FIRE HISTORY OF A GIANT AFRICAN BAOBAB EVINCED BY RADIOCARBON DATING

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ABSTRACT. The article reports the first radiocarbon dating of a live African baobab (*Adansonia digitata* L.), by investigating wood samples collected from 2 inner cavities of the very large 2-stemmed Platland tree of South Africa. Some 16 segments extracted from determined positions of the samples, which correspond to a depth of up to 15–20 cm in the wood, were processed and analyzed by accelerator mass spectrometry (AMS). Calibrated ages of segments are not correlated with their positions in the stems of the tree. Dating results indicate that the segments originate from new growth layers, with a thickness of several centimeters, which cover the original old wood. Four new growth layers were dated before the reference year AD 1950 and 2 layers were dated post-AD 1950, in the post-bomb period. Formation of these layers was triggered by major damage inside the cavities. Fire episodes are the only possible explanation for such successive major wounds over large areas or over the entire area of the inner cavities of the Platland tree, able to trigger regrowth.

INTRODUCTION

The African baobab (*Adansonia digitata* L.) is widespread south of the Sahara and generally considered a symbol of Africa (Wickens 1983; Wickens and Lowe 2008). The baobab produces faint growth rings, considered by many researchers to be annual rings (Wickens 1983; Esterhuyse et al. 2001; Robertson et al. 2006). However, these rings cannot be used for dating fallen old baobabs for 2 reasons: i) growth rings may no longer be observed in certain areas of the trunk of old specimens, and ii) the presence of large internal hollows prevents a hypothetically correct ring count. Therefore, the only accurate method for determining the age of African baobabs is radiocarbon dating of wood samples collected from their trunk. According to the published results, only 6 baobabs have been investigated by ^{14}C dating, by using different techniques that have improved over time. The first investigations to determine the age of baobabs employed gas proportional counting (Swart 1963; Robins and Swart 1964; Sheppard and Swart 1971). Recently, Grootboom, a huge baobab that collapsed in Namibia, was dated by means of accelerator mass spectrometry (AMS). It was found to be the oldest known angiosperm tree, with an age of at least 1275 cal yr (Patrut et al. 2007). Another famous baobab from Namibia was ^{14}C dated by AMS and was found to be over 980 cal yr old (Patrut et al. 2010). Other recent research used ^{14}C dating for determining whether the African baobab can be used as a proxy climate archive (Robertson et al. 2006). Up to the present, the research was limited only to ^{14}C dating of wood samples collected from the remains of dead baobabs, which decay very fast. This fact also accounts for the paucity of research of this type.

The paper reports the first attempt to extend the ^{14}C investigation to standing and live specimens of the African baobab, by dating samples collected from open inner cavities. The obtained results offer new and interesting information about the interaction of the African baobab with the abiotic and biotic environment during its life cycle.

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STUDY AREA AND METHODS

The Platland Tree and Its Area

The giant Platland tree is located on the Sunland Nursery of Platland farm, 10 km from the small town of Modjadjiskloof (formerly Duiwelskloof) and 25 km from Tzaneen, in the Limpopo Province of South Africa. Its GPS coordinates are 23º37.361′S, 030º11.864′E and its altitude is 719 m. Mean annual rainfall in the area is 492 mm (Mooketsi station).

The Platland tree is registered in the South African National Register of Big Trees and included in the South African List of Champion Trees (Department of Water Affairs and Forestry 2006). The tree lies outside its endemic area, so it is considered an exotic specimen by botanists.

The tree has a height of 18.9 m and a total circumference at breast height (cbh; 1.30 m above ground level) of 34.00 m. Its footprint of 68.0 m^2 (which corresponds to a nominal diameter at ground level of 9.30 m) and the cross-sectional area at breast height of 65.3 m^2 are the largest known for an African baobab. The trunk consists of 2 stems (I and II), with a cbh of 24.13 m (stem I) and 18.33 m (stem II), see Figure 1. These stems are connected by a partially fused section, which has a maximum height of 2.01 m and covers a shared cbh of 4.10 m.

Figure 1 The impressive 2-stemmed trunk of the Platland tree, which is also called Sunland baobab

The large trunk comprises 2 interleading cavities on either side of the fused section; they are about 0.78 m below the ground level and are connected via a small opening/doorway. The large cavity inside stem I has a maximum length of 4.10 m, a width of 4.50 m, and a height of 4.60 m. The cavity inside stem II has a length of 1.55 m, a width of 2.70 m, and a height of 2.35 m; it also has an elevated extension towards the north, with a length of 2.20 m. The owners of the Platland farm turned the very large cavity inside stem I into a bar and the tree has become heavily promoted under the name Sunland "pub" baobab.

