

Crossdating of terminal and reverse-latewood eucalypt tree-rings

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Introduction

Crossdating is a fundamental dendrochronological principle. However, despite its importance, crossdating has been applied infrequently in the eucalypt dendrochronological literature. One factor limiting crossdating in previous eucalypt tree-ring studies has been the difficulty associated with objective tree-ring identification and measurement, particularly in samples from lower montane (500-800m) sites (Bi 1994). To overcome this problem Brookhouse (1997) proposed the 'reverse-latewood' identification technique. In contrast to the terminal form, reverse-latewood occurs at the start of the eucalypt tree-ring (Fig. 1). Whilst tree-ring counts indicate that both terminal and reverse-latewood may indicate truly annual tree-ring boundaries (Brookhouse 1997, Green 1967) crossdating has not been quantitatively demonstrated for either type in eucalypts.

The present study was undertaken using samples of known age to investigate the potential of eucalypts to preserve common environmental signals by quantitatively demonstrating crossdating within and between two eucalypt species – one characterised by terminal latewood and the other reverse-latewood – and identifying the climatological source of common signals preserved within the derived tree-ring chronologies.

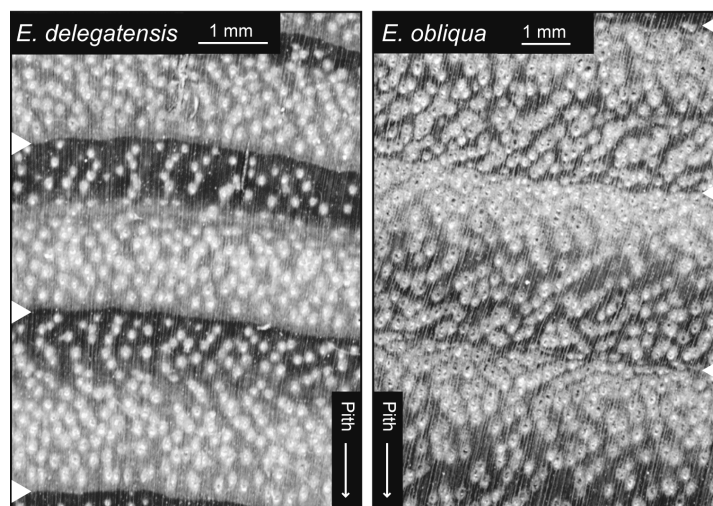


Figure 1: Terminal and reverse-latewood tree-ring structure. Dark latewood can be easily identified at the terminal boundary of Eucalyptus delegatensis tree-rings. Latewood type fibres in E. obliqua are formed at the start of the tree-ring. In tree-rings exhibiting this structure, the clear boundary between earlywood and latewood type fibres is defined as the boundary. Tree-ring boundaries and the direction of the pith are indicated.

Methods

Samples used in this study were collected from the Black and Federation Ranges in Victoria's central highlands (Fig. 2) by the Department of Sustainability and Environment, Victoria as part of regional timber resource surveys (Hamilton, 1999) and stem analysis sampling in forest stands of known age. Throughout the study area cold winter temperatures limit cambial activity leading to the formation of annual rings. Two species, one exhibiting terminal latewood (*Eucalyptus delegatensis* Baker, R.T.) the other exhibiting reverse-latewood (*E. obliqua* L'Herit), were selected for analysis.

