Originally published as:

Heinrich, I., Allen, K. (2013): Current Issues and Recent Advances in Australian Dendrochronology: Where to Next? - Geographical Research, 51, 2, 180-191

DOI: 10.1111/j.1745-5871.2012.00786.x

CURRENT ISSUES AND RECENT ADVANCES IN AUSTRALIAN DENDROCHRONOLOGY: WHERE TO NEXT?

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Abstract

Trees and shrubs constitute one of the most widely distributed terrestrial stores of environmental information. To date, dendrochronological exploitation of information stored in Australian plants has mostly relied on development and analysis of cross-dated ring-width chronologies or ring/growth zone counts. Thus far, however, ring-width chronologies have only been produced from sites in the relatively seasonal climates of southeastern and southwestern Australia and the far north. These chronologies have been developed almost exclusively for climatic analyses. Ring or growth zone counts have provided invaluable environmental information but can also be somewhat limited. We argue that evolution of a uniquely Australian dendrochronology will depend on innovative uses of information available from stable isotopes, wood property, elemental and wood anatomical analyses and ¹⁴C dating. Interdisciplinary approaches with a lesser focus on stringent requirements of cross-dating and chronology development may also

facilitate appropriate, and needed, methodological adaptation. Both high and low resolution records from across the Australian landscape can provide insights into challenges presented by the possible impacts of climate change and natural disasters across different environments and land management practices. They also have significant potential to contribute to multi-proxy reconstructions of Australian environments.

Key words: Dendrochronology, Australia, palaeoecological material

Introduction

The importance of dendrochronological techniques in addressing a wide range of ecological and environmental questions has long been established. Dendrochronology has been used to examine fire history and extent (Grissino-Mayer *et al.* 2004; Swetnam and Anderson 2008), climatic variability (Villalba *et al.* 1997; Gunnarson and Linderholm 2002; Briffa *et al.* 2002; Cook *et al.* 2006; Meko *et al.* 2011; D'Arrigo *et al.* 2011; Gary *et al.* 2011; Cook *et al.* 2010; Stahle *et al.* 2011; Christie *et al.* 2009), ecological issues (Boswijk and Whitehouse 2002; Paritsis *et al.* 2009), heavy metal pollution (MacDonald *et al.* 2011; Saint-Laurent *et al.* 2011), archaeological objects and to improve dating (Nash 2002; Reimer *et al.* 2005; Haneca *et al.* 2009). Regionally, practice and diversification of dendrochronology has been shaped by locally available species and their suitability for addressing local or regional issues. Climatic and archaeological interests in southwestern United States, archaeology/dating in western Europe and climate reconstruction in the Soviet Union led early researchers there to emphasise precision (Robinson 1990; Eckstein and Pilcher 1990). Precise dating was also important in early Southern Hemisphere (SH) work focussed on climatic reconstruction potential of SH trees (cf. Dunwiddie and LaMarche 1980). Arguably, subsequent development and expansion of Australian dendrochronology has been stymied by at least three interrelated factors: 1) attempts to strictly apply techniques developed in the Northern Hemisphere to Australian trees/shrubs; 2) an almost exclusive focus on ring-width; and 3) the relative lack of physiological information. We briefly discuss how different perceptions of dendrochronology have shaped Australian dendrochronology and then use some recent work to suggest ways Australian dendrochronology can evolve.

