The potential for dendroclimatology in the Warra LTER Site, Tasmania

K.J. Allen
Parks and Wildlife Service
Department of Primary Industries, Water and Environment,
GPO Box 44, Hobart, Tasmania 7001
and Forestry Tasmania
Current address: PO Box 94 Kingston, Tasmania 7051

Abstract

Samples for tree ring analysis have been obtained from three different species within the Warra LTER Site. Four chronologies have been developed from Phyllocladus aspleniifolius *sampled along an altitudinal gradient. Preliminary samples taken from* Athrotaxis selaginoides *indicate that cross-dating is present in this species, with further sampling necessary in order to develop a chronology. A brief examination of the rings from a sample of* Eucalyptus subcrenulata *suggests that this species, at high elevation, is worth investigating in relation to developing an accurately dated fire history for the area.* Phyllocladus aspleniifolius *and* Athrotaxis selaginoides *do not appear to cross-date with one another, suggesting cambial growth is influenced by different external stimuli.*

Introduction

Dendrochronological techniques have been useful in studies of fire frequency, hydrology, geomorphology, archaeology, and ecology and as a proxy for palaeoclimatic data (e.g. Fritts 1971; Stockton and Fritts 1973; Cook *et al.* 1996a, b). In the Tasmanian context, the most popularly known example of dendrochronological work is probably that on the Mount Read *Lagarostrobos franklinii* (see Buckley 1997; Buckley *et al.* 1997; Cook *et al.* 1991, 1992, 1996a, b). Further dendroclimatological work has been conducted on the same species in the State's north-west and samples used for radiocarbon calibration (e.g. see Barbetti *et al.* 1995; Kromer *et al.* 1998). LaMarche *et al.* (1979), Campbell (1980) and Allen (1998) have also investigated the dendrochronological characteristics of a number of endemic Tasmanian species, including *Phyllocladus aspleniifolius*, *Athrotaxis selaginoides* and *A. cupressoides*.

The Warra Long-Term Ecological Research (LTER) Site provides an excellent opportunity for a multifaceted dendrochronological investigation. The area contains at least three species previously noted for dendrochronological potential: *Lagarostrobos franklinii, Athrotaxis selaginoides* and *Phyllocladus aspleniifolius*. Interest in the area's fire history also warrants a preliminary examination of high elevation *Eucalyptus subcrenulata* at Warra. In addition, the location of Warra in the south-west of the State increases interest in attempting to develop a long chronology from the area as no robust long-term chronology for any species currently exists for this area. The south-west is reputed to be under different climatic controls from the rest of the State (R. Allan, pers. comm., CSIRO; D. Shepherd, pers. comm., Bureau of Meteorology). Other advantages include a good altitudinal range within the one area and a number of different vegetation types.

Chronology results for the four *Phyllocladus aspleniifolius* sites and early results for

e-mail: kathyallen@trump.net.au

Athrotaxis selaginoides are presented here. While this study presents only early results of dendroclimatological work at Warra, it is clear that several interrelated aspects can be developed. *Phyllocladus aspleniifolius*, for example, has a wide ecological and geographical distribution in the State and at Warra, providing an opportunity to establish sampling sites along an altitudinal gradient to examine the variation of climatic response with altitude. The construction of four chronologies permits more detailed investigation of the climate response of *P. aspleniifolius* along an altitudinal gradient (K. Allen, unpublished data).

The development of an *Athrotaxis selaginoides* chronology is planned and may be used to examine climatic variability over the last 500 years or more of this area of south-western Tasmania. The fire history of the area is of considerable interest, and known fire events can be compared to chronologies or master series in an attempt to see whether either of these two species provides a useful fire record. *Eucalyptus subcrenulata*, should it prove to have annual rings which cross-date, may be useful for short-term studies of fire frequency.

Annual ring width was the only 'tree variable' examined in this study.

The sites

In the preliminary sample collection of *Athrotaxis selaginoides*, six samples were obtained from the eastern side of Mount Weld (TASMAP series *Weld* sheet: 466000E, 5237500N – 467000E, 5238100N) and four from the western side (465500E, 5237500N). One sample from a rotted *Eucalyptus* stump was obtained from the eastern side of the mountain; this was presumed to be *E. subcrenulata*. Four sites of *Phyllocladus aspleniifolius* along an altitudinal gradient were also sampled, at approximately 100 m (478300E, 5230400N), 380–390 m (475900E, 5230400N), 550–600 m (470500E, 5237400N) and 900 m a.s.l. (467200E, 5236900N).

