Radiocarbon adjustments to the dendrochronology of a yellowwood tree

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High-precision radiocarbon dating of a millennium-old yellowwood tree from the Midlands of Natal shows that the tree-rings do, in general, record annual growth, but that both missing and false rings occur. At two places along the transect of the trunk there are blocks of 19 and 143 missing rings, respectively, and during the time of most rapid growth some 20 false rings are identified. By matching the ^{14}C results to the radiocarbon calibration curve, an uncertainty of only two or three years is achieved in the dating. The data illustrate that the age of a tree can be determined accurately with radiocarbon, but this does require the analysis of several samples. The ring-width analysis shows periods of slower and more rapid growth over the centuries that are interpreted as reflecting changes in the precipitation rate in the summer rainfall region of South Africa. Five exceptionally narrow rings around 1820 suggest that five years of severe drought after two decades of very high rainfall may have been a contributing factor to the widespread tribal warfare and devastation that occurred at that time.

The indigenous gymnosperm taxa of the Cape cedar (*Widdringtonia*) and yellowwood (*Podocarpus*) have been identified as candidates for dendrochronological analysis.[1–3] In 1976, M. Hall investigated the tree-ring growth pattern of a large *Podocarpus falcatus* trunk from the Karkloof Forest (29°25′S, 30°18′E), 25 km northeast of Howick, in the midlands of KwaZulu-Natal, and produced a ring-width curve, the fluctuations of which were interpreted as indicative of variations in past precipitation.[4] This valuable first successful attempt of using dendrochronology to reveal past climates in South Africa was accepted by Tyson in his reconstruction of climatic change on the subcontinent.[5]

The tree was felled in 1916 and a disk from *c.* 1.5 m above ground was presented to the Natal Museum in Pietermaritzburg. It has a diameter of 1.6 m and Hall identified 597 annual rings along the longest radius. In 1977, we cut a wedge of 1.06 m along this transect from the back of the disk for further investigation. A thin slice of the strip was mounted for reference purposes. The surface was sanded and polished to reveal the ring structure. The annual rings were viewed under magnification, counted and numbered. Our initial count gave 631 rings, but several instances of merging rings were noted and it was realized that missing rings may constitute a problem.

We also measured the average ring width of each successive five annual rings. Ring width measurements on this species is, however, a problem owing to changes in the width of the annual rings over short distances and the merging of rings. The same observations were made by the Tyson team for *P. falcatus* boles from Magoebaskloof and the Knysna area.[2,3] Nevertheless, the analysis does reveal extended periods of slow and rapid growth of the tree. Our initial plot is shown together with Hall's data in Fig. 1. The two curves essentially show the same general pattern of broad and narrow rings over time.

Radiocarbon dating

In order to check the ring count, 26 samples were cut from the transect for ^{14}C analysis. The pieces of *c.* 25 g each were split into matchstick-size slivers and rigorously treated with dilute acid and alkali to remove soluble organics before combustion to carbon dioxide. Since the tree was felled in 1916, there is no danger of contamination with excessive ^{14}C derived from nuclear weapon tests so that this pre-treatment is sufficient.[6,7] The purified gas was measured in a large volume proportional counter for several days and the ^{14}C activities corrected for variations in the initial isotope composition of the carbon with the aid of ^{13}C analyses.

The results of the ^{14}C analyses are given in Table 1. The ages obtained can be compared with the dendro-dates derived from the ring counts. This cannot, however, be done directly because ^{14}C ages need adjustment to convert them to true calendar dates. This is achieved with the dendrochronologically based high-precision calibration curve at present available [8] by the process we call 'wiggle matching'.[9] In Fig. 2 the ^{14}C ages are plotted against the dates inferred from our ring counting (pluses and thin line). Also shown as a full line is the calibration curve for the southern hemisphere adjusted to best match the Pretoria dating equipment.[10] Although the general shapes of the two curves is the same, there are obvious discrepancies, indicating that there are errors in the ring counting.

