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The climate reconstruction potential of *Acacia cambagei* (gidgee) for semi-arid regions of Australia using stable isotopes and elemental abundances

G. Bradd Witt [a, *], Nathan B. English [b], Daniel Balanzategui [c], Quan Hua [d], Patricia Gadd [d], Henk Heijnis [d], Michael I. Bird [e]

[a] *The University of Queensland, School of Geography, Planning and Environmental Management, Brisbane, QLD, Australia*
[b] *Central Queensland University, College of Medical and Applied Sciences, Townsville, QLD, Australia*
[c] *Section 5.2: Climate Dynamics & Landscape Evolution, Dendrochronology Laboratory, Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, Telegrafenberg, D-14473 Potsdam, Germany*
[d] *Australian Nuclear Science and Technology Organisation, Institute for Environmental Research, Lucas Heights, NSW, Australia*
[e] *James Cook University, College of Science, Technology and Engineering, Centre for Tropical Environmental and Sustainability Sciences, Townsville, QLD, Australia*

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A B S T R A C T

To provide multi-centennial, annually-resolved records of climate for arid and semi-arid areas of Australia it is necessary to investigate the potential climate signals in tree species in this large region. Using a stable isotope and x-ray fluorescence approach to dendrochronology in *Acacia cambagei*, this study demonstrates short (10 years) proxies of temperature and precipitation are possible. Because rings in *A. cambagei* are difficult to see, precluding traditional dendrochronology, we used elemental abundances of Ca and Sr as an annual chronometer back to 1962. Radiocarbon analysis confirmed that our dating of wood from two trees. We compared $\delta^{13}C$ and $\delta^{18}O$ from the α-cellulose of the dated wood over the most recent 10 years ($n = 10$) to local climate records demonstrating significant relationships between $\delta^{18}O$ and precipitation ($r = -0.85$, $p < 0.002$); mean monthly maximum temperature ($r = 0.69$, $p < 0.03$); and drought indexes (CRU scPDSI 0.5°, $r = -0.89$, $p < 0.001$) for February and March. *Acacia cambagei* may be useful in developing regional networks of climate proxies for drought. Using modern trees, in combination with architectural timbers, it may be possible to construct a multi-century, annually-resolved proxy-record of rainfall and temperature for semi-arid north-eastern Australia.

1. Introduction

The intense and prolonged dry and subsequent extreme wet intervals in the first decade of the 21st Century in eastern Australia had catastrophic social, environmental and economic effects. Although ‘drought and flooding rains’ are conspicuous features of Australia's climate, this most recent cycle has received considerable analysis in terms of whether it had any precedents and to what extent the influence of anthropogenic climate change may be superimposed on past climate variability (eg. Kirono et al., 2011; Gergis et al., 2012; Timbal and Fawcett, 2013). For much of eastern Australia, climatic variability over the decade 2002 to 2012 exceeded that of instrumental records (largely limited to the period 1890s to present), leading to great uncertainty among pastoralists, insurers and policy makers about what the climate of the future is likely to hold (CSIRO, 2014).

Significant periods of above and below average rainfall have a strong forcing effect on the vegetation structure and composition (stability) of semi-arid environments, affecting their ability to provide agricultural outputs and to conserve environmental values. Indeed the role of past climate cycles are a key component of debate about the stability of vegetation in these regions (Witt, 2013). There is some emerging and anecdotal evidence that the century between 1760 and 1860 was considerably drier on average than the subsequent century (William Landsborough, cited in The Queenslander, 1877; Lough, 2011). There are also a range of forecasted anthropogenic effects that will have an impact on climate (Kirono et al.,

* Corresponding author.
E-mail address: bwitt@uq.edu.au (G.B. Witt).

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2011) and thus the future effects on production and biodiversity are very difficult to predict.

Annually resolved, multi-century climatic reconstructions over several centuries, such as those provided by tree-ring and other chronologies, are required to verify other records and should improve future climate forecasts. Records of past climate change and variability in the semi-arid subtropics of Australia are sparse over the late Holocene and recent centuries (Lough, 2011; Denniston et al., 2013; Haig et al., 2014; Neukom et al., 2014; O'Donnell et al., 2015), yet these unique ecosystems occupy a region impacted by large-scale climate phenomena, including the Sub-Tropical Ridge and El Nino/Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO) and Interdecadal Pacific Oscillation (IPO) variability (Timbal et al., 2010). Although recent dendrochronology research has been carried out in semi-arid and tropical regions of Australia (Heinrich et al., 2008; Boysen et al., 2014; Baker et al., 2008; Cullen and Grierson, 2009; O'Donnell et al., 2015; O'Donnell et al., 2010), most research has tended to focus on high latitude or other environments with distinct growing seasons (see Heinrich and Allen, 2013). Like many other tropical and subtropical regions of the world, native trees in northern Australia frequently do not meet some of the main assumptions of traditional dendrochronological research methods because radial stem growth may occur more opportunistically, rather than seasonally. However, recent traditional dendrochronological studies and advances in analytical methods, particularly the use of elemental abundance of Calcium (Ca) and Strontium (Sr) measurements using X-ray fluorescence (Martin et al., 2001; Poussart et al., 2006) in concert with well-established bomb radiocarbon methods for accurately validating tree-ring ages (Biondi et al., 2007; Hua et al., 2003; Wood et al., 2010; Pearson et al., 2011) and stable isotopic analysis (particularly δ^{13}C and δ^{18}O) techniques, have meant that trees in seasonally-dry and tropical and subtropical environments are attracting attention for their climatic and environmental reconstruction potential (Zuidema et al., 2012; Schollaen et al., 2013). What has shown promise for tree species with difficult-to-detect rings is the non-destructive high-resolution (50–200 μm) identification of growth periods through the analysis of relative elemental abundances of Ca and Sr by micro X-ray fluorescence (via ITRAX scanning technology) (Keunecke et al., 2011; Mannes et al., 2007; Heinrich and Allen, 2013; Hietz et al., 2014). Silkin and Ekimova (2012) have demonstrated annual cycles corresponding with increasing abundance of Ca and Sr in particular.