The lower site (Site 100) was dominated by *Eucalyptus obliqua* and *Phyllocladus aspleniifolius*, with the general area containing some *Nothofagus cunninghamii* and *Acacia melanoxylon*. The most frequently occurring species in the understorey were *Gahnia grandis* and *Blechnum wattsii*. Evidence of recent fire (1972, from Forestry Tasmania records) was clearly evident both to the north and immediate south of the area sampled. The site was generally flat. The 400 m site (Site 400) lay on an approximate 10–20° slope, with considerably less understorey than Site 100. It was dominated by *E. obliqua* and *P. aspleniifolius*. The understorey was dominated by *Blechnum wattsii*. The 600 m site (Site 600) was dominated by *E. obliqua, P. aspleniifolius* and *N. cunninghamii,* with an understorey consisting mostly of a dense jungle of *Anodopetalum biglandulosum*. Slope varied from approximately 5° to 30°. The 900 m site (Site 900) was located in a small patch of rainforest vegetation along the side of a small lake between Lobster Lake and Trout Lake. The site looked to have been one of a number of small pockets in the immediate area which had been protected from fires in relatively recent times. It did not appear to be as old, for example, as Site 600. Dominant species in the canopy layer included *P. aspleniifolius, N. cunninghamii*, *Pittosporum bicolor*, *Anopterus glandulosus* and *Richea pandanifolia*. Slope varied from approximately 5° to 15°.

The *Athrotaxis selaginoides* trees on the eastern side of Mount Weld were located in low-lying subalpine scrub areas in relatively open conditions at 900–1100 m. Slope was variable, from 0° to 20°. In contrast, trees on the western side of the mountain were located in the low-lying scrubby *Nothofagus cunninghamii – Eucryphia milliganii* heath community on a relatively steep slope of approximately 15–30° at 800–900 m.

Methods

At each of the three lower *P. aspleniifolius* sites, two cores were obtained from all sampled trees, with a third core taken where a cursory on-site examination of the cores indicated that another may be required. This occurred mainly at the 600 m site where ring compression or wedging was more apparent than at the other sites. At the 900 m site, three cores were taken from most trees due to their relative youth. Where possible, two cores were taken perpendicular to the slope and at opposite sides of the trees. This was done to avoid compression wood. The third core was taken between these two cores. Obvious wedging sites around the trunk, likely compression wood sites and old injuries were avoided. While this method worked well for almost all trees at the two lower sites, it was not possible for a number of trees at the 600 m site where the lower 1–2 m of tree trunks was often 'enclosed' in a dense tangle of *Anodopetalum biglandulosum*. In these cases, cores were obtained where it was possible to obtain them while still avoiding unfavourable sites. All *Athrotaxis selaginoides* specimens were cored three times. Samples were taken with a 16" corer and temporarily stored in plastic straws. At Site 100 m, three *P. aspleniifolius* cross-sections were also obtained although only two could be used. In the laboratory, samples were mounted and sanded with successively finer grades of sandpaper to 600 grit at which point the detailed ring structure became clearly visible.

After sample preparation, the first step in establishing a ring-width chronology is cross-dating. Essentially this is the matching of patterns of wide and narrow rings between samples (see Stokes and Smiley 1968). If cross-dating at a site cannot be achieved, then it is not possible to build a reliable chronology for that site. The cores from an individual tree were first visually cross-dated with the aid of a microscope. For discs, two radii from the outer edge (the sapwood had already decayed) to the centre of the disc were marked and rings checked between these radii. Very narrow rings for all samples were noted. Computer-assisted cross-dating for each site was carried out after visual cross-dating was completed for individual trees. A measuring stage attached to a digital display unit and a computer was utilised. The data quality control program, COFECHA (Holmes 1994), was used to check dating of specimens. For the 600 m site, more than half the samples showed suppression between approximately 1720 and 1850, COFECHA indicating that up to 60 rings were absent over this period for some samples. In this event, the use of COFECHA, series plots and the wood itself, allowed the inclusion of parts of several series which would not otherwise have been utilised.

Ring wedging is a frequent problem in the species (see Allen 1998), and missing rings are often a result of this phenomenon rather than a consequence of regional influences such as climatic variation. Therefore, a ring missing in a single sample, or two of three samples from a tree, was replaced with the mean ring width for that year of other samples from the same tree. However, in order to verify whether or not this is a valid approach for the *A. selaginoides,* a number of cross-section samples from various locations would need to be examined. This was not possible within the context of the current work but is planned for future work.

