Dating spotted gum (*Corymbia citriodora*) tree rings in south-eastern Queensland using ^{14}C measurements of cellulose

Michele D. Akeroyd[1,2], Fred W. Leaney[2], Michael Mathieson[3], Damien Moloney[4] and Geoffrey C. Smith[3]

[1]Murray-Darling Basin Commission, GPO Box 409, Canberra ACT 2601, Australia
Email: michele.akeroyd@mdbc.gov.au
[2]CSIRO Land and Water, PMB 2, Glen Osmond SA 5064, Australia
[3]QPWS Forestry and Wildlife Division, Sustainable Forestry Sciences Unit, Queensland, Australia
[4]Maroochy Shire Council, PO Box 76, Nambour 4560 Queensland, Australia

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Summary

Application of a radioisotope dating technique to a spotted gum (*Corymbia citriodora*) tree in south-east Queensland showed that the observed growth rings were annual. The dating technique is based on a comparison between the concentration of ^{14}C measured in tree ring cellulose and historical measurements of ^{14}C in the atmosphere. This information improves our understanding of forest processes and growth over time, and undoubtedly will contribute to more efficient measures of forest growth.

Keywords: growth rings; dendrochronology; carbon; isotopes; estimation; *Corymbia citriodora*; Queensland; Australia

Introduction

To understand the successional processes and long-term dynamics of forest ecosystems, it would be highly beneficial to obtain information on actual tree age and growth rates. Estimates of relative tree age can be made from a comparison of individual trees within a stand by observing age-related morphological features such as bole size and crown form, but this provides little information on the actual age or the time-scale of forest dynamics. Knowledge of the absolute age of individual trees can be used to calibrate the rate of successional processes within the forest stand and provide time-scales for sound forest management in terms of both productivity and conservation.

The most widely applied method of estimating tree age is the counting of growth rings across the radius of a cross-section of the tree bole. Most dendrochronological work in Australia and overseas has been in areas of cold climate where seasonality has engendered distinct bands of early and late wood. However, this method is of questionable use in sub-tropical eucalypts due to the perceived lack of distinct, annual growth rings in many species (Ogden 1978, 1981).

One method for estimating tree age that, in theory, does not rely on the production of distinct annual rings, is radiocarbon dating. ^{14}C is a natural isotope of carbon which exists with other isotopes of carbon in the atmosphere. The isotopes are incorporated into wood cellulose in the same ratio as they occur in the atmosphere (Auclair *et al.* 1990). If the wood is more than 200 y old, its age can be determined by measuring the decay of ^{14}C assuming a constant or near-constant concentration of ^{14}C in atmospheric CO_2. Samples are taken from the tree and dated through the analysis of ^{14}C levels in the cellulose. This conventional form of radiocarbon dating has been used to confirm dendrochronology age estimates (Gill 1971; Ogden 1978) for tree rings ranging in age from a few hundred to several thousand years. The standard deviation of analysis for this age range is routinely about 50 y (i.e. ranging from <1% to about 25% of the age of the wood sample).

An alternative method of dating is available for tree rings less than 50 y old. Nuclear testing during the 1950s and1960s increased the abundance of ^{14}C in the atmosphere, resulting in peak values for ^{14}C in the mid-60s. This increase in abundance of atmospheric ^{14}C is well documented and can be used to date recently formed tree rings (Babourina *et al. pers. comm.*). Hence, the year in which a specified ring was laid down from 1950 to the present can be estimated with reasonable accuracy by comparing the ^{14}C trends in the tree rings and the atmosphere.

The aim of this pilot study was to learn if the ^{14}C-trend analysis dating technique can be used to determine the years in which tree rings were formed, and the periodicity of ring formation since 1950. If the technique could provide a relatively accurate method for evaluating tree age, the potentially improved knowledge of forest age structure would support sustainable forest practices.

Method

The last remaining spotted gum tree was taken from an abandoned experimental spotted gum (*Corymbia citriodora*) plantation that had been established in December 1946 at Yarraman State Forest (SF 289) (151.95°E 26.82°S) within the South Burnett province of south-eastern Queensland. The tree was at an early mature growth stage and measured 23 m in height and had a diameter at breast height (DBH) of 60 cm. A complete stem section was collected from the single spotted gum tree. The stem section was

Table 1. A comparison between the ^{14}C of the atmosphere and tree ring cellulose and for each of the tree ring sequences analysed in this study. This comparison assumes that growth was annual.

Year representative of tree ring formation	Atmospheric ^{14}C (% modern carbon)	Cellulose ^{14}C (% modern carbon)	Variation (%)
1946–1947	97.5	95.3	2
1965–1966	161.0	152.2	5
1976–1977	134.4	145.6	8
1987–1988	117.3	122.7	5
1998–1999	109.2	109.3	0

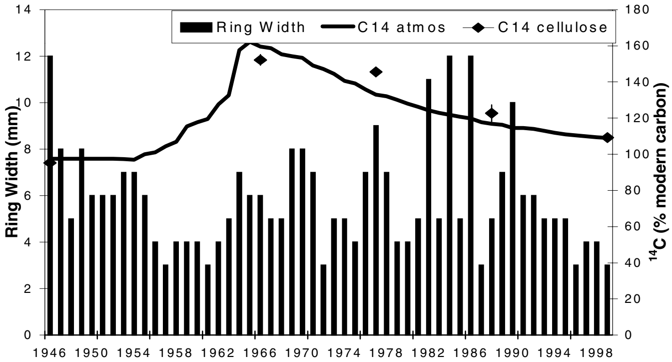

Figure 1. Measurements of tree ring width and ^{14}C of tree ring cellulose from spotted gum (± SE) and the atmosphere (Pretoria, South Africa). Both methods suggest that tree ring growth is annual.

sanded to a high polish so that the tree rings could be distinguished and counted and the width recorded with the aid of a light microscope. Since a complete stem section was available, several radii were used to clearly identify each growth ring around the circumference of the stem section, but ring width was measured along only one radius.