59 **Perceptions of dendrochronology**

60 In general terms, two approaches to dendrochronology can be identified, the first tied to
61 production of precisely dated annual chronologies. In this ‘classical’ approach to
62 dendrochronology, all studies using chronologies of annual growth layers that can be
63 assigned (or can be assumed to be assigned) to specific years can be considered
64 dendrochronological (Fritts 1976). In general terms, this literature defines annual tree
65 rings by the distinction between larger thin-walled cells (earlywood) and thicker-walled
66 smaller cells that form later in the season (latewood) (gymnosperms) and/or other
67 anatomical features such as porosity (angiosperms) (Fritts 1976; Speer 2010). Classical
68 dendrochronological research is fundamentally premised on a nexus of principles and
69 concepts. Cross-dating, the most fundamental of these (Fritts 1976), is the ability to
70 match annual ring width (or other features) patterns across different samples from a
71 single tree, and among samples from different trees at the same site. It facilitates
72 chronology development and identification of false/missing rings. Other important
73 principles of classical dendrochronology include uniformitarianism, sampling
74 replication, limiting factors and aggregate growth. Under uniformitarianism, the
75 processes that occur today occurred in the past, implying the relationship between
76 climate variables and growth does not change over time. Adequate sampling replication
77 is necessary to ensure cross-dating and development of a robust chronology. The
78 principle of limiting factors, based on Liebig’s law of the minimum (the most limiting
79 environmental factor will limit growth), helps guide site selection, especially for
80 climatic studies. The principle of aggregate growth explicitly acknowledges the
81 importance of biological age trends, stand-wide and non stand-wide disturbance events,

as well as climate, in determining woody growth (see Cook and Kariukstis 1990). Cross-dating relies on the ability to detect a site-wide signal over and above other factors affecting woody growth. For greater detail, see Fritts (1976), Cook and Kariukstis (1990) and Speer (2010).

The perception of dendrochronology as fundamentally based on these principles is not universal and the second approach to dendrochronology moves away from stringent requirements of annual rings and cross-dating. Both Schweingruber (1996) and Banks (2000) described ecological studies aiming to obtain environmental information from tree-ring series as dendroecological. A natural expansion of this is to consider tree rings as a form of palaeoecological material regardless of whether cross-dating is possible or rings strictly annual. Both classical dendrochronological studies and studies relaxing stringent criteria would be considered dendrochronological. Significantly, this approach is inclusive of dominant genera across the Australian landscape, such as the abundant well-adapted evergreen Eucalypts, Acacias and Callitris that often show opportunistic growth in response to highly variable and erratic rainfall events (Brodribb *et al.* 2010; Drew *et al.* 2011) rather than reliable annual rings. Schweingruber (1992) noted that although few of the 670 shrub and tree species from across the southern Australian mainland he examined were likely to be cross-datable, many of them exhibited ‘growth zones’ that could be used to infer an approximate age. This immediately suggests many species can offer information about forest structure and dynamics. For description of Schweingruber’s classification see Table 1.

Examples of tree-rings as an Australian palaeoecological archive

Crossdated ring-width chronologies

The distribution of published crossdated ring-width chronologies (Table 2) in Australia has been limited to the seasonal climates of southwestern and southeastern Australia and the far north (Pearman 1971; Ogden, 1978; Dunwiddie 1980; LaMarche *et al.* 1979, Campbell 1982, LaMarche and Pittock 1982; Ogden 1978,1981; Ash 1983a; Cook *et al.* 1991,1995; Buckley *et al.* 1997; Cook *et al.* 2000; Allen *et al.* 2001,2002; Pearson *et al.* 2002; Brookhouse and Brack 2006; Cook *et al.* 2006; Heinrich *et al.* 2008, 2009; Cullen *et al.* 2009; D'Arrigo *et al.* 2008; Baker *et al.* 2008; Simkin and Baker 2008; O'Donnell *et al.* 2010; Pearson *et al.* 2011, Allen *et al.* 2011, McDougall *et al.* 2012). Almost all these studies sought climatic information. Greatest success has been achieved with the very old coniferous species in Tasmania (Ogden 1978; Cook *et al.* 1992, Allen *et al.* 2001, Allen *et al.* 2011) (Table 2).

