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A new method for dating tree-rings in trees with faint, indeterminate ring boundaries using the Itrax core scanner

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ABSTRACT

Eastern Australia is known to experience multi-decadal periods of flood and drought. Subtropical Southeast Queensland is one region where these devastating extreme events occur regularly yet a full understanding of their frequency and magnitude cannot be determined from the short duration (< 100 years) climate data available for the region. Tree-rings are a potential source of long-term (> 100 years) proxy rainfall information but locating suitable forest stands is difficult due to extensive land clearing by European settlers. Another factor deterring the use of trees as proxy data sources is that longer-lived species frequently contain anomalous rings, particularly faint rings, hindering their use for paleoclimate study. Here we present a method which overcomes the problems of identifying faint ring boundaries in trees by using X-radiographs and density patterns developed on the Itrax core scanner. We analysed 39 tree cores from 20 trees at a site in D'Aguilar National Park located just north of Brisbane city in Queensland, Australia. Each core had a 2 mm lath cut perpendicular to its rings which was then passed through an Itrax core scanner. The tree-ring boundaries were identified on the image by both the visual features in the radiograph and the change in density observed between rings. From this information we developed a tree-ring chronology. The chronology was checked using bomb-pulse radiocarbon dating on five trees to confirm the annual nature of the rings, and to correct dating errors in the chronology due to false rings which are common in this species. Climate response function analysis showed Austral annual rainfall (June–May) was the dominant environmental variable driving tree growth. Finally, a 69-year statistically significant reconstruction of Brisbane precipitation was produced showing that this non-destructive Itrax ring identification technique together with age validation by bomb-pulse radiocarbon dating is useful for dendroclimatological studies of trees with faint ring boundaries.

1. Introduction

Many tropical and subtropical regions of the world lack long-term (> 100 year) climate records. These regions are known to have highly variable climates, specifically in regards to rainfall, with some areas such as the east coast of Australia known to experience multi-decadal periods of drought as well as floods of extreme magnitude (Warner, 1997; Erskine and Warner, 1998; Rustomji et al., 2009). Proxy records that extend back over several hundred years are needed in such regions to understand these decadal climate patterns. Dendroclimatology has been suggested as a possible proxy technique for reconstructing long-term climate records in these environments (Baker et al., 2008; Boysen et al., 2014; Haines et al., 2016). However, to date few tree-ring based studies have been carried out on Australia's east coast (Heinrich et al., 2008, 2009). The main deterrent to such studies is the long-held belief, originating with work undertaken by Ogden (1978), that issues with ring anomalies in Australian tropical tree species make them unsuitable for dendroclimatological investigation. More recent studies have begun to investigate the climate response of some Australian tropical tree species (Baker et al., 2008; Heinrich et al., 2008; Drew et al., 2011) but compared to temperate regions very little work has been undertaken in the tropics and subtropics. Recent reviews on the progress of Australian dendrochronological studies have suggested that multi-technique approaches should allow for both the development of ring-chronologies

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and climate reconstructions (Heinrich and Allen, 2013; Haines et al., 2016).

One subtropical Australian environment that is lacking in both historical and long-term instrumental climate data is Southeast Queensland (SEQ). This region, and more specifically Brisbane which is the major urban centre of SEQ, would benefit from a long-term, tree-ring rainfall reconstruction to understand its highly variable climate. SEQ and Brisbane are characterized by a history of high magnitude, destructive floods and decade long drought events related to inter-annual rainfall variability specific to Australia's east coast (Kiem et al., 2003; Rustomji et al., 2009; van den Honert and McAneney, 2011; Haines and Olley, 2017). Such extreme events are known to have major environmental and economic costs, with the recent Millennium Drought (1996–2010) causing billions of dollars in loss across the country and heavily affecting Queensland's agricultural sector, which is one of the main economies in SEQ (Bond et al., 2008; ABS, 2011; van den Honert and McAneney, 2011; Heberger, 2012; BoM, 2015a). Understanding the frequency and long-term pattern of such events is a priority for climate scientists in SEQ. Recent rainfall analysis by Haines and Olley (2017) has indicated that while rainfall across the whole of SEQ is spatially variable there are regions that demonstrate strongly correlated rainfall patterns. This analysis indicated that to develop a precipitation reconstruction for Brisbane tree-ring sites in close proximity to the city should be selected. Urban settlement, land clearing, and logging have made such sites difficult to locate (Kemp et al., 2015) but D'Aguilar National Park located directly to the north of the city does fall within Brisbane's rainfall zone as identify in Haines and Olley (2017). More importantly this park is known to contain species such as those in the *Callitris* and *Araucariaceae* families which grow in response to climate, and can therefore be used for climate reconstructions (Ash, 1983a, 1983b; Baker et al., 2008). One of these species is *Araucaria cunninghamii* (Mudie) which was shown by Ash (1983a) to produce annual growth rings which are limited by precipitation. As such these trees can be used to reconstruct long-term past rainfall records. Unfortunately, coring of *A. cunninghamii* trees within D'Aguilar National Park demonstrated that the cores from these trees produced rings which are too faint to be identified visually. Previous studies in tropical environments elsewhere in the world have however used density patterns in wood to indicate ring boundaries and develop annual growth patterns (Worbes et al., 1995; Tomazello et al., 2000).