After each growth ring had been identified, groups of rings were collected for ^{14}C measurements. To establish a ^{14}C pattern along the stem, a series of samples was collected for every 10 growth rings, starting with the first two growth rings and ending with the last two growth rings. Each sample consisted of two consecutive growth rings. Two rings were selected to ensure there was enough wood available for analysis, assuming that there would be small differences in ^{14}C in consecutive years. This approach resulted in a total of five samples for ^{14}C analysis. The samples were cut from the stem using a bandsaw. They were ground to a fine mesh, and 5–6 g of wood was weighed into a fibre filter bag to extract alpha-cellulose. The fibre filter bags allow batch processing of samples.

Alpha-cellulose was extracted from the milled spotted gum tree-ring wood samples following the methods described by Epstein *et al.* (1977), Sternberg (1988) and Leavitt and Danzer (1992). This process involved a series of solvent extractions followed by acid washes. The alpha-cellulose was converted to carbon dioxide using an automated Roboprep combustion system at CSIRO Land and Water, Adelaide. The carbon dioxide was subsequently converted to graphite and analysed for isotopic ^{14}C concentration by accelerator mass spectrometry (AMS) at the Australian National University, Canberra.

Measurements of tree ring cellulose ^{14}C were compared to records of atmospheric ^{14}C over a period spanning 53 y.

Results and discussion

From the stem section it could be seen that the tree rings were clearly defined bands comprising distinguishable early and late wood for each growth period. Counting of the tree rings suggested that ring growth was annual (Fig. 1) and that the amount of growth, or stem wood production, varied seasonally.

The bars on the graph represent the widths of the distinct growth rings counted on the stem section. Typically the widths of growth rings may be expected to initially increase exponentially after planting, and then decrease as the tree gets older. This is because more wood volume is required to produce a growth ring as stem diameter and height increase (Fritts 1976). This trend was not observed in the tree investigated (Fig. 1). Variations in growth rings may occur as a result of fluctuating environmental conditions, such as rainfall and soil moisture (Dupouey *et al.* 1993; Livingston and Spittlehouse 1996). For example, in the tree investigated, growth was particularly good during the early 1980s and poor during the late 1950s.

Figure 1 shows that the ^{14}C concentration of tree ring cellulose follows closely that of the atmospheric ^{14}C corresponding to the tree ring sequences, if annual ring formation is assumed. There are small differences between the ^{14}C of cellulose and the atmosphere, and this is likely to be related to recycling and redistribution of ^{14}C from the previous year's carbohydrate store. For example, the years when the cellulose ^{14}C is greater than expected are preceded by years of higher ^{14}C in the atmosphere and vice versa.

Trees can use carbohydrate reserves from the previous year's growth to form the current year's tree ring (Grootes *et al.* 1989a,b), although Grootes *et al.* (1989a,b) found that the contribution of carbon from the previous year's storage was often much less than 15%. There are also errors associated with preparation, such as converting samples to gas and the subsequent conversion to graphite, which are in the order of 2–4%. Given these factors the measured ^{14}C values of cellulose are still within 10% of those of the atmosphere (Table 1), when the periodicity of ring formation is assumed to be annual.

Both the radioisotope analysis and the counting of growth rings suggest that the rate of tree ring production is one ring per year. The results indicate that both tree ring counting and ^{14}C dating are suitable techniques for estimating the rate of ring formation for spotted gum in south-east Queensland. This work, however, has assessed the dating techniques on only a single tree as a preliminary study. Other research has suggested that tree ring periodicity can vary within species due to environmental conditions (Akeroyd 2002; Babourina *et al. pers. comm.*) and there is little information available on the frequency of ring formation for overmature trees, particularly those with hollows. It is therefore recommended that these techniques be tested on trees having a broader range of ages and from other climatic zones, to confirm that these results represent typical frequencies of tree ring formation for spotted gum.

Other recent research (Akeroyd 2002) has found that the ^{14}C technique can be useful in dating eucalypts that are in the 50–200 y range. Difficulties were encountered when the frequency of growth rings appeared to be less than annual. However, this is still a positive outcome for the method since: (a) rates that differ from annual growth can be detected, and (b) coarse estimates of the rates of ring formation can be based on some indicative information even if actual dates of growth cannot be determined. Further more detailed work could use the ^{14}C method to identify the years in which growth actually took place, to identify an environmental cue for growth or non-growth as the case might be. The technique could also be used to identify specific years in which exceptional growth patterns occurred, thus improving our understanding of the cues and dynamics of tree growth.

Conclusions

The major conclusions of this study can be summarised by the following points.

1. The ^{14}C dating technique worked successfully on a single spotted gum in south-eastern Queensland. There were some differences related to recycling and redistribution of ^{14}C from the carbohydrate stores of previous years, but the variations observed between the measured cellulose samples and the atmosphere are within the ranges of normal variability and suggest that the ^{14}C technique can be used to estimate the rate of growth ring formation for spotted gum.
2. Simple ring counting measurements were consistent with the results of the ^{14}C analysis. Therefore the suggested dating technique could be useful in mature spotted gum forests since it is less destructive than cutting a stem section. (The technique can be used on tree cores if necessary.)

The ^{14}C dating technique could potentially be used to date the age structure of entire mixed-aged forests in south-eastern Queensland. This information would improve our understanding of forest processes and growth over time, and undoubtedly contribute to more efficient measures of forest growth.

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