Once cross-dating was complete for each individual site and species, a master series for each site was produced. Each annual value in this master series was an average across all samples (raw data series) for an individual year after samples had been crudely detrended with a 32-year spline. These master series were used for cross-dating purposes only and were not used for chronology development or climatic construction purposes. Only those portions of the master series with more than five samples in them were used for the purposes of this study. The master series of the two *A. selaginoides* subsites were compared, and the master series of the *P. aspleniifolius* sites were compared to that for each of the *A. selaginoides* subsites.

Following cross-dating, raw data series of the *Phyllocladus aspleniifolius* sites were

Table 1. Basic chronology statistics for the Phyllocladus aspleniifolius *and* Athrotaxis selaginoides *sites.*

	Phyllocladus aspleniifolius				*Athrotaxis selaginoides*	
Statistic	Site 100	Site 400	Site 600	Site 900	Mt Weld East	Mt Weld West
Aspect	N / NE	N / NE	N / NE	E / NE	E	W
Slope	0°	10–20°	5–30°	5–20°	5–20°	20–30°
Period covered	1653–1998	1710–1998	1543–1998	1738–1999	1591–1998	1774–1998
No. of samples	21	30	31	31	10	310
No. of trees	15	15	15	15	6	4
Average ring width (mm)	1.75	1.53	0.939	1.009	0.939	1.009
Max. age of specimen	309	268	430	262	430	262

detrended with a 128-year, 50% cutoff cubic smoothing spline in a bid to remove non-climatic variance likely to be related to microsite factors (see Wold 1974). Stationary index series for each site were produced through the division of the raw ring-width values by their expected value (as given by the spline). Because subsequent analyses assume no autocorrelation in ring-width series, all three index series were autoregressively modelled and the pooled model of autocorrelation (for a single site) reincorporated into the chronology produced for each site.

Results and discussion

Preliminary results obtained from the ten *Athrotaxis selaginoides* trees sampled indicate that cross-dating between individuals of this species at Mount Weld exists. However, ring wedging was a problem for at least two trees, these being the oldest individuals at the site. While some of this could be resolved, there were several instances where it could not. This implies that more than three core samples per tree, a greater number of trees, or both, are required in order to build a satisfactorily robust chronology for this species. Further, samples from opposite sides of the mountain only weakly cross-date, suggesting that they should be treated as two separate populations for the purposes of dendrochronology for the time being. Two possible reasons for this poor cross-dating are: firstly, trees sampled on the western side of the mountain are considerably younger than those on the eastern side; or alternatively, the environment in which the trees are growing differs greatly between subsites. In any case, at this early stage of investigation, the two subsites should not be combined into a single site for any dendroclimatological purpose. It may be possible, with an increased number of older samples from the western side, to show sufficiently strong cross-dating between the east and west sides of the mountain. Table 1 shows some summary data for all sites.

Pointer years for each site of *Phyllocladus aspleniifolius* and each subsite of *Athrotaxis selaginoides* are shown in Table 2. Eighteen of the 30 signature rings observed for either the western or eastern *A. selaginoides* sites

Table 2. 'Event Years' at the five sites. All dates shown are 1s below the mean ring width for the site indicated. Two ticks indicate a value 2s below the mean ring width for that site. Only years where sample depth was greater than five samples have been shown. See Table 1 for time spans of chronologies. The year noted will be the year in which growth began. For example, a date of 1998 means the growing season beginning in 1998, from approximately September 1998 to May 1999.