Other types of chronologies

Consistent with success elsewhere (Poussart and Schrag 2005; Poussart *et al.*, 2006), recent work on the Australian mainland showed that a $\delta^{18}\text{O}$ stable isotope chronology from *Callitris columellaris* contained a moisture signal (Cullen and Grierson 2007; Cullen *et al.* 2008). High-resolution analysis of stable isotopes of oxygen, carbon and nitrogen holds particular promise for tropical dendrochronology because seasonal isotopic fluctuations can reveal seasonality in samples that do not have clear rings (Elhani *et al.* 2003; Evans and Schrag 2004; Helle and Schleser, 2004; Poussart and Schrag 2005; Poussart *et al.*, 2006; Loader *et al.* 2007; Anchuikitis *et al.* 2008; Gagen *et al.* 2011). Interest in decadal-scale resolution stable isotope records (Böttger *et al.* 2009;

Esper *et al.* 2010; Gagen *et al.* 2011) suggest isotopic records from trees whose rings are not necessarily annual may also be useful in this regard.

Wood density, in particular maximum latewood density, often has superior climate sensitivity compared to ring-width at temperature-limited sites (Briffa *et al.* 2002). Preliminary wood density chronologies developed for *Phyllocladus aspleniifolius* and *Athrotaxis cupressoides* in Tasmania (Allen *et al.*, 2012) appear to possess stronger climate signals than the ring-widths of these species and may enable temperature reconstructions for different regions of Tasmania not possible based on ring width chronologies. Importantly, intra-annual density variations in tropical trees have previously helped identify macroscopically barely visible tree-ring boundaries (Worbes *et al.*, 1995; Vetter, 2000). Thus far, no work examining this possibility for Australia's tropical trees has been published, making it an important avenue for future research.

Cell wall thickness, tracheid radial diameter and microfibril angle (the angle of fibres in the cell wall) that are useful determinants of wood quality (Downes and Raymond 1997; Downes *et al.* 1997) have recently been used to produce climatically-sensitive cross-dated chronologies (Drew *et al.* in review, Allen *et al.* in prep.). Results suggest the possibility of developing climatically sensitive annual wood property chronologies from many species/locations where climatically sensitive ring-width chronologies could not be developed (Buckley *et al.* 1997; Allen *et al.* 1999; Allen *et al.* 2011). Physiological research addressing why wood properties appear more sensitive than ring width to temperature and possibly less sensitive to disturbance (Drew *et al.* in review) may have implications for an interpretative expansion of the principle of aggregate growth. This work, however, still relies on annually produced rings.

Studies based around ring counts

Many Australian species challenge the notion that identifiable rings will be annual or false/missing rings readily identifiable (Pearson *et al.* 2011; Drew 2008), but useful information from these species has nevertheless been derived. Simple ring counts or ring count averages have yielded information about changes in fire frequency (e.g. Burrows *et al.*, 1995; Hickey *et al.* 1999; von Platen *et al.* 2011), approximate age of trees (Brookhouse 2006), plant/community dynamics and regeneration (e.g. Banks 1982; Singer and Burgman 1999; Bell and Pate 1996; Franco and Morgan 2007; Coppleman *et al.* 2011), impacts of anthropogenic disturbance (Brookhouse 2006), biotic interactions (Spooner *et al.* 2004; Brookhouse 2006), insect defoliations (Morrow and LaMarche 1978), flood events (Martens 1993; Argent *et al.* 2004; George 2004), forestry (Stock *et al.* 2012), and ages of fossilised *Melaleuca* spp. in western Tasmania (Rowell *et al.* 2001). Tree girth – ring count relationships in *E. pauciflora* have provided insights into stand structure and disturbance history (Rumpff *et al.* 2009) and relationships between approximate tree age and hollow formation in *Eucalyptus* species has provided information concerning flora/fauna interactions (Gibbons *et al.* 2001; Koch *et al.* 2008). Comparison of ring-widths of introduced *Salix* spp. (Martens 1993) and *C. glaucophylla* (Pearson *et al.* 2001) across single sites have enabled inference about past environmental conditions or climate influences on growth (Bowman *et al.* 2011).

