

Dendroclimatology of *Toona ciliata* in Australia

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Introduction

Tree-ring chronologies have been used to reconstruct the variability of past climate in many regions of the world, particularly in North America and Europe. Dendrochronology has rarely been applied in the Australian tropics due to the extreme shortage of species producing anatomically distinct annual growth rings. Only near the coast and its hinterland trees flourish but decrease in size along a rainfall gradient into the inland area. Dendroclimatological studies (e.g. Ash 1983; Rayner 1992) have been conducted with preliminary results indicating that some Australian tree species are suitable for reconstructing climate patterns. In neighbouring countries it has been demonstrated that dendroclimatological studies in the tropics can be successful (Berlage 1931; Jacoby and D'Arrigo 1990; Murphy 1994; Buckley *et al.* 1995; Stahle *et al.* 1998). Other sources for terrestrial proxy-data in Australia are rare and only in the semi-arid to humid zones can sources such as lake sediments, or other archives of vegetation change (Stocker 1971; Kershaw 1978; Hopkins *et al.* 1990, 1996; D'Costa and Kershaw 1995; De Deckker 2001; Bowler *et al.* 2003) and tree-rings (Ogden 1981; Schweingruber 1992) be expected. The inland zone is too dry to conserve any natural archives and adjacent savanna and dry eucalypt forest communities are prone to regular fires, and consequently cannot hold any long-term records (Bowman and Cook 2002). Additionally, trees do not have the chance to grow to old trees due to the damage by insects such as termites (Mucha 1979), thus no long-term annually resolved climate proxy tree-ring records do exist yet for mainland Australia.

Therefore, the objective was made to show that *Toona ciliata* M. Roemer (*Meliaceae*), Australian red cedar, can be used to build tree-ring chronologies and reconstruct climate along the east coast of Australia reaching into pre-instrumental periods. The study concentrates on *T. ciliata* because it is one of the few deciduous tree species in Australia experiencing a seasonal dormant period of the cambium, a general indicator that missing rings might not be a problem as in many other non-deciduous tropical tree species. In addition, it has a wide latitudinal range occurring from Cape York to just south of Sydney which enables the application of a sample strategy adjusted for the tropics, whereby starting in higher latitudes and, with more knowledge gained, approaching the lower latitudes (Stahle 1999).

Toona ciliata belongs to the *Meliaceae* family which is commonly known as the mahogany family and is part of the Indo-Malayan floristic element. The genus *Toona* is closely related to *Cedrela*, the neotropical counterpart, with which it has been repeatedly united and separated

(Boland *et al.* 2002). *Toona ciliata* is a tall deciduous often buttressed tree usually to about 40 m in height and with stem diameters up to 1-3 m. The species occurs in the remnants of warm temperate, subtropical and tropical rainforests between sea level and 1500 m above sea level where it grows in both primary and secondary rainforests. In Australia, *T. ciliata* grows best on rich alluvial or volcanic soils having a neutral to acid pH-range in wind-sheltered positions and is also common on krasnozems derived from basalt. It can tolerate a few frosts each year and prefers a mean annual rainfall of 1200-3800 mm.

This study consists of three parts: dendrometer band studies, growth experiments and dendroclimatology using tree core samples.

Methods

Growth experiments and pinning

Growth experiments consisting of different treatments, *i.e.*, restricting water, temperature, light, and fertilizer supplies were conducted in order to examine their effects on wood anatomy and tree growth. Two additional experiments attempted to induce false rings (density fluctuations of the fibre cells, tangential bands of vessels, extra parenchyma bands, *etc.*). In the first group, trees were defoliated in the middle of their active growth period, and in the second, trees were kept under very low light conditions, *i.e.*, 200 $\mu\text{mol}/\text{m}^2/\text{s}$ photosynthetic active radiation (PAR). The first experiment tried to imitate natural loss of foliage due to insect attack, cyclone or drought damage and the second one aimed to reproduce wet-season tropical conditions with a thick cloud cover and high temperatures prevailing during a major monsoonal depression or a cyclone.