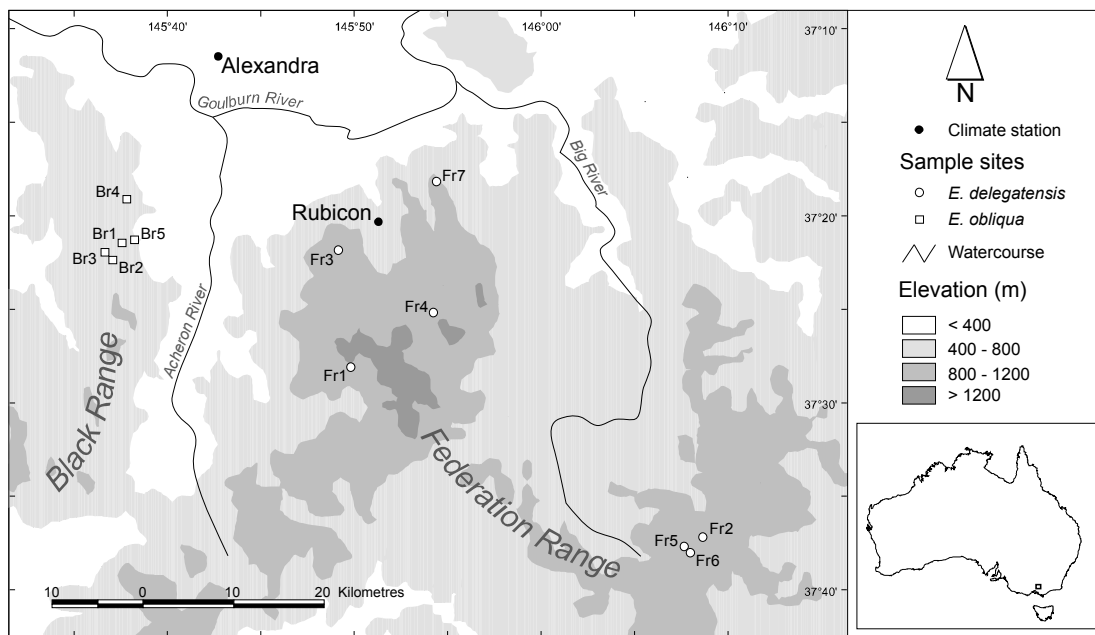


Figure 2: Location of sample sites and climate stations.

Sample disks were stored, allowed to air-dry and then sanded. Up to four radii, evenly spaced around each sample disk, were selected for identification and measurement on each sample. In many instances fewer than four radii were selected due to sample deformities. Tree-ring structure of all samples was examined under stereo-microscope. Tree-rings were identified on each radius and calibrated against other radii on the same sample. Radii were then visually crossdated with samples from the same site. Tree-ring widths were measured to the nearest 0.01 mm using Henson and LINTAB tree-ring measurement stages and TRIMS and TSAP software.

Verification of visual crossdating was conducted in Xmatch (Fowler 1998). Although the outermost ring year of each sample was known, Xmatch was permitted to conduct a 'best-fit' search. Only samples for which the Xmatch best-fit was consistent with visual crossdating were retained for further analysis. COFECHA (Holmes 1983) was used to assess the placement of missing rings. Product moment correlation coefficient significance testing was conducted between crossdated radii. Only radii with highly significant ($p < 0.0001$) inter-tree radial correlation were retained for chronology development.

A two-stage detrending approach within ARSTAN was used for standardisation using a negative exponential or simple linear function followed by a cubic smoothing spline. Mean individual species chronologies were calculated using an arithmetic mean. Autoregression of each chronology was conducted to remove serial correlation. The Expressed Population Signal (EPS) statistic (Briffa and Jones 1990) and Mean Sensitivity (MS) were calculated for each chronology. The Gleichläufigkeit (GLK) was also calculated between the species' chronologies.

Climatological analysis was based upon monthly mean maximum temperature and total monthly precipitation data from the Rubicon (838 m) climate station (Fig. 2). Analysis was restricted to a time period common to both tree-ring chronologies (1952-1998). The influence of both the current and previous season's climate conditions were analysed using 24 months of mean temperature and precipitation data (September_{n-1}-August_n). Seasonal (three-month) temperature means and precipitation totals were calculated and included in analysis. Correlation between climate and each species' chronology was evaluated using the product moment correlation coefficient.

Results

Crossdating results are summarised in table 1. Only nine missing rings, constituting 0.002% of the entire crossdated dataset, were identified. Each of these missing rings was identified during visual crossdating. Although achieved intra-specifically, inter-specific radial crossdating was not achieved. The crossdated proportion of the original sample varied markedly between species – 76% and 40% of *E. obliqua* and *E. delegatensis* radii, respectively.

Table 1: Full and crossdated sample summary

Species	Sample radii (trees)		Missing rings	
	All	Crossdated	Visual	Xmatch
<i>E. delegatensis</i>	60 (19)	24 (15)	1	0
<i>E. obliqua</i>	41 (14)	31 (13)	8	0

Chronology statistics are presented in table 2. Mean sensitivity and within and between tree correlations indicate that both chronologies hold relatively equal dendroclimatological potential. Autocorrelation is relatively low and non-significant and the EPS exceeds 0.85 in both instances.