External measurements of the tree were done by using an inverted Macroscope 25 mounted on a tripod in conjunction with an Impulse 200 laser rangefinder, as well as with the aid of a compass and graduated tapes. Measurements inside cavities were performed with a Bosch DLE 50 Professional digital laser rangefinder.

Sample Collection

According to our new method of dating samples collected from open inner cavities, several wood samples were collected from different positions of the walls (samples 1, 2, 3, and 5) and ceiling (samples 4 and 6) of the 2 cavities of the Platland tree (see Figure 2). Samples from the lateral walls were obtained by using a Haglöf CO600 increment borer (60 cm long, 0.43 cm inner diameter). Twenty-cm-long samples were extracted from the ceiling of the cavities with a sharp cutting tool. The projections of sample positions on the cross-section of the trunk are shown in Figure 3.

Figure 2 Collecting samples from the inner cavities

This paper focuses on the investigation of 16 segments, which were extracted from determined positions of the original 6 samples. The respective segments, with a length of 1 cm, correspond to a depth of up to 15–20 cm in the wood. The segments were processed and investigated by AMS ^{14}C dating.

Sample Preparation

The standard acid-base-acid pretreatment method (Olsson 1986) was used to remove soluble and mobile organic components. The resulting cellulose samples were combusted to CO_2 by the closed-tube combustion method (Sofer 1980). Then, CO_2 was reduced to graphite on iron catalyst, under hydrogen atmosphere (Vogel et al. 1984). Finally, the graphite samples were analyzed by AMS.

AMS Measurements

^{14}C measurements were carried out at the National Ocean Sciences AMS Facility of the Woods Hole Oceanographic Institution with the Pelletron tandem 500kV AMS system (Roberts et al. 2010) and the Tandetron 3MV AMS system (von Reden et al. 1994). The surface of the graphite samples was sputtered with cesium ions and the secondary negative ions were extracted and accelerated in the AMS system. ^{12}C and ^{13}C ions were measured in Faraday cups, where a ratio of their currents was recorded. ^{14}C ions were collected in a solid state detector, so that ratios of ^{14}C to ^{12}C were also

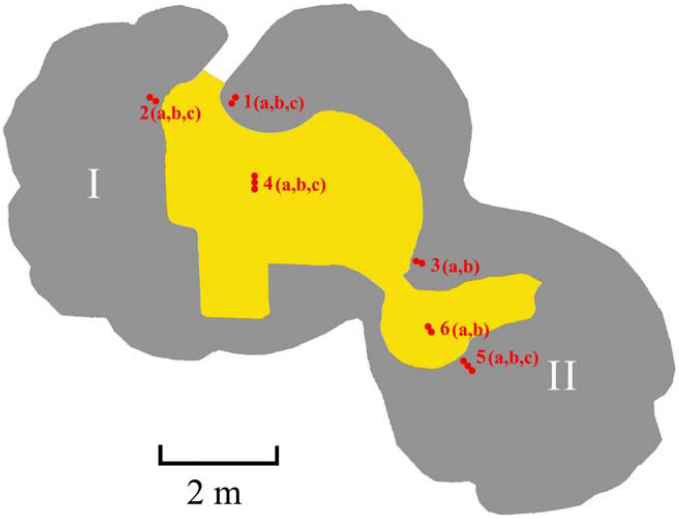

Figure 3 Cross-section of the 2-stemmed trunk, showing the 2 connected cavities and the projections of sample and segment positions.

recorded. These raw signals were compared to ratios obtained with a known standard material (oxalic acid I, NIST-SRM-4990) and converted to a fraction modern (Fm) value, which was corrected for isotopic fractionation with the normalized δ^{13}C value of –25‰.

Fm values were ultimately converted to a ^{14}C date. ^{14}C dates and errors were rounded to the nearest year. However, Fm values greater than 1 were not converted into ^{14}C dates, given that this would have yielded irrelevant negative values.

Calibration

Fm values were calibrated and converted to calendar ages with OxCal v 4.1 for Windows (Bronk Ramsey 1995, 2001), by using comparatively Northern vs. Southern Hemisphere data sets, in order to verify the influence of the Intertropical Convergence Zone on regional/local ^{14}C concentration. For 8 segments showing values Fm > 1, corresponding theoretically to negative ^{14}C dates, the Post-bomb atmospheric NH zone 3 and Post-bomb atmospheric SH data sets (Hua and Barbetti 2004) were employed. The 8 segments with values Fm < 1, corresponding to positive ^{14}C dates, were calibrated with the IntCal04 (Reimer et al. 2004a) and SHCal04 (McCormac et al. 2004) atmospheric data sets. In the text, ^{14}C dates/uncalibrated ages are reported as ^{14}C yr BP or simply BP, while calibrated ages are provided as cal yr or AD.