In the past, the pinning method has been identified as a useful tool for studying the timing of annual wood formation (Mariaux 1967; Wolter 1968). Recently, the pinning method has also been used as an intra-seasonal marker system to measure and explore radial growth within one year. For the present study a small needle was inserted into the stem on a quarterly basis.

Dendrometer bands

Dendrometer bands have often been used to detect seasonal growth patterns of trees because they offer an easy way for measuring changes in the diameters of tree trunks. In contrast to dial gauge dendrometers they have the advantage of recording average circumferential increase which can be converted to average radial increase for the entire bole section (Bormann and Kozlowski 1962). Due to their sufficient accuracy and low-budget construction costs dendrometer bands were used in the current study. Two trees were banded and monitored at the Australian National Botanic Garden (ANBG) in Canberra and three trees each on private properties in Robertson and Upper Kangaroo Valley (UKV) during the growing period 2001-2002. The ANBG site is located outside of the species' natural distribution because winter temperatures and annual amounts of precipitation are too low. In Robertson, higher amounts of annual rainfall but occasional frosts are experienced, and hence, the site is situated near the limit of the natural distribution of the species. The third site UKV shows evenly distributed monthly amounts of rainfall and higher temperatures, and

therefore, is found within the natural range of the Australian red cedar. The increment data measured with dendrometer bands at the three sites are compared with temperature and rainfall data which have been averaged and summed, respectively, corresponding with the number of days of each measurement interval.

Preparation of samples for microscopy and digital imagery

For further microscopic analysis thin transverse sections of the pinning areas were cut in large quantities by applying a more time-efficient technique invented by Heady (1997). The light microscopy analysis was done with a Zeiss Axioskop optical microscope equipped with a digital camera. First, the samples were examined for possible tree-ring boundaries that had occurred during the period of the experiment. These observations were then combined with phenology data. Secondly, the images of the pinning areas were imported to digital imagery software which facilitated the measurements of distances from each wound tissue to the cambium at four radii. Along the radii but outside the wound tissue zones numbers and sizes of vessels were noted and averaged for each quarterly pinning zone per tree. The diameter measurements were converted into values of area and then multiplied by the vessel counts. In addition, the measurements were divided by the corresponding values for growth increments represented by the length between the pinning wound tissue and the cambium.

Dendroclimatology

The dendrochronological methods applied in the current study follow the general routines described in Stokes and Smiley 1968, Fritts 1976, Schweingruber 1983, and Cook and Kairiukstis 1990. On the Atherton Tablelands and in Lamington National Park located in north and south Queensland, respectively, 57 dominant to subdominant trees were sampled. The surfaces of the core samples were smoothed according to routine sample preparations with a belt-sander using paper grit size of 240 (Bowers 1964) followed by an orbital sander treatment with paper of increasingly fine grit size up to 1200 (Pilcher 1990). The smooth surface of the cores allowed them to be scanned in high resolution mode and imported to the WinDENDRO program for further analysis (WinDENDRO 2003). Initial crossdating was achieved visually and graphically in WinDENDRO and the final quality control was aided by COFECHA software (Holmes 1994).

After the quality of the crossdating was verified the variance was stabilised using a power transformation. The overall age trend was removed by means of a cubic smoothing spline function with (Cook and Peters 1981). The resulting tree-ring indices were exposed to simple correlation analysis with monthly climate data to identify important forcing factors controlling tree growth. The monthly climate data available comprised precipitation, maximum, minimum and mean temperatures.

Results and discussion

The growth experiments helped to identify crucial aspects of the growth of *Toona ciliata*. They revealed that the treatments were successful in adjusting the phenological performance due to changed environmental conditions.