Table 2: Species chronology statistics. Reported statistics are autocorrelation (AC), mean sensitivity (MS), correlation within (W_t) and between (B_t) trees and expressed population signal (EPS).

Species	n (years)	AC	MS	W_t	B_t	EPS
<i>E. delegatensis</i>	47	0.11	0.22	0.57	0.34	0.87
<i>E. obliqua</i>	58	0.06	0.27	0.51	0.38	0.90

Correlation between the two chronologies is highly significant (Fig. 3). This apparent potential for interspecific chronology crossdating potential is also indicated by the relatively high inter-specific GLK.

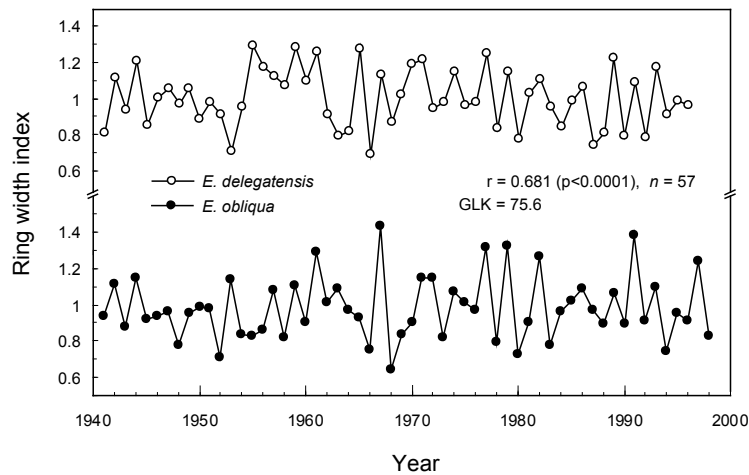


Figure 3: Standardised tree-ring chronologies for *E. delegatensis* and *E. obliqua*. Inter-chronology correlation and Gleichläufigkeit (GLK), or absolute first order concordance, is reported.