RESULTS AND DISCUSSION

AMS Results and Calibrated Ages

The 16 investigated segments, which were labeled a, b, and c, originate from the total of 6 wood samples numbered 1 to 6, as follows: 2 each from samples 3 and 6, and 3 each from samples 1, 2, 4, and 5. The AMS dating results and calibrated ages are listed in Table 1. For all sample segments, the 1-σ probability distribution (corresponding to the 68.3% confidence interval) was selected for deriving calibrated age ranges. Each 1-σ probability distribution (with the exception of segments 1b, 4b) corresponds to several ranges of calendar years.

Table 1 AMS ^{14}C dating results and calibrated ages.

Segment code [stem] (NOSAMS accession nr)	Depth[a] [height[b]] (10^{-2} m)	Fraction modern [error]	^{14}C date [error] (^{14}C yr BP)	Calibration curve	Cal AD range(s) 1-σ [confidence interval]
1a [I] (OS-61159)	8–9 [130]	1.1220 [±0.0040]	—	Bomb04 NH3	1993–1995 [68.2%]
				Bomb04 SH	1994–1996 [68.2%]
1b [I] (OS-67077)	13–14 [130]	1.0151 [±0.0022]	—	Bomb04 NH3	1955–1957 [68.2%]
				Bomb04 SH	1956 [68.2%]
1c [I] (OS-76795)	19–20 [130]	0.9633 [±0.0033]	300 [±27]	IntCal04	1522–1575 [46.6%] 1584–1590 [3.8%] 1625–1646 [17.7%]
				SHCal04	1515–1541 [19.1%] 1625–1660 [49.1%]
2a [I] (OS-62009)	7–8 [90]	1.1360 [±0.0037]	—	Bomb04 NH3	1958 [5.2%] 1991–1993 [63.1%]
				Bomb04 SH	1959 [8.4%] 1990 [6.9%] 1992–1994 [52.9%]
2b [I] (OS-67043)	14–15 [90]	0.9746 [±0.0024]	207 [±19]	IntCal04	1658–1673 [19.0%] 1778–1799 [33.4%] 1942–1953 [15.8%]
				SHCal04	1670–1682 [11.1%] 1731–1783 [50.7%] 1795–1802 [6.4%]
2c [I] (OS-71902)	18–19 [90]	0.9625 [±0.0041]	307 [±33]	IntCal04	1521–1592 [51.2%] 1620–1644 [17.0%]
				SHCal04	1511–1552 [28.1%] 1558–1573 [8.1%] 1622–1655 [32.0%]
3a [I] (OS-62011)	7–8 [50]	1.1703 [±0.0040]	—	Bomb04 NH3	1958 [3.8%] 1988–1989 [64.4%]
				Bomb04 SH	1960 [6.9%] 1988–1991 [61.3%]
3b [I] (OS-67070)	14–15 [50]	0.9898 [±0.0029]	82 [±23]	IntCal04	1699–1722 [20.1%] 1818–1833 [13.3%] 1880–1916 [34.8%]
				SHCal04	1816–1829 [23.4%] 1892–1921 [44.8%]
4a [I] (OS-61322)	7–8 [375]	1.1752 [±0.0046]	—	Bomb04 NH3	1987–1989 [68.2%]
				Bomb04 SH	1959 [5.2%] 1960 [12.0%] 1987 [12.4%] 1988–1990 [38.7%]
4b [I] (OS-61982)	12–13 [380]	1.0104 [±0.0042]	—	Bomb04 NH3	1954–1956 [68.2%]
				Bomb04 SH	1955–1957 [68.2%]
4c [I] (OS-67071)	18–19 [386]	0.9756 [±0.0028]	198 [±23]	IntCal04	1661–1680 [18.1%] 1764–1800 [34.5%] 1939–1953 [15.6%]
				SHCal04	1669–1694 [18.4%] 1726–1784 [41.1%] 1795–1807 [8.7%]
5a [II] (OS-67082)	6–7 [40]	1.1237 [±0.0026]	—	Bomb04 NH3	1993–1995 [68.2%]
				Bomb04 SH	1994–1996 [68.2%]
5b [II] (OS-67821)	12–13 [40]	0.9900 [±0.0036]	80 [±29]	IntCal04	1697–1725 [21.0%] 1815–1835 [14.9%] 1878–1915 [32.3%]
				SHCal04	1712–1719 [4.3%] 1813–1836 [24.1%] 1891–1923 [39.8%]

