

The potential of the baobab (*Adansonia digitata* L.) as a proxy climate archive

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Abstract

The large girth and immense size of the baobab has caused many to speculate about its age. Unfortunately reliable age estimates cannot be determined from growth rates as the girth varies in response to different moisture regimes. In a similar way, ages cannot be determined from ring-width measurements or X-ray densitometry as the absorbent nature of the soft fibrous wood and distortion upon drying prevent the application of these techniques. The Southern Hemisphere bomb radiocarbon curve was used to demonstrate that the rings of a recently-fallen baobab (*Adansonia digitata* L.) from Kruger National Park appear to be annual. The detrended C isotope values of finely-ground wholewood from another baobab specimen were found to be highly associated with January precipitation ($r = 0.72$; $p < 0.01$). This study demonstrates that high resolution information about past climates may be obtained by analysing the C isotope values from baobab samples even if distortion of ring-widths has occurred during drying. However, this relationship must be replicated before the baobab can be demonstrated to be a reliable palaeoclimatic proxy.

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1. Introduction

The African baobab (*Adansonia digitata* L.) is perhaps one of the most recognisable of all African tree species. It is distributed across the majority of Africa, south of the Sahara, yet our knowledge of it is surprisingly limited (Wickens, 1982). The trees can grow to immense size and this had led to considerable speculation about the age of specimens.

In AD 1749, the French naturalist Michel Adanson examined two living trees on the Magdalene Islands off Cape Verde on the coast of Senegal, which he estimated to be 5150 years old (Wickens, 1982). However, the African missionary and explorer, David Livingstone, questioned these calculations as a tree of this age would pre-date the Great Flood of the Old Testament. Assuming annual growth rings, Livingstone calculated that a baobab 85 feet (26 m) in circumference was 14 centuries old and consequently within the Christian era (Livingstone, 1861). Even today, estimates of the oldest tree ages vary and some of the less than scientific

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age estimates have been perpetuated through the literature. Although Wilson (1988) stated that few baobabs exceed 400 years; published maximum age estimates range from 2 ka (Coates Palgrave and Coates Palgrave, 2002) to 3 ka (Esterhuysen et al., 2001) with some samples reported to be over 4 ka old (van Wyk, 2000). Irregular and asymmetrical growth (Wickens, 1982), seasonal changes in girth caused by water losses and gains (Fenner, 1980) and the shrinkage of older trees make it extremely difficult to measure the girth of baobabs accurately and caution is required if growth rates are to be used to determine age (Weyerhaeuser, 1985; Guy, 1982).

If the rings are annual, as Livingstone assumed, the cross-dating of samples (Stokes and Smiley, 1963) would enable the establishment of chronologies with absolute confidence in the integrity of dates. However, although the soft, fibrous wood is arranged in concentric layers (Baum, 1995), “Practically every authority consulted states categorically that baobabs do not form annual rings.” (Guy, 1970).

Although the absorbent nature of the wood structure may preclude the use of the baobab for conventional dendroclimatology or X-ray densitometry, the potential exists for stable isotope techniques to be applied to this archive as a measure of past climates. As baobabs are known to be very sensitive to climate (Guy, 1970), research is required to expand upon the pioneering work of Swart (1963) to determine if the rings are annual. The aim of this pilot research project is to determine if the rings of the baobab are annual and, if so, can any proxy parameters be related to climatic variables.

2. Methods

The locations of recently-fallen baobabs were recorded during the annual aerial wildlife census in Kruger National Park in August AD 2001. It is thought that many of these trees died sometime after the extreme floods that occurred during January and February AD 2000. A radial segment was obtained from the base of a recently fallen tree close to the Luvuvhu River near to Pafuri (22°25.09'S, 31°14.18'E; circumference = 13.3 m) (Tree 1). The tree was hollow at the base with some roots present. There were several branches with leaves indicating that some sections of the tree were still actively photosynthesising. An additional 12 mm diameter core was obtained from a living tree of known age (Tree 2) that was planted in Skukuza in AD 1972

(24°59.21'S, 31°34.92'E; circumference = 1.5 m). Both of these samples were obtained in April 2002.