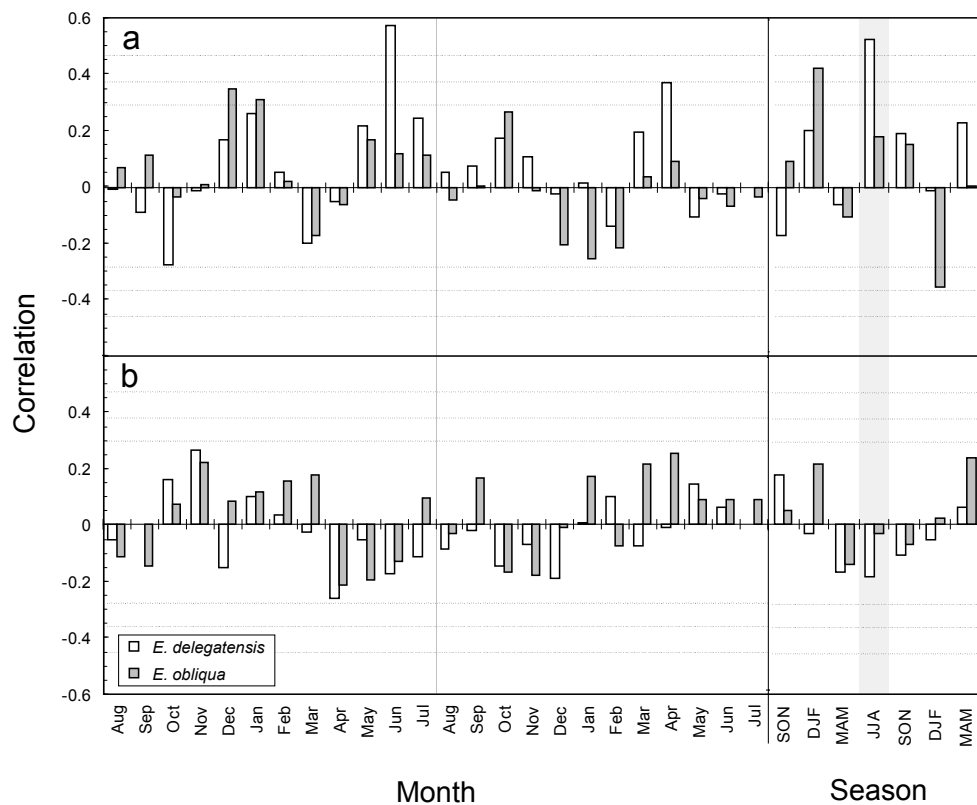


Figure 4: Climate response graphs for *E. delegatensis* and *E. obliqua*. Response graphs summarise correlation between 24 months of monthly and seasonal temperature (a) and precipitation (b) each species chronology. Dashed horizontal lines indicate 0.05, 0.01 and 0.001 significance levels. The boundary of the preceding and current growing season is indicated for monthly (line) and seasonal (shaded).

Climatological results are presented in figure 4. No significant correlations were observed between precipitation and either chronology. Significant correlations were identified between each chronology and temperature. Significant positive correlation between the *E. delegatensis* chronology and mean temperatures was identified for the preceding June ($r=0.573$, $p<0.0001$), current April ($r=0.370$, $p<0.05$) and preceding winter (June-August; $r=0.533$, $p<0.001$). Significant positive and negative correlations were identified between the *E. obliqua* chronology and temperature during the preceding December ($r=0.348$, $p<0.05$). Similarly, significant correlation was identified between seasonal mean temperature during the preceding ($r=0.420$, $p<0.01$) and current summers ($r=-0.351$, $p<0.05$).

Discussion

Crossdating

Correlation analysis of visually crossdated eucalypt tree-ring series – independently confirmed in Xmatch – verified crossdating within separate species exhibiting terminal and reverse-latewood. The capacity for intra-specific crossdating of eucalypt samples collected over a broad geographic area indicates that macro-scale environmental signals are preserved within eucalypt tree-ring data and provides an important validation of the reverse-latewood identification technique. Similarly inter-specific chronology crossdating indicates that new chronologies from separate species may be used for cross-verification.

Climate analysis

Analysis of temperature data revealed significant correlation with tree-ring widths. Whilst, positive correlation between *E. delegatensis* ring-width and April temperatures of the current season may express the extension of the growing season during a warm autumn, correlation between preceding winter temperature and *E. delegatensis* ring width indices may be due to lag effects of frost injury and cold induced photoinhibition of overwintering foliage (Holly et al. 1994, King and Ball 1998, Rolland et al. 1999, Butterworth 2000, Thomson et al. 2001, Davidson et al. 2004).

In contrast to *E. delegatensis*, standardised *E. obliqua* ring widths were positively correlated with temperature during the previous summer and negatively correlated with temperature during the current summer. Negative correlation between summer temperature has been reported relatively frequently in the dendroclimatological literature (Cregg and Dougherty 1988, Richter et al. 1991, Pan et al. 1997, Rubino and McCarthy 2000, Yeh and Wensel 2000, Peterson et al. 2002) and has been interpreted as a result of increased evaporation and transpiration depleting soil moisture. However, high summer temperatures may affect carbon assimilation, and hence growth, of eucalypts independently of soil moisture by regulating transpiration and carbon assimilation through stomatal control (Wong et al. 1978, Körner and Cochrane 1985) and by inducing thermodormancy (Blake 1976).

Positive correlation between *E. obliqua* ring width and previous summer temperature may correspond with the long-term tree level carbohydrate budget. Stored carbohydrates during a previous season may provide an important basis for later growth (Kozłowski 1971). In eucalypts stored carbohydrates may be critical for eucalypt survival and recovery following drought and disturbance (Fensham and Bowman 1992, Walters et al. 2005). Hence,

carbohydrates that remain unused during the current growth season, due to thermodormancy or stomatal closure may remain available for leaf, canopy and stem diameter growth during the following season (Fritts 1976).

Whilst this study has demonstrated that crossdating between samples and identification of potential climatological influences on eucalypt growth from tree-ring data are possible it has also presented a problem. Approximately half of all radii were not crossdated and the proportion of crossdated radii varied dramatically between the two species. Hence, the question of how the efficiency of eucalypt dendrochronological sampling be improved, must be addressed.

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