Date	Site 100	Site 400	Site 600	Site 900	Mt Weld E	Mt Weld W
1575			◷			
1584			◷			
1586			◷			
1588			◷			
1593			◷			
1608			◷			
1613			◷			
1630			◷			
1632			◷			
1635			◷			
1643			◷◷			
1644			◷			
1647			◷			
1660			◷			
1661			◷◷			
1662			◷			
1663			◷			
1677			◷			
1683			◷			
1687			◷◷			
1691			◷◷			
1696			◷◷			
1704			◷			
1707			◷			
1709			◷			
1715			◷			
1719					◷	
1723			◷			
1730			◷			
1734			◷			
1735					◷	
1736			◷			
1744		◷				
1745			◷◷			
1747	◷	◷	◷			
1749		◷				
1752						
1753					◷	
1754			◷			
1755					◷	
1756	◷					
1762					◷	
1763					◷◷	
1771			◷			
1774	◷					
1776		◷	◷			
1777	◷		◷			
1783						
1785		◷	◷			
1788	◷					
1789	◷					
1790					◷	
1796		◷	◷◷	◷		
1797			◷			
1801			◷	◷		
1802					◷	
1803				◷		
1805		◷			◷	
1806	◷◷			◷		
1807	◷					
1808	◷	◷	◷	◷		
1811			◷	◷		
1814	◷	◷◷	◷	◷	◷	
1816	◷	◷	◷			
1823			◷			
1825	◷			◷		
1828						
1832		◷				
1834			◷			
1836			◷	◷		
1840	◷	◷		◷◷		
1844					◷	
1847		◷	◷	◷		
1850	◷		◷	◷		
1853					◷	
1854	◷	◷				
1858	◷	◷		◷		
1860	◷	◷◷	◷			
1863			◷			
1866		◷	◷			
1869		◷	◷			
1871					◷	
1872		◷	◷			
1876				◷		
1880		◷	◷			
1882			◷			
1887			◷			
1889	◷◷	◷				
1890		◷				
1892			◷		◷	
1894	◷					
1897		◷	◷	◷		
1898	◷	◷				◷
1899		◷				
1902					◷	
1908	◷	◷◷	◷◷	◷	◷	
1910	◷	◷	◷	◷		
1912			◷			
1914	◷	◷				
1917		◷				
1920	◷	◷◷				
1921	◷	◷				
1925					◷	◷
1927					◷	
1928		◷		◷	◷◷	
1934	◷	◷◷	◷	◷		
1935		◷				
1938		◷◷		◷		
1940						◷
1946	◷	◷◷	◷◷			
1949						◷
1950		◷◷	◷◷			
1951				◷		
1953	◷		◷	◷		
1955	◷				◷	
1957						◷
1959					◷	
1960		◷	◷		◷	
1961		◷		◷		
1963	◷	◷				
1966	◷◷	◷◷	◷	◷		
1968						◷
1976		◷		◷		
1978	◷					
1981	◷				◷◷	
1985		◷	◷◷		◷	
1989		◷			◷	

Table 3. Correlation matrix (Spearman rank correlation) for Athrotaxis selaginoides *and* Phyllocladus aspleniifolius *chronologies. Figures in brackets indicate the level at which the correlations are significant.*

	Site 100	Site 400	Site 600	Site 900	*A. selaginoides*
Site 100	1	0.590 (0.00)	0.450 (0.00)	0.360 (0.00)	-0.065 (0.23)
Site 400		1	0.700 (0.00)	0.460 (0.00)	0.005 (0.94)
Site 600			1	0.430 (0.00)	0.032 (0.54)
Site 900				1	-0.062 (0.32)
A. selaginoides					1

are not shared by *P. aspleniifolius*. The lack of pointer years in common is of considerable interest and serves to illustrate the poor cross-dating between the two subsites and *P. aspleniifolius* sites. The correlation matrix (Table 3) again reinforces this lack of cross-dating between the two species, hovering around zero for all cases. This may suggest that the two different species are responding to different climatic stimuli. Response function results for one site of *A. selaginoides*, developed by Campbell (1980), suggested this may be the case, although caution in the interpretation of response functions is warranted (Blasing *et al.* 1984). It is also possible that *A. selaginoides* is not reflecting regional influences such as climate but is more related to micro-site factors; hence, the lack of a clear signal and strong cross-dating between the two *A. selaginoides* subsites and sites of *P. aspleniifolius*. More likely, there are insufficient samples to obtain a strong signal from the species. It is also notable that relatively low (but significant) correlations are observed between the master series for Site 900 and those for the other *P. aspleniifolius* sites (Table 3). Strongest correlations were observed between the master series for Sites 400 and 600.

Standardised chronologies for *Phyllocladus aspleniifolius* for Sites 100, 400, 600 and 900 are shown in Figures 1–4. *Phyllocladus aspleniifolius* has been noted as a primary coloniser at a number of sites after fire events or disturbance (pers. obs.). Therefore, the minimum time since the disturbance might be supplied by the earliest date given by the developed chronology plus an allowance for the trees to reach the height at which they were cored. Hickey *et al.* (1999) stated that average growth increment of the species is 10.8 cm / year, suggesting that 12 years are required before trees reached 1.3 m. Although this does not seem unreasonable for the lower two sites, it is likely additional time would be required at the higher sites where conditions were notably more limiting to growth. In this case, 20–30 years would probably be a reasonable period. This translates to an establishment date of approximately 1610–1640 for Site 100, 1665–1695 for Site 400, 1480–1520 for Site 600, and 1660–1700 for Site 900, constituting three establishment events. Although older trees may exist at sites, the probability of trees substantially older than those sampled is relatively small, as the oldest trees at each site were sought after.