- It was found that tree growth is sensitive to low temperatures, poor soil and drought conditions.
- The general macroscopic wood anatomical features in terms of vessel size and numbers also changed when trees grew in different environments.
- When restrictions to the supply of water, temperature and soil nutrients applied trees at first reduced growth increments in the latewood zone and then reduced vessel size and increased vessel numbers.
- False rings occurred but only in younger trees or in adult specimens under very extreme conditions, such as total defoliation during a direct cyclone hit or a very extreme drought followed by a fire entering the rainforest, as suggested by Herwitz *et al.* (1998).

The current study illustrated that the home-made dendrometer bands were adequately accurate to monitor stem diameter growth on a weekly to monthly basis for one growing season. The specimens monitored shed all their leaves, stayed leafless for several weeks and entered a dormant period. Growth recorded by means of dendrometers was found to be related to either temperature or precipitation depending on the geographical location. While the tree increments in Canberra were correlated positively with temperature, growth in Robertson and Upper Kangaroo Valley showed more coherence with precipitation. The ANBG is located outside the natural distribution of the species and the continental climate often is extensively hot in summer and cold in winter for longer periods. This might explain the stronger relationship between tree growth and temperature in Canberra compared to the coastal sites where tree growth was mainly influenced by the more maritime climate.

In Upper Kangaroo Valley, diameter growth of *T. ciliata* decreased during both extremely dry and wet periods in December 2001 and February 2002, respectively. This result confirms similar results found for the same species by Bhattacharyya *et al.* (1992) in India that very humid conditions can also limit growth in *T. ciliata*. These humid conditions can be the result of heavy rainfall events or due to soils with poor drainage properties intensifying the problem of water-logging. The question of where is the upper limit for the rainfall values to start exerting a negative effect on tree growth in Upper Kangaroo Valley could not be answered due to the lack of suitable data. To solve this problem long-term dendrometer band studies are strongly recommended. At the beginning of the dendroclimatology section, tree-ring statistics for the two study sites derived from COFECHA and MS Excel outputs are listed in table 1. The trees grew 3.05 to 3.58 mm per year in average. The minimum and maximum values of the annual increments exhibit a wide range typical for tree growth in the humid tropics extending from 0.01 to more than 2 cm. The coefficients of variation expressed as percentages of the mean shows that the standardisation has reduced the variation around the mean immensely to approximately 20 % to 10 %.

Table 1: Summary statistics for the two site chronologies

	Atherton Tableland		Lamington National Park	
Chronology length	2001-1592		2001-1717	
Length (years)	410		285	
No. of trees	37		20	
No. of samples	53		38	
Mean (min./max.) annual increment (mm)	3.58 (0.1/20.55)		3.05 (0.1/21.49)	
Standard deviation (mm)	2.89		2.64	
Coefficient of variation before and after Standardisation (in %)	833.21	21.64	696.84	19.05
Mean sensitivity	0.597		0.588	
Mean autocorrelation before and after standardisation	0.427	0.254	0.316	0.012
1 st year EPS below 0.85	1920		1900	
Series intercorrelation	0.522		0.539	

The values for the mean sensitivity of the sites are large suggesting that they are suited for dendroclimatic research. The values for the series intercorrelation indicate common variance implying that tree growth is controlled by one main common factor. The values for the mean autocorrelation have decreased after the standardisation indicating that the low-frequency variance originating from non-randomness other than climate has been filtered out by the cubic smoothing spline.

The site chronologies from Atherton Tablelands and Lamington National Park are presented in figure 1. The site indices (dark grey graph) were only computed for a minimum of 5 samples. This limit was reached in Atherton Tablelands in 1861 and in Lamington National Park in 1856. The response plots in figures 2 and 3 illustrate that these site indices correlate with precipitation as well as temperature records.