In the laboratory, the samples were air dried over several weeks to minimise the effects of shrinkage. Although the fragile nature of the segment prevented the use of a measuring stage, ring-widths were measured using a hand lens and graduated scale. To examine the nature of the concentric rings, 3 samples obtained from the segment of the recently-fallen baobab (Tree 1) were selected for high-precision ^{14}C analysis at the Quaternary Dating Research Unit, Pretoria, South Africa. The samples (*ca.* 30 g) were collected from identifiable growth bands and the number of growth bands between each sample counted. Each sample was then split into matchstick size pieces and pre-treated using standard techniques to remove soluble organic components (Tans and Mook, 1980). The ^{14}C content of the samples was determined by gas proportional counting (Vogel and Marais, 1971).

Additionally, samples from each ring of the core (22 in total -Tree 2) were removed as a fine homogeneous powder using an electric drill, taking care not to char or fractionate the sample of wood. Stable C isotope measurements were determined using a PDZ Europa 20/20 continuous flow stable isotope ratio mass spectrometer and ANCA GSL elemental analyser. Results are expressed using the conventional notation as deviations from the Vienna Pee Dee belemnite (VPDB) standard (Coplen, 1995). The average precision on replicate results was 0.12‰, which reflects sample preparation and measurement errors.

3. Results

The atmospheric testing of nuclear weapons caused the Northern Hemisphere atmospheric ^{14}C levels to peak at almost double the natural value in AD 1963–1964. Even though the majority of tests were carried out in the Northern Hemisphere, the Southern Hemisphere experienced a similar change albeit of a reduced magnitude in AD 1965 (Vogel et al., 2002; Hua et al., 2003). As the elevated ^{14}C value of atmospheric CO_2 is still above natural levels and trees directly record atmospheric CO_2 (Hua et al., 1999), Southern Hemisphere tree-ring samples can be dated to approximately the nearest year from AD 1955 to present (Vogel et al., 2002). Although the technique is relatively straightforward, a ^{14}C value will usually have two possible calibrated dates depending upon the intercept with the ‘bomb

carbon' curve (Vogel et al., 2002). Initial calibration with the Southern Hemisphere ^{14}C dataset revealed two equally valid calibrated dates for each sample from Tree 1 (Table 1). However, using *a priori* information about the time-series, such as that the inner portion of the segment must be relatively older than the outer parts, it was possible to eliminate improbable dates.

Of the 38 rings in the segment, the three samples for radiocarbon dating were obtained from rings 6, 9–10 and 26, where ring 1 is located towards the centre of the section (Fig. 1). The outer sample (ring 26) had a ^{14}C value of 157.9 ± 0.4 pMC (PTA-8789) which corresponds to a calibrated radiocarbon date of AD 1959 or AD 1989/90 (Table 1). The date of the middle sample (rings 9–10) which had a ^{14}C value of 148.6 ± 0.6 pMC (PTA-8731) must be older than the outer sample (Table 1). Whatever

date is chosen for the middle sample (AD 1963 or AD 1972), it is clear that AD 1959 can now be rejected for the outer sample. By a similar process of elimination, it is possible to reject the date of AD 1963 for the middle sample (rings 9–10). Therefore, the gap of 16–17 rings between the outer (ring 26) and the middle sample (rings 9–10) corresponds to the period of 17–18 years (Fig. 1). Within the errors of radiocarbon dating, the rings of the recently fallen baobab (Tree 1) would appear to be essentially annual in nature.