Hickey *et al.* (1999) also referred to a further site downslope and east of Site 600 where samples from two *Phyllocladus aspleniifolius* were obtained and aged. The inner ring on one of these was 1549. The similarity of this to Site 600 suggests that both may have been established at the same time, after wildfire. The data from the two stands suggest a fire date around 1500. For Sites 100 and 400, it is equally plausible that fire events occurred just prior to establishment.

Apart from establishment dates possibly indicating fire events, fire sensitive species may also become stressed in years in which fires occur in the region. This may be through increased soil dryness / reduced precipitation or increased temperatures over the summer period. However, fires may

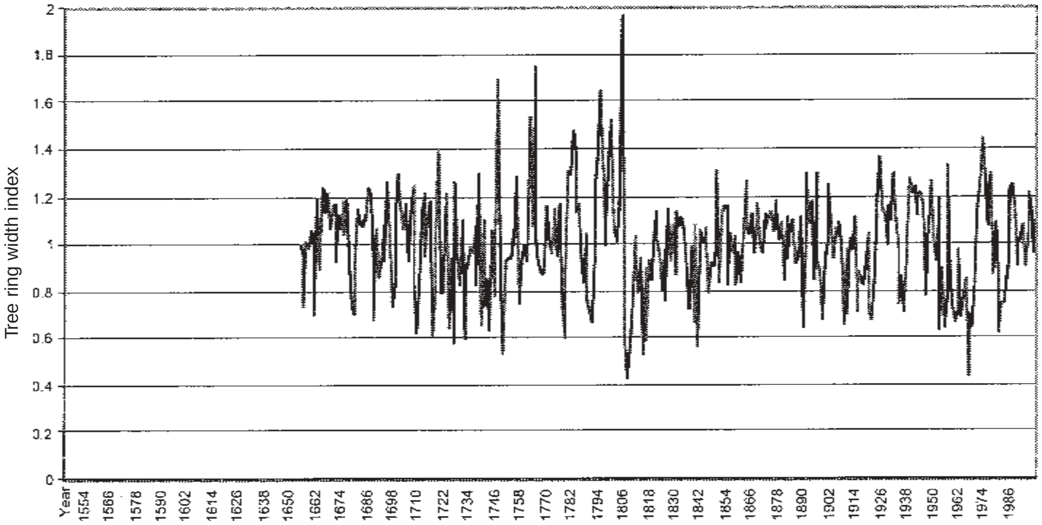

Figure 1. Standardised chronology for Phyllocladus aspleniifolius *for Site 100.*

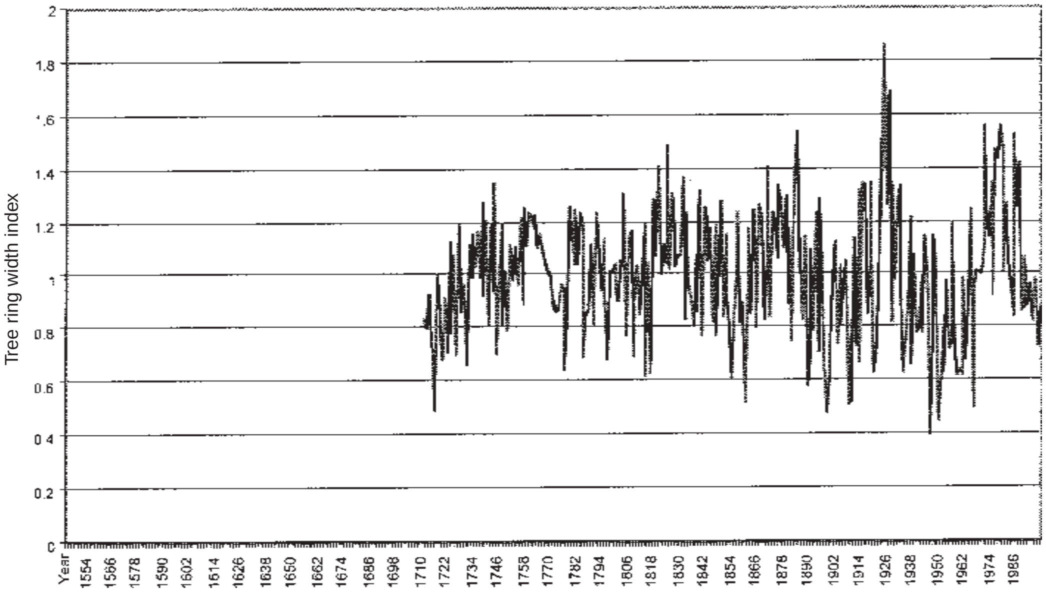

Figure 2. Standardised chronology for Phyllocladus aspleniifolius *for Site 400.*