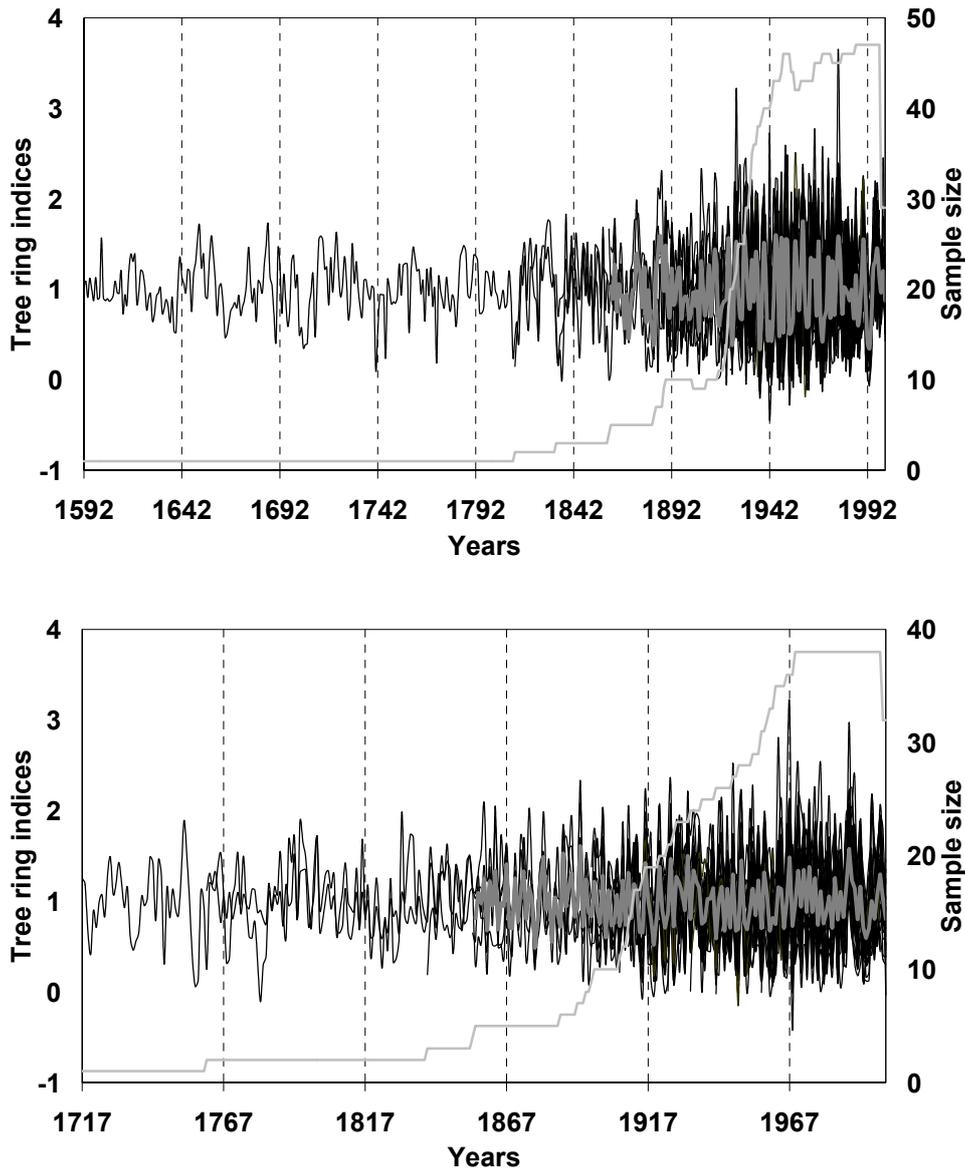


Figure 1: Tree-ring indices with averages (dark grey graph) and sample size (light grey graph) from Atherton Tablelands (top) and Lamington National Park (bottom)

The results of the correlation analysis for the Atherton Tablelands indicate that the precipitation of the months March to June of both the previous and the current season seem to be most important for tree growth (figure 2a). Tropical cyclones bringing torrential rains and other unfavourable tree growth conditions to the region might explain the insignificant correlation patterns during the first part of the current growing period between September and February. The temperature data of the previous year correlate mainly positively with tree growth (figure 2b). This suggests that the specimens from north Queensland seem to have a “temperature memory”, *i.e.*, high temperatures in the second half of the previous year influence tree growth of the present season positively.