By sampling at the extreme limits of a plant's distribution, it is likely that the plant response to climate will be enhanced relative to extraneous noise (Schweingruber, 1988). To test this hypothesis, a 12 mm diameter core was obtained from a baobab (Tree 2) growing at the Staff Housing at Skukuza ($24^{\circ}59.21'S$, $31^{\circ}34.92'E$) to enable the association

Table 1

Calibration of radiocarbon dates using independently-dated plant and animal material and direct Southern Hemisphere atmospheric measurements from the year AD 1959 (Vogel et al., 2002)

Sample reference	Sample designation	$\delta^{13}\text{CVPDB}$ (‰)	^{14}C (pMC)	Calibrated Southern Hemisphere date (AD)
PTA-8789	Ring 6 (inner)	-25.1	157.9 ± 0.4	1964 or 1968/9
PTA-8731	Rings 9–10 (middle)	-25.6	148.6 ± 0.6	1963 or 1972
PTA-8739	Ring 26 (outer)	-26.1	117.3 ± 0.5	1959 or 1989/90

The high precision radiocarbon values of Tree 1 were determined at the CSIR in Pretoria, South Africa (Vogel and Marais, 1971). pMC denotes the radiocarbon content as percent modern carbon relative to the standard reference sample (NBS Oxalic acid).

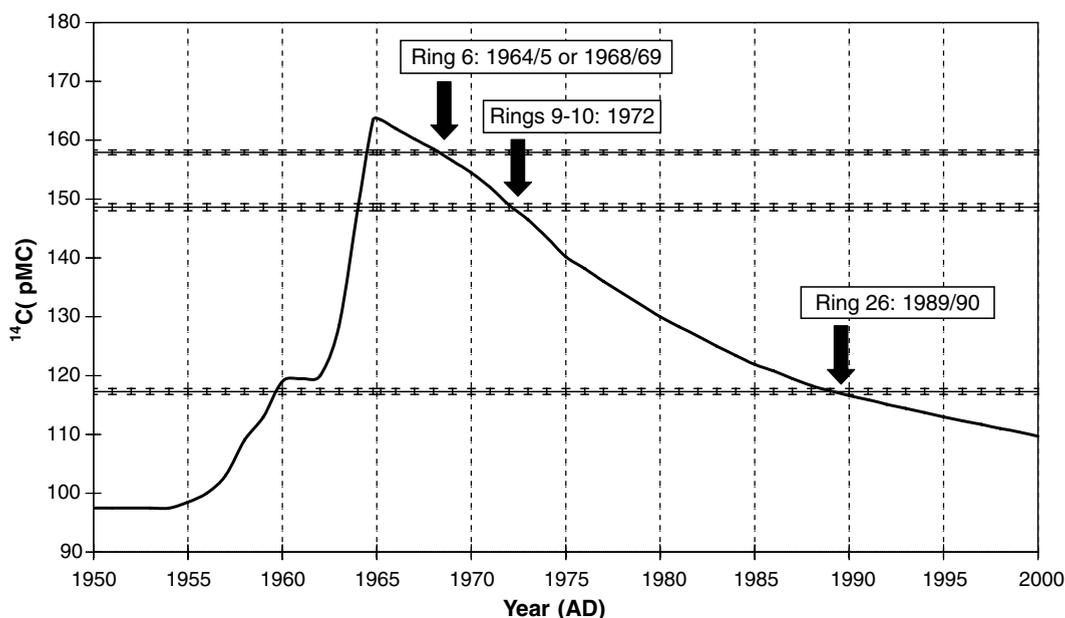


Fig. 1. The average annual summer ^{14}C values (pMC) for mid-southern latitudes (Vogel et al., 2002) from AD 1950 to 2000. Superimposed upon this figure are the ^{14}C values for the samples obtained from rings 6, 9–10 and 26 of the recently-fallen baobab (Tree 1). The error bars on the radiocarbon dates represent the standard 1σ errors.

with temperature and precipitation recorded at the nearby Skukuza meteorological station (24°59'S, 31°36'E) to be investigated. The mean monthly precipitation at Skukuza is illustrated for the period 1981–2002 (Fig. 2). It is evident that the majority of precipitation falls during the summer months (October–April).