Starting from the right-hand side of the figure, at AD 1916, we see that the dendro-dates for the samples in the period back to *c.* AD 1500 are several years too old. By matching the sample ages, specifically those that fall into the 17th century where the calibration curve is steep, the best fit shows that 20 ± 2 rings too many were counted on the outer part of the transect. Scrutiny of this section indeed revealed some 20 rings that are suspect in that they are rather diffuse without a distinct outer boundary of small dark cells. In particular, we identified 7 false rings between ring no. 36 and ring no. 56 (Sa2); 10 false rings between ring no. 56 and ring no. 97 (Sa3); and 3 more between ring no. 121 (Sa5) and ring no. 135 (Sa6). When corrections for these false rings are made, the ^{14}C values fall very closely onto the calibration curve back to ring no. 418 (Sa21), but now the next five ^{14}C samples have dendro-dates that are too young. There must, therefore, be rings missing between samples 21 and 22, i.e. between ring no. 418 and ring no. 442. At ring no. 436 there is a scar on the radial transect which is the probable place where the missing rings should be. The best match of the next three ^{14}C dates to the sharp rise on the calibration curve indicates that 19 ± 3 years need to be added at this point. Finally, the two innermost samples still have

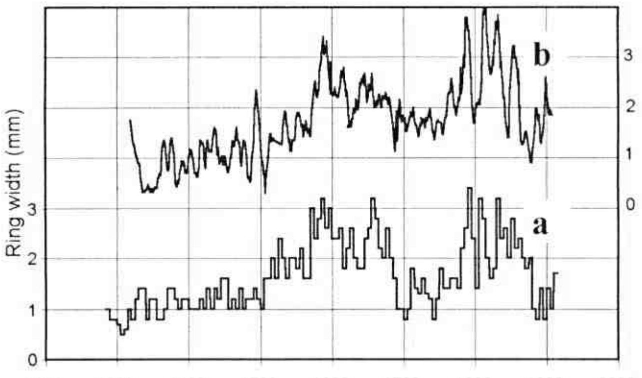

Fig. 1. Ring-width curves along the longest radial transect of the Karkloof tree trunk; **a**, average of each successive five annual rings as measured by us; **b**, seven-year running average as measured by Hall.[4] In general there is good concordance between the two curves.

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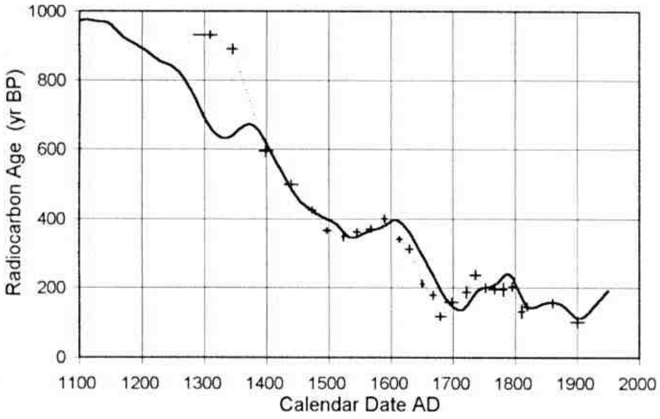

Fig. 2. Radiocarbon ages plotted against the dates derived from the initial ring-count (pluses and dotted line). The calibration curve for radiocarbon ages is shown as a solid line. Comparison of the two curves clearly shows that there are errors in the ring-count. The horizontal bars on the points reflect the number of rings in each sample, while the vertical bars indicate the one sigma uncertainty of the ^{14}C measurements.

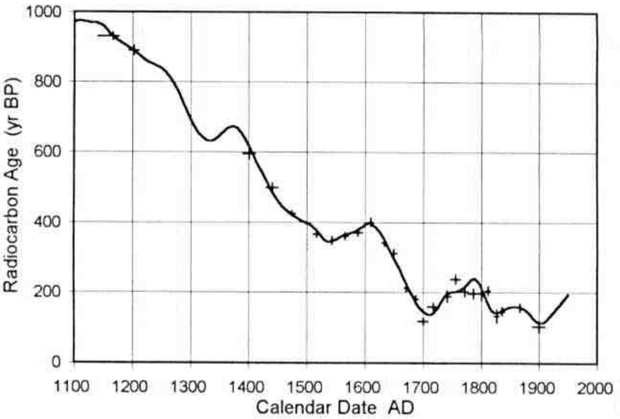

Fig. 3. The calendar dating of the radiocarbon ages after 'wiggle matching', that is, after elimination of 20 false rings in the 19th century, and insertion of 19 rings at AD 1481 and 143 rings at AD 1215. The dating of the outer part of the bole is estimated to be accurate to within two or three years, while that of the core has an uncertainty of ±7 years.

dendro-dates that are much too young. At ring no. 558 there is another distinct scar on the transect, with rings on its outside merging together, again indicating that no wood had been formed on this radial strip. By matching the two inner dates to the calibration curve, we are compelled to conclude that some 143 ± 7 rings are missing where the scar occurs. This is a remarkably large number of rings to be missing, but a scar on part of the outer surface of a slow-growing tree like the yellowwood, caused, for instance, by a lightning strike or fire, may well take that long to heal.

