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ORIGINAL ARTICLE

Dendroecological potential of *Callitris preissii* for dating historical fires in semi-arid shrublands of southern Western Australia

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Abstract

Historical fire regimes in the semi-arid shrublands of southern Western Australia are poorly understood, largely owing to a lack of quantitative historical data. We sought to determine the dendroecological potential of fire-sensitive *Callitris preissii* Miq. trees to date historical fires and extend the length of fire-history data available from remotely sensed imagery. We sampled *C. preissii* trees from known fire areas in the Lake Johnston region in southern Western Australia. Our objective was to assess the capacity to date historical fires using stand establishment date as a proxy measure of time since fire. We measured stem basal diameter and height and collected stem sections of *C. preissii* trees and saplings from five areas that were burnt on known dates between 1974 and 2001. We also sampled older trees (>35 years), which were used to create a master chronology to assist with dating of seedlings and saplings. Tree age could not be reliably estimated from stem basal diameter and tree height, with 95% prediction intervals of more than 17 years. However, we were able to successfully determine tree age and develop a ring-width chronology using standard dendrochronological techniques. The cross-dated chronology showed a relatively high inter-series correlation in ring width ($r=0.63$) indicating consistency in growth rate among samples and sites, while mean sensitivity (0.39) signified high inter-annual variability in ring width. The age structure of *C. preissii* stands revealed consistent recruitment within 1 year of fire occurrence and maximum intra-stand variation in tree age of 4 years. Our results confirm that *C. preissii* has significant dendroecological potential to accurately date past fire events and that this approach will assist in extending fire-history records beyond recent decades for much of southern semi-arid Australia.

Keywords: Recruitment; Tree-ring analysis; Dendrochronology; Allometry; Tree-age estimation

Introduction

Extensive wildfires are natural and common occurrences in many landscapes worldwide and play an important role as modifiers of ecosystem structure and dynamics (Bond and Keeley, 2005; Thonicke et al., 2001). However, historical fire regimes are poorly

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understood in many ecosystems, particularly in semi-arid and arid biomes of the southern hemisphere, largely owing to a lack of quantitative data and limited long-term records. Where historical records are lacking, dendrochronological techniques have often been used to reconstruct spatial and temporal attributes of past fire events (Beniston, 2002; Pearson and Searson, 2002). Dendrochronology-based reconstructions of fire histories usually rely on distinguishing cambial fire scars in the trunks of 'fire-tolerant' tree species and analysing their distribution within and among trees to estimate the date of fire events and their extent within the landscape (Dieterich and Swetnam, 1984; Niklasson and Granstrom, 2000; Beaty and Taylor, 2001; Heyerdahl et al., 2001; Rollins et al., 2004). However, fire-scarred trees are not always available, particularly in environments where fires tend to be stand-replacing and trees are killed outright (e.g. Bergeron, 1991; Kipfmueller and Baker, 1998; Keeley, 2006). In these situations, dendrochronological techniques may be used to examine stand age structure and establishment dates as alternative evidence of fire occurrence and a proxy measure of the age of the last stand-replacing fire (Brown et al., 1999; Floyd et al., 2000; Grau and Veblen, 2000).

Several difficulties have so far limited the use of fire-sensitive tree species for reconstructing fire events. First, the lag in tree establishment following disturbance may be highly variable both within and among stands; hence, establishment dates may represent only the minimum possible age of the disturbance. Second, samples collected at heights above the base of the stem may not include all growth rings, since it may take several years for a tree to reach sampling height. Estimates of tree age from samples taken above the base of the stem may therefore provide only a minimum potential age (Ogden, 1981; Duncan, 1989; Villalba and Veblen, 1997; Wong and Lertzman, 2001). However, lags in stand establishment following a disturbance can be estimated by calibrating stand age against the date of known disturbance events, and the uncertainty of tree-age estimates at sample height can be reduced by calibrating against tree-age estimates from the base of the stem or alternatively, by taking samples from the base of the stem where all years of growth are likely to be represented. Therefore, with calibration, fire-sensitive tree species may provide a useful and accurate data source to confirm and date historical fire occurrence in regions where fire-tolerant (fire-scarring) tree species are unavailable.

Over the last several decades, fire ecology studies have used remote-sensing techniques to reconstruct historical fire regimes (e.g. Minnich, 1983; Minnich and Chou, 1997; Kadmon and Harari-Kremer, 1999; Minnich et al., 2000; Miller and Yool, 2002). While remotely sensed data can be used to accurately reconstruct spatial attributes of fire, the ability to determine temporal attributes (i.e. fire dates) is limited beyond the last several decades owing to large temporal gaps between image dates prior to the beginning of satellite imagery. Dendrochronological techniques may be used in conjunction with remotely sensed imagery to add fire dates to spatial fire maps and extend the temporal length of fire-history data beyond the most recent few decades. Furthermore, the use of remotely sensed images in fire-history research may extend the potential geographic range of dendropyrochronology. Fire data derived using remote-sensing techniques provides the ability to reconstruct spatio-temporal fire patterns for regions such as the chaparral shrublands of California, USA (Zedler, 1995; Keeley, 2006), subalpine forests of the Rocky Mountains, USA (Kipfmueller and Baker, 1998), and the semi-arid shrublands of southern Australia (Bell et al., 1984) where stand-replacing fires are common and therefore only time since fire data can be derived dendrochronologically.

While dendrochronological techniques have been widely used to reconstruct historical fire regimes in the temperate and boreal regions of Europe and North America (e.g. Niklasson and Granstrom, 2000; Stephens et al., 2003; Moody et al., 2006), dendrochronology has received relatively little attention in Australia (Pearson and Searson, 2002). The adoption of dendrochronology in Australia has been hindered by a lack of knowledge regarding suitable tree species and several methodological problems (Ogden, 1981; Brookhouse, 2006). To date, tree-ring research in Australia has included investigations of *Eucalyptus* (Banks, 1987; Burrows et al., 1996; Argent et al., 2004; Brookhouse and Brack, 2006), *Toona* (Heinrich and Banks, 2005) and several coniferous genera: *Araucaria; Agathis* (Dunwiddie and LaMarche Jr., 1980b; Ash, 1983a); *Phyllocladus*; *Athrotaxis* (Dunwiddie and LaMarche Jr., 1980b); *Lagarostrobus* (Cook et al., 1991); and *Callitris* (Lange, 1965; Pearman 1971; Ogden, 1978; Perlinksi, 1986; Cullen and Grierson, 2006, 2009). These studies have mostly focused on the dendrochronological characteristics of these species and the capacity to reconstruct past climates by analysing ring-width patterns.

Few Australian tree species have been examined for their dendroecological utility for reconstructing fire histories. Investigations of the utility of fire-tolerant species for dendroecological analysis have included the monocot grass tree, *Xanthorrhoea preissii* (e.g. Ward et al., 2001; Enright et al., 2005; Miller et al., 2007), and a small number of *Eucalyptus* species (e.g. McBride and Lewis, 1984; Burrows et al., 1996; Brookhouse, 2006). However, methodological difficulties associated with unclear ring definition, intra-annual bands and unreliable scar formation in eucalypts (McBride and Lewis, 1984; Burrows et al., 1996; Brookhouse, 2006), and high frequencies of false positive and false negative fire records in *Xanthorrhoea preissii* (Miller et al., 2007)