The stable C isotope values were measured on the 22 apparent rings from the core sample (Fig. 3). Based upon the results from the baobab segment (Tree 1), it was assumed that baobabs could exhibit annual growth rings. Although some studies assign the calendar year to the year in which growth commenced (LaMarche et al., 1979), the calendar year was assigned to the period of maximum growth and therefore, it was estimated that the core sample covered the period AD 1981–2002. For this short modern time series, the raw C isotope values (Fig. 3) were detrended to remove possible non-climatic trends (i.e.: changing atmospheric ^{13}C composition) by fitting a linear trend through the data. One possible limitation of this technique of statistical detrending is that for longer time series potential low-medium frequency climatic trends could also be removed (McCarroll and Loader, 2004). The relationship between detrended C isotope values and meteorological variables was investigated using SPSS/WIN. Over the period AD 1981–2002, the

highest association was found between January precipitation and the detrended C isotope series ($r = 0.72$; $p < 0.01$) (Fig. 4).

4. Discussion: annual rings and potential for palaeoclimate research

Stomatal conductance and photosynthetic rate are the two key factors that determine the C isotope value of trees rings (McCarroll and Loader, 2004). Baobabs have the ability to minimise water loss by decreasing stomatal conductance (Fenner, 1980). However, the positive relationship between detrended C isotope values and precipitation cannot be explained adequately by the widely reported equations for C_3 plants:

$$\delta^{13}\text{C}_p \approx \delta^{13}\text{C}_a - a - (b - a)(c_i/c_a)$$

where $\delta^{13}\text{C}_p$ and $\delta^{13}\text{C}_a$ represent the C isotope values of the plant and atmosphere respectively; a represents the diffusional fractionation factor; b is the biochemical fractionation and c_i and c_a represent the intercellular and ambient concentrations of CO_2 (Vogel, 1980; Farquhar et al., 1982).

Although most studies refer to the baobab as a tree; it is strictly a succulent with a poorly determined ecology or physiology (Fenner, 1980) and with the exception of *Adansonia digitata*, the genus

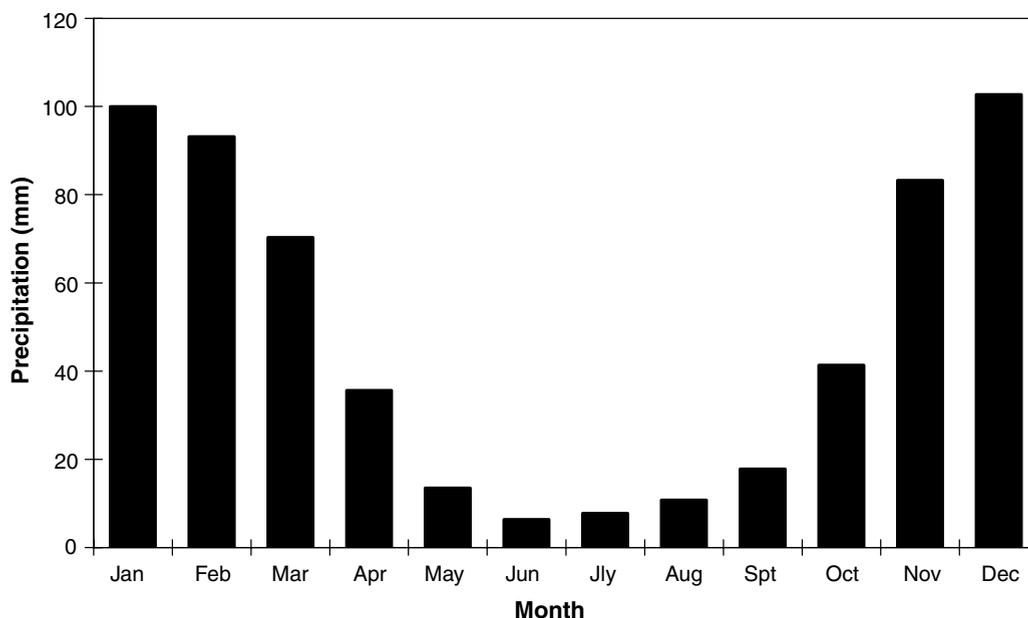


Fig. 2. Mean monthly precipitation recorded at the Skukuza meteorological station (24°59'S, 31°36'E; elevation 263 m) over the period 1981–2002.