Table 1 AMS ^{14}C dating results and calibrated ages. *(Continued)*

Segment code [stem] (NOSAMS accession nr)	Depth[a] [height[b]] (10^{-2} m)	Fraction modern [error]	^{14}C date [error] (^{14}C yr BP)	Calibration curve	Cal AD range(s) 1-σ [confidence interval]
5c [II] (OS-62013)	18–19 [40]	0.9761 [±0.0036]	194 [±29]	IntCal04	1663–1681 [16.7%] 1739–1744 [3.3%] 1763–1802 [34.4%] 1938–1952 [13.8%]
				SHCal04	1669–1699 [17.5%] 1723–1785 [33.3%] 1794–1809 [8.4%] 1839–1844 [2.0%] 1868–1877 [3.7%] 1934–1937 [1.1%] 1946–1951 [2.2%]
6a [II] (OS-62012)	7–8 [227]	1.1709 [±0.0034]	—	Bomb04 NH3	1958 [4.1%] 1988–1989 [64.1%]
				Bomb04 SH	1960 [8.4%] 1988–1990 [59.8%]
6b [II] (OS-62014)	13–14 [233]	0.9683 [±0.0036]	259 [±29]	IntCal04	1530–1538 [5.9%] 1635–1666 [51.5%] 1784–1796 [10.8%]
				SHCal04	1644–1672 [36.7%] 1745–1755 [8.6%] 1764–1770 [4.8%] 1780–1797 [18.1%]

[a] Depth in the wood from the cavity wall/ceiling.

[b] Height above cavity level (which is 0.78 m under ground level)

The cal age ranges of the investigated segments correspond to lower calendar age values than expected from their positions in the stems of the tree. Eight segments were found to be very young, showing ages greater than Modern, which fall after the reference year AD 1950, in the so-called post-bomb period (Reimer et al. 2004b). This indicates that all dated wood of the 16 sample segments, which correspond to a depth of up to 15–20 cm, originate from different layers of new growth/regrowth and not from the original old wood of the respective positions.

Origin of New Growth Layers

Adansonia species are not only tropical stem-succulent trees, able to store large amounts of water in their trunk, but also sapwood trees, which do not form heartwood (Fisher 2001). Like other sapwood trees, baobabs exhibit self-healing ability deep within the stem and also in their large internal cavities (Ng 1986).

The new growth layers from the sample segments of the Platland tree are a consequence of repairing the interior xylem after substantial wood damage inside the cavities. The wood in baobab stems is comprised mainly of parenchyma tissue, much of which remains alive for a long time and at significant depths into trunk. Baobab wood contains a greater proportion of parenchyma cells in its trunk (69–88% by volume) than any other investigated tree species (Chapotin et al. 2006). Therefore, its original old wood, i.e. old secondary xylem, contains xylem parenchyma that is alive. As a consequence, the old dead vessels and xylem fibers have adjacent metabolically active parenchyma cells. The repair of the damaged interior xylem is a result of wound callus production by the division of living parenchyma cells, just below the affected wood surface. It can be associated with the wound healing by exposed secondary xylem, observed on the surface of branches of an African baobab, which were transversely cut (Fisher 1981). Regrowth from damage is common in the species.

Dating results of the investigated segments document the presence of 6 new growth layers inside the cavities of the Platland tree, which cover the original old wood. These new growth layers inside the cavities represent a response of the baobab to its interaction with abiotic and biotic factors in the environment, which could inflict injuries and wounds. Three of the regenerated secondary xylem layers were identified in both cavities from the cavity level up to the ceiling. Fire damage is the only reasonable explanation for such successive major wounds over large areas or even over the entire area of the internal cavities of the Platland tree, which may trigger regrowth.

In the investigated samples, the successive regrowth layers reach a maximum depth in the range from about 15 cm (samples 3 and 6) to 20 cm (samples 1, 2, 4 and 5); the initial old wood corresponding to the respective positions in the stems is located at greater depths, below the regrowth layers. Dating results of old wood segments, corresponding to depths values greater than 15–20 cm in the wood of inner cavities, which are not provided in this article, indicate that the 2 stems (I and II) of the Platland tree are independent and fused completely up to a height of ~2 m over 450 cal yr ago.