Further expanding information available from tree-rings

Use of Xylaria

Recent work (O'Donnell 2010; McDougall *et al* 2012) illustrates the need to persist with the search for mainland Australian species from which cross-dated ring-width chronologies can be developed, or from which rings or growth zones counts could be used to approximate plant age (*sensu* Schweingruber 1992). Due to the high number of Australian species that have not been examined for dendrochronological potential, additional effort to examine xylarium samples (cf. Worbes 2002) may allow relatively quick identification of species with dendrochronological potential, reducing the need for field surveys. The 'Dadswell' collection containing approximately 2,400 Australian species has excellent potential in this regard and will soon become part of a larger collection at CSIRO, Cresswick Victoria (McLaughlin 2011). Collections like this with multiple specimens of a species may enable comparison of wood anatomy along natural distribution gradients of species (Liphschitz and Waisel 1970; Carlquist 1977; Roig, 1986; Wilkins and Papassotiriou 1989; February, 1993), providing important clues as to why chronologies for some species can only be developed from some sites, or why false rings form occasionally at some sites (cf. Pearson *et al.* 2011). Such studies may help elucidate the dendrochronological potential of relatively unexplored *Eucalyptus* spp. (*sensu* Brookhouse 2006).

Anatomical detail

Attention to anatomical detail and wood structure may be particularly useful for many species (cf. Schweingruber 1996). Expansion of Ash's (1983a&b) early use of anatomical observations in Australian trees may prove useful for matching features across samples and/or provision of environmental information. It is known that some *Eucalyptus* spp. can rapidly adjust the size and number of vessels in response to

drought/precipitation (Searson *et al.* 2004; Drew 2008). This suggests anatomical changes in wood structure of Eucalypt species, in combination with ^{14}C dating, may provide important clues to past water availability in remote areas (cf. Argent *et al.* 2004) where meteorological records are scarce or very short-lived.

'Bomb-pulse' dating

Many nuclear detonations in the 1950s and 1960s resulted in a 1965 SH atmospheric ^{14}C peak that rapidly decayed (Hua and Barbetti 2004). This atmospheric radiocarbon content is reflected in tree rings at the time of their formation (Stuiver *et al.*, 1981). Significant year-to-year differences in atmospheric ^{14}C exist for consecutive years (Hua and Barbetti 2004; Hua 2009), making it possible to use the technique to assess the annularity of rings and detect dating errors over the past half century or so (Akeroyd *et al.* 2002; Hua *et al.* 2003; Bowman *et al.* 2011; Pearson *et al.*, 2011). It is an important complementary tool to dendrochronological techniques (Hua 2009) and could plausibly be used to develop error ranges for ring counts. Where a chronology is to be developed, however, bomb-pulse dating' does not replace cross-dating of multiple samples from multiple trees. For sample wood formed prior to the bomb testing period, ' ^{14}C wiggle matching' based on a comparison of the relevant hemispheric calibration curve and a series of dates taken from multiple rings in a sample, can be used to date samples (Zoppi *et al.* 2004; Barbetti *et al.* 2004; Hua 2009; Wood *et al.* 2010). 'Wiggle matching' is also clearly applicable to wood without rings from which other types of information, such as high-resolution isotopic variability, may be available.

Elemental analysis

Elemental analysis (e.g. Ca, K, SR, Fe, Mn, Si, Pb, Zn, Br, Ti, Al, As, Rb, Zr) of wood profiles has barely been exploited yet. While there is a great deal of exploratory work to be done, early work in northeastern Australia has suggested higher nutrient levels in eucalypts may be used as indicators for past forest fire activities (Heinrich 2006). Elsewhere, Ca has been used to age trees and been linked to precipitation (Poussart *et al.* 2006). Additionally, enrichment of some elements occurs in earlywood while enrichment in others occurs in the latewood (pers. comm. Erik Brown, University of Minnesota). Morrison *et al.* (2012) aim to examine the potential for elemental chronologies of *Erythroleum chlorostachys* that can be used to improve archaeological dating of trees culturally modified by Aboriginal peoples (Long 2002).

