildfires struck caught the country (and scientists alike) by surprise. Although several arsonists were arrested and charged, some speculate that climate change contributed to the severity and spatial extent of these wildfires, although this is still a highly debatable topic (Sullivan 2009).

In October 2003, San Diego County in southern California (USA) witnessed three simultaneous wildfires that were the largest and deadliest in the state's history. Sixteen people were killed, 2,400 homes were destroyed, and 1,520 km^2 were scorched. In October 2007, San Diego County found itself again inundated by nine simultaneous wildfires that required the evacuation of 300,000 people and caused the loss of more than 1,800 homes. Nine people lost their lives, 1,500 km^2 were charred, with an estimated cost of over US$ 80 million (San Diego Wildfires Education Project 2009). Up to 2008, the year 2006 is the worst year on record for wildfire activity (not counting prescribed or wildland fire use fires) for the United States when 39,150 km^2 burned (National Interagency Fire Center 2009).

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These events underscore the importance of research that provides background information on the history of wildfires so that land management agencies can develop more informed fire management policies and guidelines that take into account the longer-term perspective available via paleofire reconstructions (Kipfmueller and Swetnam 2001; Willis and Birks 2006). Several means exist that provide this perspective on past wildfires, such as analyzing temporal sequences of charcoal (microscopic and macroscopic) from lake, wetland, and pond sediments (Horn and Sanford 2002; Whitlock et al. 2008) and from soil (Gavin et al. 2007; Hart et al. 2008) coupled with radiocarbon dates. Tree-ring studies also have provided a wealth of information on past wildfires, taking advantage of the ubiquity of potential tree species that record wildfires in their tree rings coupled with the annual and sub-annual resolution available from the tree-ring record.

2 The Tree-Ring Record of Wildfires

The record of wildfires in the tree-ring record has long been recognized as an important contribution to ecosystem studies (Clements 1910; Leopold 1924). In their book *Plant Ecology*, Weaver and Clements (1938) observed that "The time of fire may be determined by counting the number of rings of wood put down since the burn scar was formed. Sometimes the burn scar may be double or even triple and thus give the dates of successive fires." Later studies by Spurr (1954) in Minnesota, Weaver (1959) in Oregon, and McBride and Laven (1976) in California, among others, further laid the groundwork for investigating wildfires based on fire scars. The incorporation of crossdated tree-ring records added a level of accuracy that helped advance the quantification of tree-ring based fire history data in both Europe and the U.S. (Zackrisson 1977; Madany et al. 1982; Swetnam 1983). Another major milestone was the introduction of composite fire interval analysis that used crossdated fire scars from numerous trees in a study site to evaluate the spatial dynamics of wildfires (Dieterich 1980, 1983). Later, Thomas W. Swetnam and the Fire History and Ecology Group at the Laboratory of Tree-Ring Research (University of Arizona) would greatly advance our knowledge of fire regimes in North America and elsewhere (Baisan and Swetnam 1990; Swetnam 1993, 1996; Grissino-Mayer and Swetnam 2000).

Field and laboratory techniques for analyzing wildfires from tree-ring dated fire scars have been documented in many publications (Zackrisson 1977; Baisan and Swetnam 1990; Grissino-Mayer 1999; Kipfmueller and Swetnam 2001). Obtaining dates for past wildfires back centuries and even millennia with annual precision is itself a major accomplishment, but the next revolution occurred in the 1990s with the quantification of fire regimes from tree-ring data. Statistical descriptors of fire activity (such as the Mean Fire Interval) were then already commonplace and important for managing fire-prone ecosystems, but more information was needed on the historical range of wildfire activity (Morgan et al. 1994; Brown et al. 2000). Using more advanced modeling of the fire-free interval data available from tree rings, we now can provide improved descriptors of fire activity in the past, such as the Weibull Median Probability Interval (which is a better measure than the Mean Fire Interval) and the Lower and Upper Exceedance Intervals, which help define the historical range of variation in fire regimes (Grissino-Mayer 1999, 2001; Fulé et al. 2003; McEwan et al. 2007).

Another major advance in tree-ring studies of wildfire activity actually has a long history in dendroecology. Fire scars are found most often in ecosystems where low-severity fires are common. A moderate to higher severity wildfire could kill most or all trees in a stand, especially in ecosystems where wildfire is less common (such as in boreal and subalpine forests) causing a cohort of trees to establish after the fire. Early studies used the age structure of trees to reconstruct the history of fire disturbance in forest stands (Heinselman 1973; Tande 1979). Tree-ring dating can determine (with some small degree of uncertainty) when these trees established, thus allowing a more complete reconstruction of wildfire activity across a broader spectrum of fire severities (Ehle and Baker 2003; Brown and Wu 2005).