Wood density variation was first used as a dating method for tree-ring analysis by Polge (1970) and is based upon the magnitude of change in density between latewood and earlywood as seen through X-ray densitometric scanning (as detailed in Polge, 1966). Many improvements have been made since this early work on the X-ray scanning techniques but the principles in density analysis have remained the same. After X-ray scanning, we noted that the *A. cunninghamii* samples taken from D'Aguilar National Park demonstrate typical densitometric patterns where the change in density between the end of one ring's latewood and the beginning of the next ring's earlywood indicate the potential location of ring boundaries. Here we first date the core samples taken from *A. cunninghamii* trees in D'Aguilar National Park using X-radiographs and wood density patterns. From this, we develop a precipitation reconstruction for Brisbane, Australia and report on the usefulness of this method for wider paleoclimatic study in instances where the physical features of tree cores/slabs do not allow for easy visual ring identification.

2. Regional setting

Southeast Queensland, Australia is located along the Queensland-New South Wales state border and extends from the coast on the east, to the Great Dividing Range to the west, and north to the Sunshine Coast region (Fig. 1). Brisbane is located midway up the east coast of Australia and is the most populous urban area in subtropical Australia (ABS, 2016). Annual precipitation is around 1020 mm with the majority falling between November to March. Average minimum and maximum temperatures range from 10 °C to 21 °C and 22 °C to 30 °C respectively (BoM, 2017). Directly to the northwest of the city is the South D'Aguilar section of D'Aguilar National Park which contains large regions of subtropical rainforest (QDNPSR, 2015a). Based on work by Haines and Olley (2017) that demonstrates spatially homogeneous regions of rainfall are located across SEQ, it was determined that the rainfall variability seen in Brisbane will be closely correlated to the rainfall variability observed within this park.

Brisbane and the regional areas surrounding the urban centre have been heavily modified since European settlement began in the 1820s. These changes include widespread logging activities and land clearing (Horne and Hickey, 2001; Kemp et al., 2015). In subtropical Queensland most of the rainforest has been removed with the majority of remnant rainforest vegetation stands found in State Forest and National Parks (Horne and Hickey, 2001). This makes the D'Aguilar National Park a key location to help understand long-term rainfall conditions in Brisbane as there are few other locations within SEQ that a tree-ring based rainfall reconstruction can be created for the city.

D'Aguilar National Park was developed as a series of small national parks that were joined together under one title in 2009 (QDNPSR, 2015b). The subtropical rainforest in the Maiala section was the first region preserved in 1930. This region had been previously logged and replanted with *Araucaria cunninghamii* trees prior to including it in the National Park (QDNPSR, 2015b). Discussion with D'Aguilar park rangers and staff suggested that the replanting of this area had occurred during the mid to late 1800s. This location is similar to the few other remnant Australian subtropical rainforest settings in SEQ as the Maiala *A. cunninghamii* site (referred to herein as DMA) sits on a hillslope where a thin layer of soil covers a volcanic bedrock material. The vegetation in all of the SEQ *Araucariaceae* rainforest remnants is similar in composition but the understory, composed of vines and smaller plant species, is less dense at Maiala than rainforest stands which have never been logged such as the World Heritage Protected rainforest in Lamington National Park. *A. cunninghamii* is the dominant species in the Maiala rainforest with few trees of other species reaching canopy height at this location (Fig. 2). It is unclear if the dominance of *A. cunninghamii* at this site and/or the light understory cover is due to previous logging activity or if this is the natural vegetation condition found at this location.

The Maiala section was further developed for visitor use in the early 2000s when a parking area to access trails, a picnic shelter with barbeque facilities, and a toilet block were added. These facilities are found a few hundred meters away from the replanted *A. cunninghamii* trees. The researchers were not aware at the start of this study that the septic system for the toilet block involves a discharge of filtered groundwater which flows underground and is released within the forest at a location directly uphill from the *A. cunninghamii* DMA site. Park rangers undertaking works on the site confirmed evidence presented in aerial photographs that indicated the septic system was buried at this location in 2002.

3. Materials and methods

3.1. Tree-ring chronology development

Trees selected for this study ($n = 27$) needed to meet the following criteria: to have reached canopy height, represent a dominant or subdominant tree in the stand, not appear to be competing for resources with another dominant/subdominant tree, and appear on visual inspection to not be affected by localized factors such as insect infestation or heavy strangler vine coverage. Two 12 mm diameter cores were taken from each tree in the study ($n = 54$) at a minimum of 90° apart. Each sample was labelled and placed in vented plumbers piping for transport back to the lab.

Samples were air dried for 3–5 days in the lab before being placed in a drying oven at 40 °C for 4–6 h to remove any remaining moisture.