also occur when neither temperature nor soil dryness has been extreme for long periods. A narrow ring denoting a stressed year for a tree, or stand, therefore may or may not relate to fire conditions. It is worthwhile, in a preliminary investigation, briefly examining the coincidence of signature rings at the various sites and fire events. Major fire events since 1850 occurred in 1851, 1854, 1859, 1862, 1875, 1881, 1887/88, 1897/98, 1903, 1906, 1912, 1914, 1915, 1922, 1926, 1934, 1939, 1940, 1941 and 1947 (Hickey *et al.* 1999). Of these, only 1854, 1887, 1897, 1898, 1912, 1914 and 1934 are noted as event years by *P. aspleniifolius* (Table 2). There is only one signature ring

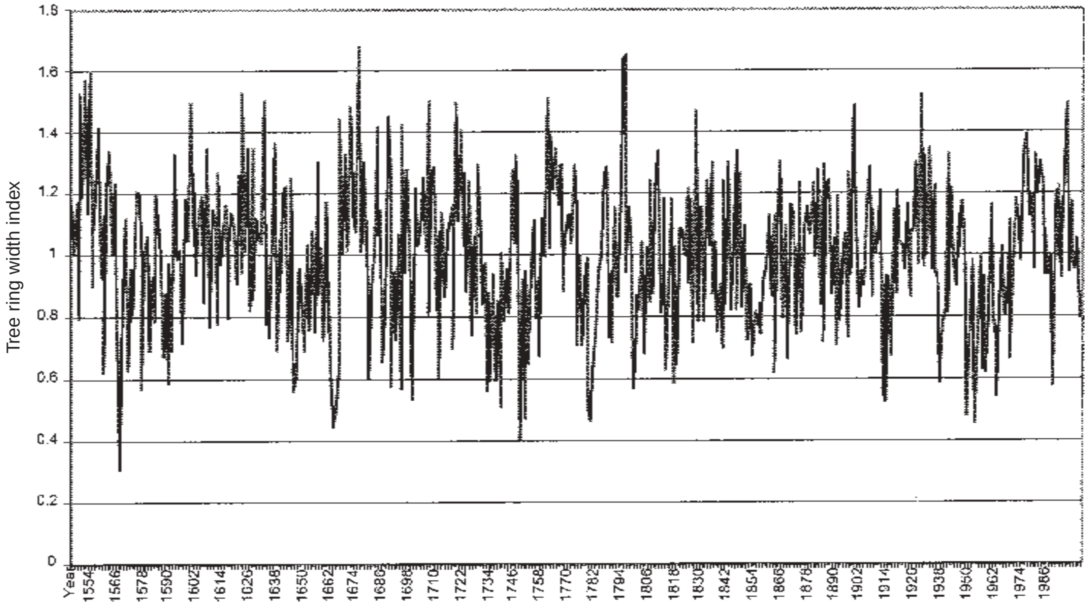

Figure 3. Standardised chronology for Phyllocladus aspleniifolius *for Site 600.*