In contrast, high maximum and mean temperatures during the current growing season seem to exert detrimental effects to tree growth. For example, during March of the previous and current growing season trees seem to grow best when humid conditions with high minimum but low maximum temperatures prevail.

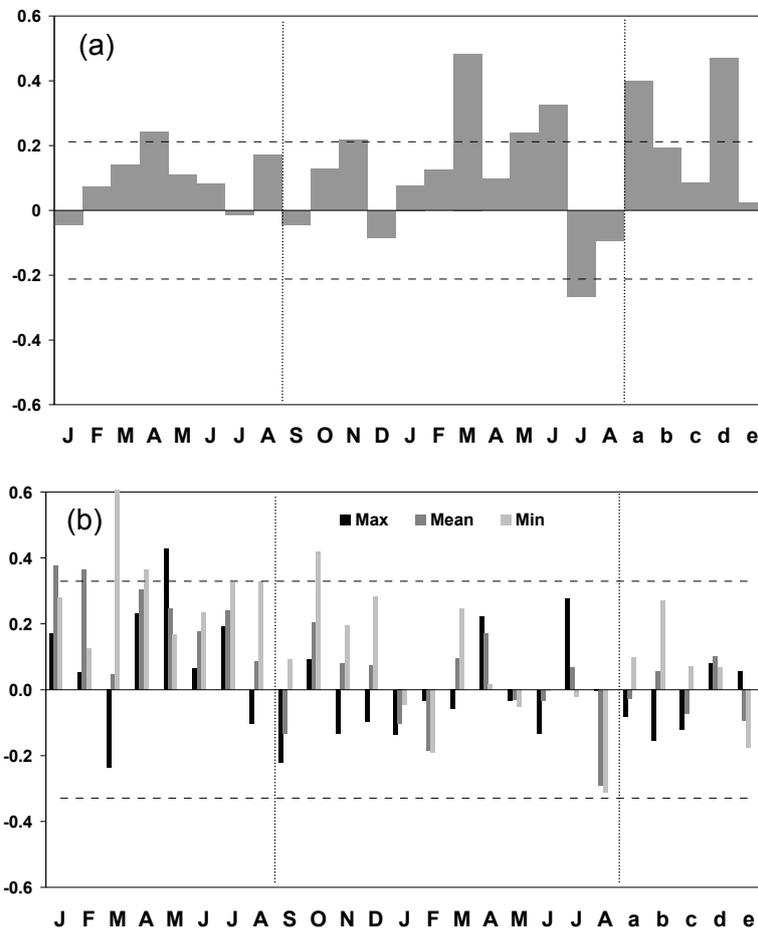


Figure 2: Climate response plots for the Atherton Tableland site with Kairi research station meteorological data: Monthly coefficients of correlation for precipitation (2a) and maximum, minimum and mean temperatures (2b). The left half of the diagram covers the period January to August before the current season the middle part stands for this season (September to August) and the small letters a to e stand for the annual value and the averages for the periods for September to November, December to February, March to May and June to August of the current season, respectively. (Source: Bureau of Meteorology, Canberra 2002)

Figure 3a illustrates that apart from precipitation in August none of the months of the previous year exert significant influence to this season's growth. From September to December of the current season no correlation is discernible. Subsequently, the correlation grows to a significant level in January and remains positive until the end of the season.

The response plot also shows a significant positive correlation value for annual precipitation (letter “a” in diagram 3a). Temperatures of the previous and at the beginning of the current season until November are positively related to tree growth (figure 3b). From December to the end of the growing season maximum temperatures correlate negatively.