There are already a number of tree species in northern Australia (see Boysen et al., 2014; Baker et al., 2008; Cullen and Grierson, 2007; Pearson et al., 2011; Heinrich and Allen, 2013; O'Donnell et al., 2015) used for dendrochronological research that show promise in terms of their potential for climate reconstruction. *Callitris* spp. have received particular attention in arid and semi-arid regions (see Heinrich and Allen, 2013). While *Agathis* (Boysen et al., 2014) and *Araucaria* (Haines et al., 2015) have been a focus in northern Australian areas receiving higher rainfall. One species that has not received any formal attention is *Acacia cambagei* (gidgee). This highly drought-tolerant tree occurs across much of subtropical semi-arid eastern Australia and is assumed to be long lived as it can reach diameters of 50 cm. This species is resistant to rot and termites, is salt-tolerant, and is both fire-retardant and fire-sensitive (Bui et al., 2014; Nano et al., 2012). Living *A. cambagei* may reflect climate variability spanning possibly a century or so. *Acacia cambagei* was, and continues to be used extensively in the areas where it grows for building construction. Where the date of construction of historical buildings is known, it is likely that these timbers can increase the ability to reconstruct climate back into the early 1800s, and possibly to the time of European colonisation of Australia. This preliminary study explores the potential of *A. cambagei* to serve as a robust climate proxy through the use of micro XRF, bomb radiocarbon dating and stable carbon (δ^{13}C) and oxygen (δ^{18}O) isotope ratios of tree-ring α-cellulose. The resulting δ^{18}O record is compared to local instrumental climate records to determine its ability to represent past climate in the area. Further research opportunities and dating issues are discussed, however, it does appear that gidgee can assist in climate reconstructions for the large region where it naturally occurs.

2. Methods

2.1. Study location and climate records

The wood used in this study was collected at Ambathala, a grazing property in south-western Queensland (26°02′24″S: 145°21′22″E) in mid-February 2012 (Fig. 1). Conventional core sampling was not possible due to the density of *A. cambagei* (~1283 kg/m^3; Venn and Whittaker, 2003). The growth habit of *A. cambagei* trunks makes it difficult to determine from external observation the internal arrangement of the rings or to identify the 'centre' of the tree (Fig. 2). For these reasons, we felled living trees to examine both the visible rings and their continuity. Many trees in the area have been harvested several times in the past century for construction, fencing, fuel-wood and for thinning to improve pasture production. Cutting was undertaken with the permission of the property owner, and this property has been used for several studies into long-term environmental change in the region in the past decade (Witt et al., 2006, 2009).

Local instrumental precipitation and temperature data from the nearest Bureau of Meteorology recording station at Adavale (approximately 76 km to the west) were compared to stable isotope variation in wood α-cellulose between 2002 and 2011. Ambathala is located in a semi-arid subtropical climate, with the highest rainfall occurring in November through March (40–70 mm/month), also coinciding with the highest temperatures (mean maximum monthly temperature of 21.7 °C). In the winter months, rainfall is generally below 30 mm/month and daily temperatures are still warm (~20 °C). We also used non-detrended 0.5°-gridded (interpolated) temperature and precipitation data set for Australia (CRU TS 3.22) from the Climate Research Unit (University of East Anglia Climatic Research Unit (CRU)) for comparison with the instrumental precipitation and temperature data with the stable isotope records.

2.2. Growth ring identification and dating

2.2.1. ITRAX micro x-ray fluorescence and radiography

Our attempts to visually measure rings on eight sanded and polished *A. cambagei* wood discs failed to reliably identify alternating bands earlywood and late wood. Visual ring measurements were hampered by diffuse porous wood, indistinct ring boundaries, vessels in diagonal arrangements, and in some cases wedging, although this could be avoided in most sections. To investigate the possibility that the variability in isotopic ratios and elemental abundances would provide annual markers, we cut 2 cm wide by 5 mm thick radial lengths from two discs of gidgee wood with the least amount of wedging. Based on visual appearance, site location and ringbarking scars we felt these samples might contain the simplest record of isotopic and elemental variability. Elemental abundances were measured from these two trees using the ITRAX core scanner (Croudace et al., 2006) (COX Analytical systems, Sweden) at the Environmental Radioactivity Measurement Centre located at the Australian Nuclear Science and Technology Organisation (ANSTO, Lucas Heights, NSW). Radial lengths were placed on a Perspex block and optical images taken at 200 μm intervals and