Methodological adaptation

Argent *et al.*'s (2004) impressive skeleton plotting based on anatomical detail is one example of how modification of existing methodologies and attention to detail can be necessary and informative. Development of 'cross-matching' techniques and associated formal statistical data quality checking would be a useful innovation, possibly enabling production of replicated decadal-scale records with a common signal from some long-lived eucalypt species that have approximately annual rings. Such records would make valuable contributions to low-frequency multi-proxy climate reconstructions (c.f. Trachsel *et al.* 2012).

Numerous publications have indicated the usefulness of statistical or mathematical techniques that were not previously widely applied to dendrochronological analysis (e.g. Allen *et al.* 1999, Devineni *et al.* in press, Woodhouse 1999). Alternative approaches such as Fowler *et al.*'s (2008; 2012) examination of chronology variance

structure and subsequent reconstruction of ENSO variability are also important. Evolution of a uniquely Australian dendrochronology will necessarily entail other methodological adaptations and interdisciplinary approaches.

Complementary physiological information

Lack of knowledge concerning the ecology/life histories of many tree species still presents a significant challenge for Southern Hemisphere dendrochronology (Cook 1990). Therefore, physiological studies have an extremely important role to play in improving understanding of species' growth and their potential for dendrochronological studies in Australia. Controlled growth experiments investigating responses to droughting (Brodribb 2010), temperature (Read and Busby 1990) defoliation (Heinrich and Banks 2006a), or mechanical injuries (Heinrich and Gärtner 2007) have provided important insights into wood structure and anatomical responses to stimuli.

Phenological studies have identified phenological cues for some Australian species as internal water status (Williams *et al.*, 1997), soil moisture, relative humidity and a variety of complex interactions between atmospheric and soil moisture (Myers *et al.* 1998). Growth monitoring by point or band dendrometers (Mucha 1979; Downes *et al.*, 1999; Heinrich and Banks 2005) has provided invaluable insights into timing and duration of growth. Very high precision point dendrometers (logging every 15 minutes) installed on *Eucalyptus* plantations in Australia have revealed the opportunistic nature of growth of plantation forestry species (Downes *et al.* 1999, Drew *et al.* 2011) and are currently providing high-resolution information on the response of the palaeoclimatically important Mt Read Huon pine (D. Drew, CSIRO pers comm.), that

may, in combination with wood properties analysis, enable improved interpretation of the temperature record developed from the site.

Microcores 1-2mm in diameter and up to 2cm in length (Forster *et al.*, 2000; Rossi *et al.*, 2006) can be used repeatedly over the growing season to monitor and compare intra-annual formation of wood anatomical features such as tracheid or vessel areas known to correlate well with climate (e.g., Fritts *et al.*, 1991; Fonti and García-González, 2004; Heinrich and Banks, 2006b; Vaganov *et al.*, 2006). Tracheidograms (Vaganov *et al.* 2006) may also promote better understanding of tracheid development and climatic responses in Eucalypts or Podocarpaceae.

The way forward

As high-resolution sources of palaeoenvironmental information, trees have important potential to provide continental-scale palaeoecological information (Pearson and Searson 2002). Evolution of a uniquely Australian approach to dendrochronology needs to be shaped by local and regional questions and the available woody material rather than by tenets of a classical dendrochronology that evolved in response to very different environmental conditions. High-resolution climate indicators in Australia's aseasonal environments are rare (Neukom and Gergis 2012) and continued reliance on producing climate-sensitive annual ring width chronologies is likely to yield few results for the majority of the continent, despite an abundance of woody material. Different types of chronologies, still rooted in classical dendrochronological principles, are only part of a response. While cross-dated annual-resolution chronologies (of various types) allow greater dating precision, other information available from lower resolution non cross-dated (but possibly 'cross-matched') material may also provide environmental