In summary, by wiggle matching a set of ^{14}C measurements to the radiocarbon calibration curve, we are able to identify three different errors in the annual ring count along the radial transect of the Karkloof yellowwood tree:

1) some 20 false rings during the 19th century, which, incidentally, was the period of most rapid growth;
2) 19 missing rings at a scar formed in *c*. AD 1480;
3) about 143 missing rings where there is a distinct scar and subsequent merging of rings on that part of the trunk subsequent to *c*. AD 1220.

Figure 3 shows the results after adjustments are made for these three counting errors. Since the historical dating is, in each instance, based on several high-precision ^{14}C dates, the uncertainty is considered to be less than three years for the outer section of the transect back to AD 1360 and slightly more for the inner part of the bole. The actual match of the ^{14}C ages with the calibration curve that is achieved is highly satisfactory. The slight scatter of the values around AD 1800 can be ascribed to statistical fluctuations of the measurements. Incidentally, the close correspondence of the five samples that date to the 17th century, i.e. the period when the ^{14}C ages are relatively insensitive to the precise calendar date, confirm the accuracy of the calibration currently in use with the Pretoria laboratory equipment. Based on the calibrated date of AD 1167 for the core sample, which

Table 1. Results of the radiocarbon measurements on samples from the transect of the Karkloof tree. The uncertainties attached to the ^{14}C ages are the one sigma errors, while those of the calendar dates indicate the number of annual rings in the sample.

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Sample no.	Anal. no. Pta–	Distance from core (mm)	Ring no.	$\delta^{13}C$ (‰ PDB)	^{14}C age (yr BP)	Date from ring count AD	Corrected date AD
		1060	1			1916	
1	5302	1025–1040	16	–22.2	102 ± 15	1900 ± 10	1900 ± 10
2	5312	965–990	56	–22.2	157 ± 11	1860 ± 5	1867 ± 3
3	2205	857–880	97	–21.6	146 ± 11	1819 ± 5	1836 ± 4
4	6675	837–857	106	–22.2	133 ± 18	1810 ± 4	1827 ± 4
5	2216	798–828	121	–22.0	204 ± 12	1795 ± 5	1812 ± 4
6	5300	765–790	135	–22.0	196 ± 18	1781 ± 5	1801 ± 4
7	2208	740–765	149	–21.8	196 ± 13	1767 ± 9	1787 ± 9
8	6529	720–740	164	–21.3	200 ± 12	1752 ± 6	1772 ± 6
9	2221	698–715	180	–21.9	237 ± 12	1736 ± 8	1756 ± 8
10	6668	680–692	194	–21.8	188 ± 16	1722 ± 6	1742 ± 6
11	2228	646–670	218	–22.1	159 ± 11	1698 ± 10	1718 ± 10
12	5319	621–646	236	–22.1	118 ± 10	1680 ± 8	1700 ± 8
13	2390	600–621	248	–22.1	179 ± 11	1668 ± 4	1688 ± 4
14	2382	550–567	265	–22.1	212 ± 9	1651 ± 2	1671 ± 2
15	2381	507–525	286	–22.2	312 ± 11	1630 ± 5	1650 ± 5
16	2376	472–489	302	–22.9	341 ± 8	1614 ± 4	1634 ± 4
17	2368	410–432	326	–21.9	401 ± 11	1590 ± 4	1610 ± 4
18	2251	348–370	348	–22.7	371 ± 10	1568 ± 7	1588 ± 7
19	2246	300–320	370	–22.2	361 ± 9	1546 ± 5	1566 ± 5
20	2551	252–266	392	–22.6	348 ± 11	1524 ± 3	1544 ± 3
21	2555	208–225	418	–22.8	366 ± 8	1498 ± 6	1518 ± 6
22	2572	172–187	442	–22.4	426 ± 8	1474 ± 6	1475 ± 6
23	5325	127–150	476	–22.3	498 ± 12	1440 ± 10	1441 ± 10
24	5396	90–107	516	–24.0	595 ± 15	1400 ± 10	1401 ± 10
25	2291	46–59	570	–23.7	889 ± 14	1346 ± 8	1203 ± 8
26	2237	0–25	606	–24.9	930 ± 11	1310 + 10 – 25	1167 + 10 – 25
		0	631			1285	1142