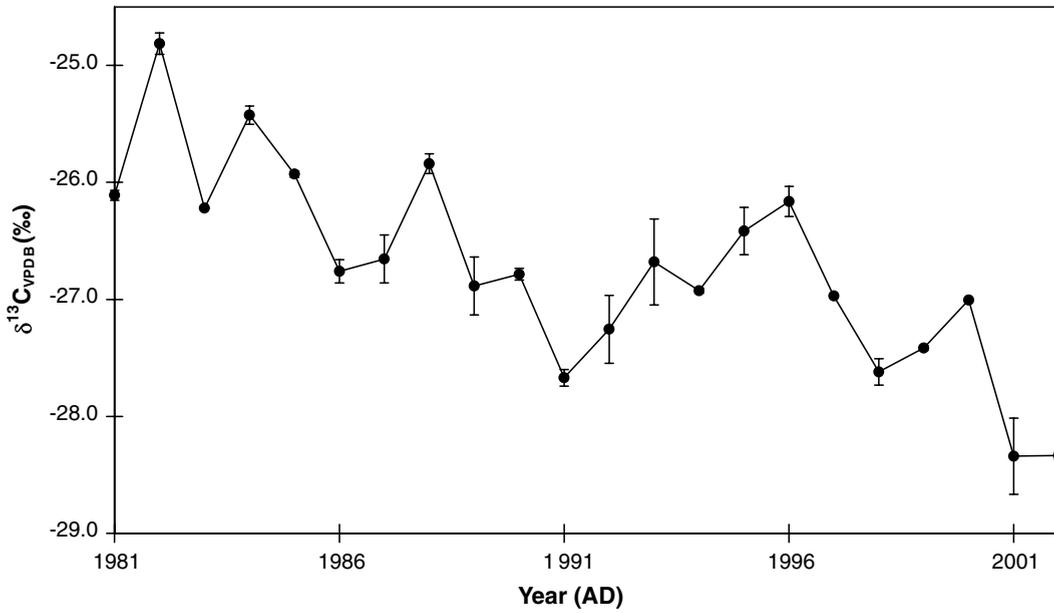


Fig. 3. Carbon isotope values determined on finely ground wholewood from Tree 2 at Skukuza over the period 1981–2002. The error bars represent the precision of replicate measurements (typically $\pm 0.12\text{‰}$).