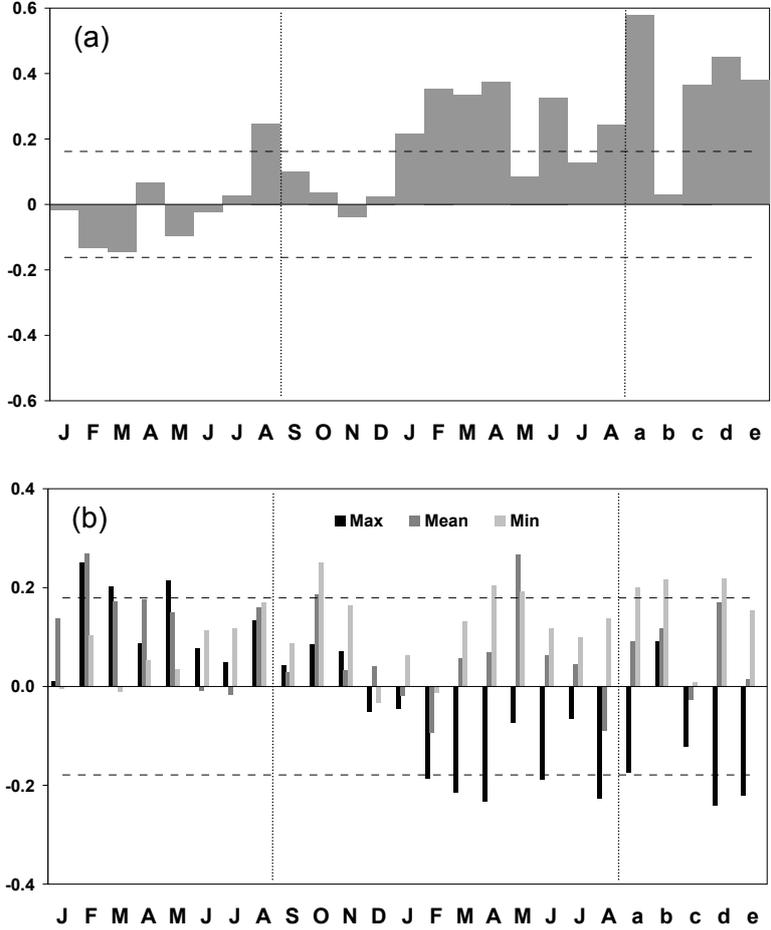


Figure 3: Climate response plots for the Lamington National Park site with Brisbane meteorological data: Monthly coefficients of correlation for precipitation (3a) and maximum, minimum and mean temperatures (3b). The left half of the diagram covers the period January to August before the current season the middle part stands for this season (September to August) and the small letters a to e stand for the annual value and the averages for the periods for September to November, December to February, March to May and June to August of the current season, respectively. (Source: Bureau of Meteorology, Canberra 2002)

The values for the minimum temperature show the reverse displaying significant positive correlations in April and May. This pattern can also be found with a weaker signal for the Atherton Tablelands. These correlations might be an indicator for the particular climate of the tropical highland rainforest which can experience cold nights at any time of the year during periods of clear skies. This is supported by the fact that in the Lamington National Park the cool temperate *Nothofagus* rain forest type can also be found adjacent to the tropical rain forest depending on the local micro-site conditions (Graham 2001).

Conclusions

This study has demonstrated for the first time that *Toona ciliata* can be used for dendroclimatological investigations in the tropics and subtropics of Australia. The site indices were found to be sensitive mainly to seasonal and annual precipitation and to smaller extent to temperature. Further analysis, not presented here, showed only weak correlation between site indices and the El Niño Southern Oscillation (ENSO). However, it was revealed that this relationship seems to be influenced by the state of the Inter-decadal Pacific Oscillation (IPO). Further tree-ring studies need to focus on both climate phenomena ENSO and IPO in order to ensure more reliable regional climate predictions of higher quality.

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