Important contributions of tree-ring based fire history analyses concern linkages now being discovered between wildfire activity and climate, especially broad-scale atmospheric-oceanic teleconnections such as the Pacific Decadal Oscillation (PDO), the Atlantic Multidecadal Oscillation (AMO) and the El Niño-Southern Oscillation (ENSO). In the American Southwest, Swetnam and Betancourt (1990) showed that positive phases of the ENSO correlate significantly with a greater percentage of trees scarred. Grissino-Mayer and Swetnam (2000) found that fires were more frequent but less widespread during the Little Ice Age (ca. AD 1400–1800), but less frequent and more widespread during the warmer period that followed. Synchronous positive phases of PDO and ENSO were found to contribute to more widespread fires in northeastern California (Norman and Taylor 2003). In the Pacific Northwest, fires occur more often in dry summers and during positive phases of the PDO, while the percentage of trees scarred showed a significantly positive relationship with ENSO (Hessl et al. 2004). Brown (2006) found that wildfires in South Dakota and Wyoming were synchronous during La Niñas coupled with positive PDO and AMO phases. These and other studies point to clear interdecadal to century-scale forcing of fire activity by climate.

3 Fire History in an Uncertain Future

New challenges face researchers who investigate fire history from the tree-ring record. The first concerns the quickening disappearance of suitable samples for fire history analyses. Ever expanding and intensifying wildfires today are actually destroying the very evidence we need to understand their history. Superimposed on this tragedy is the expanding use of controlled burns (whether prescription or naturally set fires) to help restore degraded ecosystems, which also destroy valuable evidence. Within this backdrop is the steady decay of suitable samples over time. In summer 2009, I revisited a site I had sampled in 1991 in El Malpais National Monument of New Mexico and was astounded how easily the fire history samples we wished to sample crumbled in our hands even before using a chain saw.

Second, we must ask whether restoration of ecosystems is a viable management option given the changing nature of our environment. Many dendroecologists use as one of their justifications the importance of tree-ring based fire history studies for helping land management agencies restore degraded ecosystems where fire has long been purposely excluded. Fire exclusion beginning in the early twentieth century has changed the successional trajectory of nearly all temperate forests and woodlands (sometimes now called "novel ecosystems," Hobbs et al. 2006), to the point that reintroduction of fire could have detrimental (high-intensity stand-destroying fires) rather than beneficial (lower intensity stand maintenance fires) effects. Restoration begs the question: "What are we restoring to?" Environmental conditions seen in 1880? 1600? 1491? Restoration further may not be viable given that future environments will be responding to and evolving in a world dominated by increasing global temperatures, with no guarantee that ecosystem processes (such as wildfire) will operate as they once did (Westerling et al. 2006; Fauria and Johnson 2008).

Third, climate change means change in our forests and ecosystems and the vital processes that operate to shape and maintain them. Many studies have clearly linked changes in past climate with changes in past wildfire activity, including changes in fire frequency, seasonality, severity, and spatial extent (Clark 1988; Balling et al. 1992; Swetnam 1993). What remains uncertain are the fire regimes that could be expected in the twenty-first century given increasing temperatures and the likely accompanying changes in precipitation patterns, as well as the expected but uncertain changes in spatial patterns of rainfall, temperature, and drought across the Earth's surface. Vegetation ranges certainly will not change with the rapidity with which climate is changing, meaning that forests and the disturbance processes that operate within them (including wildfires) will have to accommodate an evolving disequilibrium that could prove detrimental to the health of these forests. For example, fewer fires in western and eastern U.S. ecosystems will cause fire-intolerant species to become more dominant, a successional trajectory we see happening today (Camp 1999; Schoennagel et al. 2004; DeWeese 2007; Nowacki and Abrams 2008).

Curiously, as we head into a more uncertain future, the value of tree-ring based research on fire history and ecology becomes greater, promoting a growing field of inquiry that has increasingly important implications for land management. Between 1920 and 1970, only 30 published studies had investigated the use of tree rings to make inferences on past fire activity. By 1980, this number had more than doubled to 72 studies, to 176 by 1990, and to 433 by 2000. Furthermore, dendroecologists that specialize in fire history are being very efficient at training the next generation of tree-ring scientists, ensuring that this field of inquiry will thrive and continue to benefit society.

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