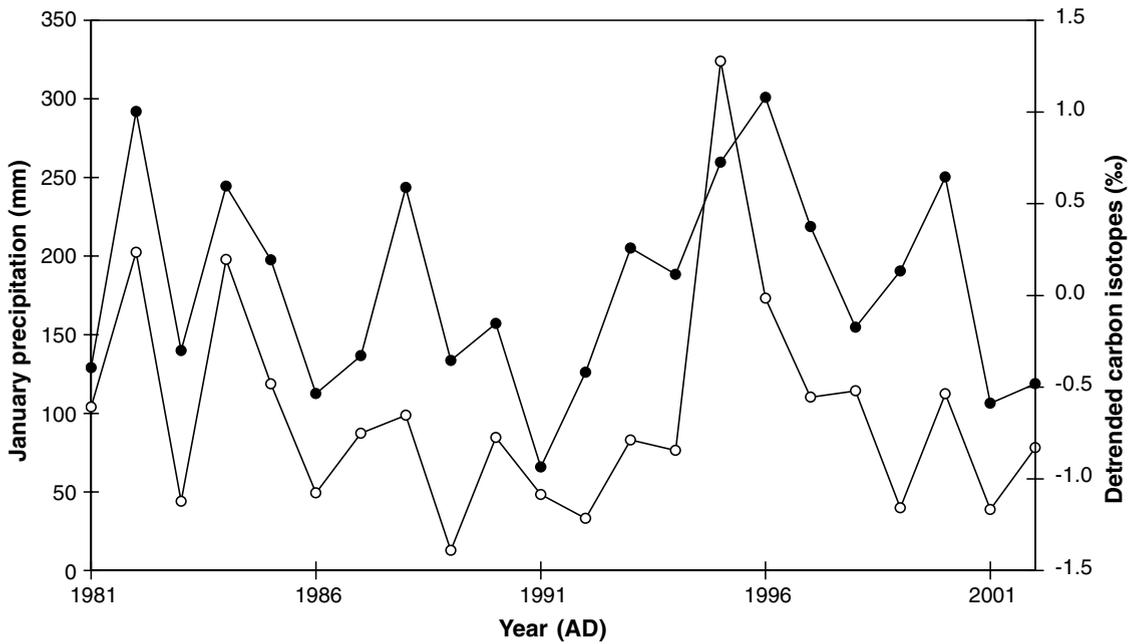


Fig. 4. Relationship between January precipitation (open circles) and the detrended C isotope series (closed circles) from Tree 2 at Skukuza ($r = 0.72$; $p < 0.01$).

is poorly known (Baum, 1995). However, it is known that baobabs have the ability to survive extremely dry winters by storing summer moisture in their swollen trunks and consequently baobab wood can contain a high proportion of water (Kelly,

2000). When leaf photosynthetic activity resumes, changes in stomatal conductance or photosynthetic rate must be invoked to explain the strong positive relationship of January precipitation with detrended C isotope values (Fig. 4). Growth-limiting factors

are typically reported as being responsible for the isotopic fractionation observed for plants. Consequently, if the rate controlling an environmental variable varies at either side of the optimum response of plant growth, a positive or negative relationship with that variable could be observed (Schleser et al., 1999).

Whatever the actual mechanism of the observed response, it is clear that the relationship between January precipitation and the detrended C isotope series ($r = 0.72$) is significant at the 99% confidence limit (Fig. 4) and demonstrates the potential of C isotope values of baobabs as a palaeoclimatic proxy. The fragile nature of baobabs, together with possible shrinkage upon drying limit the effectiveness of conventional dendroclimatology or X-ray densitometry to obtain meaningful information about past climates. However, this pilot study has demonstrated that such information can be obtained by determining C isotope values of baobab wood even if distortion of ring-width has occurred during drying.

Palaeoclimate records from tropical regions are essential to our understanding past changes in the Earth's climate system, equator-pole linkages and the sensitivity of tropical regions to future climate change. In an attempt to increase the number of high resolution palaeoclimatic records from Africa, ring-width chronologies have been carefully constructed from species previously thought impossible to date (Stahle et al., 1999; Couralet et al., 2005) and radiocarbon dating has been used to confirm tentative time-series (Vogel et al., 2001; Robertson and Woodborne, 2002). The three radiocarbon dates from the radial segment from Tree 1 demonstrate that the *Adansonia digitata* specimen growing in Kruger National Park appears to form annual rings (Fig. 1). Although it is tempting to state that baobabs have annual rings and hence, the baobab has the potential as a palaeoclimate proxy covering millennia, replication of these initial results is required to confirm these potentially far-reaching conclusions.

Analysis of baobab tissue using radiometric and stable C isotope analysis would suggest that this is indeed the case, however, the nature of the climate in this region is also such that false/partial absent rings may also be a characteristic of this species. Such a growth response is to be found in many tree species growing in marginal regions worldwide where growth is routinely influenced by external controls. Whilst this makes conventional dendro-

chronology difficult, objective construction of absolutely-dated chronologies is still possible. Conventional analyses of ring width variability may likely fail with this particular species, owing to its propensity for shrinkage and deformation; however, assuming high levels of series replication within and between plants, development of isotopic chronologies may instead provide future potential for chronology building and the study of environmental change since the isotopes are not subject to these limitations. Swart (1963) reported a baobab with an estimated age of 1010 ± 10 years, consequently, if these results can be replicated across its distribution, there is significant potential to further explore carefully dated, pristine baobabs as long term palaeoclimatic proxies with high temporal resolution.

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