information, as amply demonstrated by studies that have relied on ring counts. Substantive progress in Australian dendrochronology will partially depend on alternative approaches, methodological adaptation and innovation available through an interdisciplinary approach as well as a willingness to explore potentially powerful approaches that combine techniques such as stable isotopes and ^{14}C or perhaps wood structure and ^{14}C . Extraction of multiple records from tree-rings may also be useful (cf. ice cores, corals: Jones *et al.* 2009). Although Australian dendrochronological research has begun branching out from its more classical origins, there is still much to do, as intimated by Banks (2000) in addressing dendrochronological potential to assess ecological impacts of ENSO on the Australian landscape. Pressing questions concerning impacts of past and future climate variability on Australia's unique biota, coastlines and water availability make the potential contribution of an adaptive Australian dendrochronology all the more relevant.

ACKNOWLEDGEMENTS

Kathryn Allen was supported by ARC Discovery Project DP0878744. We appreciate the comments of two anonymous reviewers that have greatly improved this manuscript.

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720

Class	Description
Class 1	Very distinct growth rings that extend around stem circumference, even when narrow. Likely to be true annual rings.
Class 2	Growth zones easily seen, and in most cases extend around the stem. Slight intra-annual variations in growth are readily distinguishable from class 1 rings. Growth zones likely to be annual, can be counted for age estimate.
Class 2-3	Growth zones distinct on one part of trunk but often difficult to follow around circumference. Most cases, probably annual rings. Could use to estimate age to within a few years.
Class 3	Growth zones more or less distinct, but only some can be followed around stem. Counts on different radii rarely give same number of growth zones. Stem age can only be roughly estimated.
Class 3-4	Growth zones mostly indistinct. In a few cases will extend around circumference. Ageing not possible.
Class 4	More or less clear variations in growth visible, but these rarely extend around the circumference. Ageing not possible.
Class 5	Almost no growth variations. Ageing impossible.

722 **Table 1:** Schweinguber's (1992) classification of tree-rings. A growth ring is defined
723 as having a distinct latewood-earlywood boundary that extends around the

724 circumference of the stem. In a growth zone, the latewood-earlywood boundary can be
725 sometimes or always indistinct and often does not extend all the way around the stem.
726

Chronology	Species	Location	Chronology type	Start/end dates	Reference
Korlobirrahda	<i>C. intratropica</i> (<i>C. columellaris</i>)	NT	Ring width	1870- 2006	Pearson <i>et al.</i> (2011)
Hayes Farm	<i>C. intratropica</i> (<i>C. columellaris</i>)	NT	Ring width	1847- 2006	Baker <i>et al.</i> (2008), D'Arrigo <i>et al.</i> (2008)
Howard Springs	<i>C. intratropica</i> (<i>C. columellaris</i>)	NT	Ring width	1965- 2004	Baker <i>et al.</i> (2008)
Atherton	<i>T. ciliata</i>	Qld	Ring width	1860- 2001	Heinrich <i>et al.</i> (2008)
Lamington Park	<i>T. ciliata</i>	NSW	Ring width	1854- 2001	Heinrich <i>et al.</i> (2009)
Mt Kosciuszko National Park	<i>P. lawrencei</i>	NSW	Ring width	1888- 2001	McDougall <i>et al.</i> (2011)
BawBaw	<i>E. pauciflora</i>	NSW	Ring width	1792- 2002	Brookhouse (not yet published)
Garden Island	<i>C. robusta</i>	WA	Ring width	1931- 1975	LaMarche <i>et al.</i> (1979)
Garden Island	<i>C. robusta</i>	WA	Ring width	1912- 1975	LaMarche <i>et al.</i> (1979)
Lake Tay	<i>C. columellaris</i>	WA	Ring width	1655- 2005	Cullen and Grierson (2009)
Lake Johnston	<i>C. preissii</i>	WA	Ring width	1974- 2009(?)	O'Donnell <i>et al.</i> (2010)
Pilbara	<i>C. columellaris</i>	WA	δ18O	1919- 1999	Cullen <i>et al.</i> (2007)
Mt Read	<i>L. franklinii</i>	TAS	Ring width	-4126-	Cook <i>et al.</i>