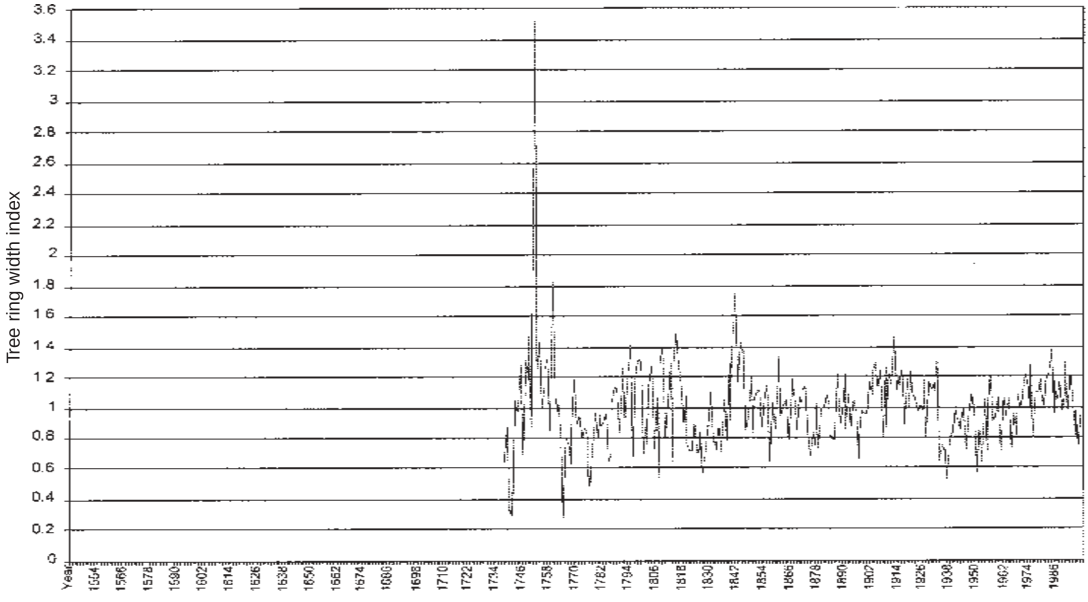

Figure 4. Standardised chronology for Phyllocladus aspleniifolius *for Site 900. Note the difference in vertical scale compared to the other three chronologies.*

for *A. selaginoides* occurring in a fire year: 1940, in the trees from the western side of the mountain. However, there are three fire events years for which *A. selaginoides* records rings more than 1s above the mean, these being 1862 for the eastern side, and 1888 and 1903 for the western side of the mountain (unpublished data).

Unfortunately, there are insufficient data to examine whether or not there is a significant link between signature rings in *P. aspleniifolius* and *A. selaginoides* and fire events. The fact that a considerable number of the recorded fire events are not matched by event years in the ring-width data may indicate that climatic conditions were not sufficiently severe over a sufficient time period to affect ring width.

A number of alternative scenarios also exist. Firstly, it is possible that proximity of a fire is important. Secondly, the size / duration of the fire and / or wind direction over successive days / weeks may be important. Low winds after a fire event may result in ash and smoke remaining in the vicinity, blocking sunlight as well as causing other stresses for the trees for a sufficiently long period to affect cambial growth. Hickey *et al.* (1999) reported three very large fires in 1898, 1914 and 1934. Notably, in 1898 and 1914, the two lower sites showed event years, while 1934 was an event year for all sites, with Site 400 being very stressed. In 1966, a large fire occurred in the nearby Arve Valley, burning an area adjacent to the Warra LTER Site (J. Hickey, pers. comm.). Note that this year was recorded as an event year for all *P. aspleniifolius* sites, although there were no significant climatic anomalies.

The core taken from the *Eucalyptus* stump displayed clear rings, with very distinctive boundaries, not seen in other *Eucalyptus* species from the Warra Site (from lower elevation) examined by the author. Further work on *E. subcrenulata* is warranted on the basis of this. Additional work should aim to determine whether or not there is cross-dating at a site level for this species and, as part of this process, whether or not the rings at a high elevation site such as Trout Lake are annual. Such work would have the potential to assist with the development of fire histories, and may prove to be capable of providing other climatic information, in these high elevation areas. This would, however, depend on the ring patterns being annual and cross-datable. Further work should concentrate on the investigation of *Eucalyptus subcrenulata* from around Trout Lake. If results can be obtained with this species and a chronology developed there is an opportunity to compare climatic responses of three different species at the one site.

No dead trees from a large, high elevation fire-killed stand of *A. selaginoides* in the Warra Site have yet been sampled, but it is intended that these be sampled at a later date. These samples will considerably improve sample depth, and it should be possible to determine whether or not cross-dating between the eastern and western sides of the mountain is possible, and hence whether or not *A. selaginoides* from this area will be suitable for a dendroclimatic reconstruction at a later stage.

Conclusions

Good cross-dating between individuals at each *Phyllocladus aspleniifolius* site was generally achieved and was noted between some individuals at each of the *Athrotaxis selaginoides* subsites. From evidence available at this stage, the two subsites of *Athrotaxis selaginoides* on the eastern and western sides of Mount Weld should be treated as two separate populations. Cross-dating between the two species is not strong at this locality. Four *P. aspleniifolius* chronologies have been developed along an altitudinal gradient.