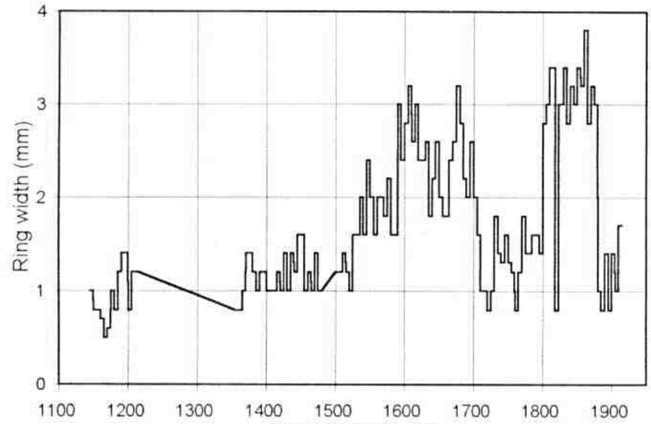

Fig. 4. The ring width curve after adjustments to the calendar dates. The increasing growth rate during the 16th century and the general high values during the 17th probably reflect high rainfall during the Warm Phase within the Little Ice Age, while the low growth in the 18th century represents low precipitation in the final stage of that Age. The five-year averaging process around 1820 is slightly adjusted to highlight the five narrow rings between 1817 and 1823.

comprised 35 rings, we conclude that the tree started growing in *c.* AD 1142 and was thus 774 years old when felled in 1916.

Climatic inferences

Although it is not good dendrochronological practice to infer past climatic conditions from the growth pattern of a single tree, Hall has argued that its location on a hill-slope in a mild environment of the summer rainfall region would imply that annual precipitation was the limiting factor for growth, and that the ring widths thus would reflect the rainfall pattern of the past.[4]

Accepting these expectations, we may have another look at the growth record of the Karkloof yellowwood. In Fig. 4 the data are presented on the adjusted time scale, again using the average thickness of each successive five rings. The graph shows two periods of generally faster growth, first during the 17th century and then again during the 19th century, as do the curves in Fig. 1, albeit with the appropriate shifts in the dating. Comparison of the area around AD 1800 in Fig. 4 and Fig. 1 suggests that Hall also counted too many rings during the 19th century, shifting his curve some twenty years to the left, as was the case with our initial count.

Insofar as Fig. 4 represents regional rainfall, we can identify the following general pattern: Low precipitation before AD 1520, followed by a gradual increase to high values during the 17th century. Between 1705 and 1800 there was again a period of low rainfall before the exceptionally wet conditions that prevailed between 1800 and 1880 and a final drier spell until 1916.

The sequence shows a remarkable resemblance to the pattern that has been proposed for the summer rainfall region by Tyson and Lindesay.[11] They concluded that cooler climate was locally associated with dry conditions and *vice versa*. We thus have the following scenario: low rainfall during the Little Ice Age that started *c.* 1300 and, according to Fig. 4 ended in 1800, interspersed with wet conditions during the Warm Phase of the 17th century. After 1800 Fig. 4 suggests unusually good rains until 1880.

Historical implications

It has been argued that past changes in the rainfall regime has had a major impact on the population density of Iron Age communities that gradually occupied the eastern summer rainfall region of South Africa since AD 400.[12–14] Of interest here is the decline in the expansion of the Iron Age farmers after the onset of the Little Ice Age in *c.* 1300, and the rapid increase, together with the occupation of the interior Highveld, at about 1600. The causal effect of the rainfall frequency on these developments seems to be confirmed by the Karkloof data presented here.

One further observation needs to be pointed out: during the high rainfall period of the 19th century there are five consecutive, very narrow annual rings in the Karkloof specimen between 1817 and 1823. As stated above, the dating is accurate to two or three years. If this represents five years of extreme drought in the region, it would have had a disastrous effect on the local farmers, especially after twenty years of unusually good rains. The high rainfall during the first two decades of the 19th century would have led to an increase of livestock and population, and the system would not have been able to cope with five successive years of crop failure and drought. Such a calamity may well have constituted a major cause for the unrest and tribal wars that occurred at that time — the Mfecane or Difiqane.

Conclusions

The set of high-precision radiocarbon dates confirm that, on the whole, the age of yellowwood trees can be determined by counting the visible annual rings. At two different places along the transect that we investigated, however, some 19 and 143 rings are missing, and during the period of most rapid growth some 20 false rings occur. These discrepancies could accurately be assessed by matching the ^{14}C assays to the calibration curve for radiocarbon age determinations.

The results demonstrate how the age of a tree can be determined to within only a few years with the aid of radiocarbon dating. Four or more carefully selected samples from the bole may, however, be needed to achieve this degree of precision.

The ring width sequence along the longest radial transect of the Karkloof tree clearly shows century-long periods of slow and rapid growth, which are interpreted as a reflection of precipitation changes in the summer rainfall region of the country.

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