				2009	(2000)
Buckley's Chance	<i>L. franklinii</i>	TAS	Ring width	910-1991	Buckley <i>et al.</i> (1997)
Lake Vera	<i>L. franklinii</i>	TAS	Ring width	69-1993	Buckley <i>et al.</i> (1997)
Lake Marilyn High	<i>L. franklinii</i>	TAS	Ring width	1542-1992	Buckley <i>et al.</i> (1997)
Lake Marilyn Low	<i>L. franklinii</i>	TAS	Ring width	1058-1992	Buckley <i>et al.</i> (1997)
Harman River	<i>L. franklinii</i>	TAS	Ring width	- 2-1990	Buckley <i>et al.</i> (1997)
Stanley River	<i>L. franklinii</i>	TAS	Ring width	-571-1991	Buckley <i>et al.</i> (1997)
Pine Lake/Mickey Creek	<i>A. cupressoides</i>	TAS	Ring width	1277-1991	LaMarche <i>et al.</i> (1979), Allen <i>et al.</i> (2011)
Lake Mackenzie	<i>A. cupressoides</i>	TAS	Ring width	1344-2008	Allen <i>et al.</i> (2011)
Walls of Jerusalem	<i>A. cupressoides</i>	TAS	Ring width	1376-2003	Allen <i>et al.</i> (2011)
Mt Field	<i>A. cupressoides</i>	TAS	Ring width	1028-2008	LaMarche <i>et al.</i> (1979), Allen <i>et al.</i> (2011)
Cradle Mt	<i>A. selaginoides</i>	TAS	Ring width	945 - 2009	LaMarche <i>et al.</i> (1979), Allen <i>et al.</i> (2011) ⁺
Moonlight Ridge	<i>A. selaginoides</i>	TAS	Ring width	1664-2009	Allen <i>et al.</i> (2011)
Lake Riveaux/ Abrotonella Rise	<i>A. selaginoides</i>	TAS	Ring width	1520-2009	Allen <i>et al.</i> (2011)
Race Course Spur	<i>P. aspleniifolius</i>	TAS	Ring width	1467-1995	Allen <i>et al.</i> (2001)

Wey River	<i>P. aspleniifolius</i>	TAS	Ring width	1629-1995	Allen <i>et al.</i> (2001)
Dove River Road	<i>P. aspleniifolius</i>	TAS	Ring width	1776-1975	LaMarche <i>et al.</i> (1979)
Pieman River	<i>P. aspleniifolius</i>	TAS	Ring width	1310-1974	LaMarche <i>et al.</i> (1979)
Mt Murchison	<i>P. aspleniifolius</i>	TAS	Ring width	1565-1996	Allen <i>et al.</i> (2001)
Franklin River Valley	<i>P. aspleniifolius</i>	TAS	Ring width	1673-19752	LaMarche <i>et al.</i> (1979)
Mt Arrowsmith	<i>P. aspleniifolius</i>	TAS	Ring width	1541-1999	LaMarche <i>et al.</i> (1979), Allen <i>et al.</i> (2001)
Clear Hill	<i>P. aspleniifolius</i>	TAS	Ring width	1554-1974	LaMarche <i>et al.</i> (1979)
Holly Range Rd	<i>P. aspleniifolius</i>	TAS	Ring width	1675-1975	LaMarche <i>et al.</i> (1979)
Scotts Peak Rd	<i>P. aspleniifolius</i>	TAS	Ring width	1525-1995	Allen <i>et al.</i> (2001)
Lower Cole Rd	<i>P. aspleniifolius</i>	TAS	Ring width	1598-1995	Allen <i>et al.</i> (2001)
S100 Warra	<i>P. aspleniifolius</i>	TAS	Ring width	1653-1998	Allen (2002)
S400 Warra	<i>P. aspleniifolius</i>	TAS	Ring width	1710-1998	Allen (2002)
S600 Warra	<i>P. aspleniifolius</i>	TAS	Ring width	1543-1998	Allen (2002)
S900 Warra	<i>P. aspleniifolius</i>	TAS	Ring width	1738-1999	Allen (2002)
Clayton's Lagoon	<i>P. aspleniifolius</i>	TAS	Ring width	1564-1995	Allen <i>et al.</i> (2001)
Lockley's	<i>P. aspleniifolius</i>	TAS	Ring width	1579-	LaMarche <i>et al.</i>