With the collection of additional samples, it should be possible to attempt climatic reconstruction through the use of *A. selaginoides*. It is likely that considerably older trees exist along the shores of Lobster Lake on the eastern side and, although their sensitivity to climate may be reasonably questioned, this may be a further area for investigation. On the western side, the most obvious course of action is to sample in the fire-killed stand of trees. This should be done prior to any sampling at Lobster Lake. A robust chronology of greater than 500 years in length is a reasonable expectation with further sampling.

Acknowledgements

Thanks to Rob Taylor, Mick Brown and Jayne Balmer for general assistance with this project, and to Leigh Edwards, Brooke Craven, Paavo Jumppanen and Rupert Davies for assistance in the field.

References

Allen, K.J. (1998). A dendroclimatological investigation of *Phyllocladus aspleniifolius* (Labill.) Hook.f. Unpublished Ph.D. thesis, University of Tasmania.

Barbetti, M., Bird, T., Dolezal, G., Taylor, G., Francey, R., Cook, E. and Peterson, M. (1995). Radiocarbon variations from Tasmanian conifers: results from three early Holocene logs. *Radiocarbon* 37 (2): 361–369.

Blasing, T.J., Solomon, A.M., Duvick, N. (1984). Response functions revisited. *Tree-Ring Bulletin* 44: 1–15.

Buckley, B.M. (1997). Climate variability in Tasmania based on dendroclimatic studies of *Lagarostobos franklinii.* Unpublished Ph.D. thesis, University of Tasmania.

Buckley, B.M., Cook, E.R., Peterson, M.J. and Barbetti, M. (1997). A changing temperature response with elevation for *Lagarostrobos franklinii* in Tasmania, Australia. *Climatic Change* 36 (3–4): 477–498.

Campbell, D.A. (1980). The feasibility of using tree-ring chronologies to augment hydrologic records in Tasmania. Unpublished Masters thesis, University of Arizona.

Cook, E.R., Bird, T., Peterson, M., Barbetti, M., Buckley, B., D'Arrigo, R. and Francey, R. (1992). Climatic change over the last millennium in Tasmania reconstructed from tree-rings. *The Holocene* 2 (3): 205–217.

Cook, E.R., Bird, T., Peterson, M., Barbetti, M., Buckley, B., Francey, R., Martins, D. and Tans, P. (1991). A 1089-year temperature record for Tasmania inferred from tree rings of subalpine Huon Pine. *Science* 253: 1266–1268.

Cook, E.R., Buckley, B.M. and D'Arrigo, R.D. (1996a). Inter-decadal climate oscillations in the Tasmanian sector of the southern hemisphere: evidence from tree rings over the past three millennia. In: *Climate Variations and Forcing Mechanisms of the Last 2000 Years* (eds P.D. Jones, R.S. Bradley and J. Jouzel), pp. 141–160. Springer-Verlag, Berlin.

Cook, E.R., Francey, R.J., Buckley, B.M. and D'Arrigo, R.D. (1996b). Recent increases in Tasmanian Huon Pine ring widths from a subalpine stand: natural climate variability, or greenhouse warming? *Papers and Proceedings of the Royal Society of Tasmania* 130 (2): 65–71.

Fritts, H.C. (1971). Dendroclimatology and dendroecology. *Quaternary Research* 1: 419–449.

Hickey, J.E., Su, W., Rowe, P., Brown, M.J. and Edwards, L. (1999). Fire history of the tall wet eucalypt forests of the Warra ecological research site, Tasmania. *Australian Forestry* 62 (1): 66–71.

Holmes, R.L. (1994). *Dendrochronology Program Manual Laboratory of Tree-ring Research*. Tucson, Arizona.

Kromer, B., Spurk, M., Remmele, S., Barbetti, M. and Toniello, V. (1998). Segments of atmospheric ^{14}C change as derived from Late Glacial and Early Holocene floating tree-ring series. *Radiocarbon* 40 (1): 351–358.

LaMarche, V.C., Jr., Holmes, R.L., Dunwiddie, P.W. and Drew, L.G. (1979). *Tree-ring Chronologies of the Southern Hemisphere,* Vol. 4. Australia Laboratory of Tree-ring Research, University of Arizona, Tucson.

Stockton, C.W. and Fritts, H.C. (1973). Long-term reconstructions of water level changes for Lake Athabasca by analysis of tree rings. *Water Resources Bulletin* 9 (5): 1006–1025.

Stokes, M.A. and Smiley, T.L. (1968). *An Introduction to Tree-ring Dating.* University of Chicago Press, Chicago.

Wold, S. (1974). Spline functions in data analysis. *Technometrics* 16 (1): 1–11.