Spur Rd				1974	(1979)
Sheepwash Creek	<i>P. aspleniifolius</i>	TAS	Ring width	1542-1974	LaMarche <i>et al.</i> (1979)
Coolangatta Rd	<i>P. aspleniifolius</i>	TAS	Ring width	1711-1975	LaMarche <i>et al.</i> (1979)
Maria Island	<i>P. aspleniifolius</i>	TAS	Ring width	1580-1994	Allen <i>et al.</i> (2001)
Blue Tier	<i>P. aspleniifolius</i>	TAS	Ring width	1157-1994	LaMarche <i>et al.</i> (1979), Allen <i>et al.</i> (2001)
Ralph's Falls Rd	<i>P. aspleniifolius</i>	TAS	Ring width	1241-1994	Allen <i>et al.</i> (2001)
Ben Ridge Rd	<i>P. aspleniifolius</i>	TAS	Ring width	1604-2007	Allen <i>et al.</i> (2001)
Maria Island callitris	<i>C. rhomboidea</i>	TAS	Ring width	1917-2006	Pearson <i>et al.</i> (2001)
Weindorfer Forest (Cradle Mt)	<i>N. gunnii</i>	TAS	Ring width	1732-1975	LaMarche <i>et al.</i> (1979)
Scott's Peak Rd	<i>P. aspleniifolius</i>	TAS	Density	1525-1994	Allen <i>et al.</i> (2012)
Pine Lake/Mickey Creek	<i>A. cupressoides</i>	TAS	Density	1277-1990	Allen <i>et al.</i> (2012)
Butters	<i>L. franklinii</i>	TAS	Average MFA	1770-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Average tracheid radial diameter	1770-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Average density	1750-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Latewood density	1790-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Maximum tracheid	1750-	Drew <i>et al.</i>

			radial diameter	2009	(In review)
Butters	<i>L. franklinii</i>	TAS	Earlywood tracheid radial diameter	1780-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Minimum MFA	1860-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Maximum MFA	1830-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Average cell wall thickness	1970-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Latewood cell wall thickness	1850-2009	Drew <i>et al.</i> (In review)
Butters	<i>L. franklinii</i>	TAS	Earlywood cell wall thickness	1750-2009	Drew <i>et al.</i> (In review)

Table 2. Existing Australian tree-ring chronologies. Included in the table are dates for full-length chronologies where available. Some of these chronologies published elsewhere will exclude early portions considered to be of low quality. No chronology quality statistics are shown here because different studies have used different measures in different ways (EPS and RBar are most common). Some use an average EPS/RBar figure for the whole chronology (e.g. Drew *et al.* in review), others show running EPS/RBar statistics (Heinrich *et al.* 2009; Pearson *et al.* 2011), some report both (e.g. Cullen and Grierson 2009) and in some cases, chronology quality statistics are not shown (e.g. Baker *et al.* 2008: Howard Springs). Studies that report running statistics also use different windows for calculation. For information about chronology quality statistics and sample depth, the reader is referred to the listed publications. Also note

739 that not all the above chronologies have yet been published (e.g. BawBaw and the
740 Butters wood quality chronologies).
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