Dates of New Growth Layers

As emphasized previously, the only possible explanation for the 6 new growth/regrowth layers is that they were triggered by 6 major fires, which affected the cavities of the Platland tree. Ages of regrowth layers allowed determining the dates when these fires occurred. Four regrowth layers were dated before the reference year AD 1950, i.e. BP (before present), while 2 regrowth layers were dated post-AD 1950, in the post-bomb period.

- **a) Post-AD 1950 regrowth layers**. The most recent 2 regrowth layers and the corresponding fires were dated after the reference year AD 1950, in the post-bomb period.
  The regrowth layer of AD 1990. The first segment of each of the 6 collected samples (1a, 2a, 3a, 4a, 5a, 6a), corresponding to a depth of up to about 7–9 cm in the wood, was dated around AD 1990 and after this year. We can state that with confidence, because the fire episode of 1990 is well known and was generated by human activity. It is obvious that the youngest new growth layer, i.e. the shallowest, was subsequent to the fire of 1990, the regrowth being triggered by the combustion. This regrowth is at least 9 cm at the location of sample 1, indicating that the new wood layer initiated by fire has experienced a growth burst of several years.
  The regrowth layer of around AD 1955. The second segment of 2 samples originating from the large cavity inside stem I (1b, 4b), which corresponds to a depth of 12–14 cm in the wood, was dated around AD 1955. The respective regrowth layer was not identified in samples collected from the cavity inside stem II.
- ***b) Regrowth layers before AD 1950***. The oldest 4 regrowth layers and the corresponding fires were dated BP (before present), i.e. before the reference year AD 1950. For each regrowth layer, we provided a cal age range for each data set, which corresponds to the set-theoretic union of the 1-σ ranges with the highest probability for the corresponding ^{14}C dates. This is only a working model and other cal age ranges, with lower probabilities, cannot be excluded.
  The regrowth layer of around 80 BP. Two segments (3b, 5b), corresponding to a depth of 12–15 cm in the wood, were dated 80 ± 29 and 82 ± 23 BP. The respective ^{14}C dates correspond to a 1-σ age range of AD 1878–1916 when using the IntCal04 data set, and AD 1891–1923 with the SHCal04 data set.
  The regrowth layer of around 200 BP. The other 3 segments (2b, 4c, 5c), which correspond to a depth of 14–19 cm in the wood, were ^{14}C dated around 200 BP, more precisely 194 ± 29, 198 ± 23, and 207 ± 19 BP. These ^{14}C dates correspond to a 1-σ age range of AD 1763–1802 with the IntCal04 data set, and AD 1723–1785 with the SHCal04 data set.

The regrowth layer of around 260 BP. One segment from the cavity inside stem II (6b), which originates from a depth of 13–14 cm in the wood, was dated 259 ± 29 BP. It corresponds to a 1-σ age range of AD 1635–1666 when using the IntCal04 data set, and AD 1644–1672 with the SHCal04 data set.

The regrowth layer of around 300 BP. Two segments form the cavity inside stem I (1c, 2c), which correspond to a depth of 18–20 cm in the wood, were ^{14}C dated to 300 ± 27 and 307 ± 33 BP. These dates correspond to a 1-σ age range of AD 1521–1592 with the IntCal04 data set, and AD 1622–1660 with the SHCal04 data set.

One should note that in none of the 6 collected samples could all 6 regrowth layers be identified. We found a maximum of 3 regrowth layers in samples 1, 2, 4, and 5. Only the youngest layer, triggered by the latest fire of AD 1990, was identified in all 6 samples. These findings are the consequences of several aspects: i) each new growth layer, except for the youngest one, was partially or totally combusted by a subsequent fire inside the cavity; therefore, it is possible that certain regrowth layers from the location of several samples were completely or almost completely charred by the next fire; ii) the fire may not affect equally the entire surface of cavities and, therefore, the thickness of a certain growth layer in the walls of cavities is variable; iii) the youngest regrowth layer, formed after the very big fire of AD 1990, is also the thickest and it was identified in all samples, given that there were no subsequent fire events that would have burned it (partially or totally); iv) it is also possible that some thin regrowth layers from certain samples were not revealed, in the absence of a point-by-point analysis.

Northern vs. Southern Hemisphere Calibration

Fraction modern (Fm) values were calibrated by using comparatively Northern vs. Southern Hemisphere data sets. As expected, age differences when using these 2 calibration data sets are small.

A comparative calibration might be of interest especially for samples with values Fm < 1, corresponding to the oldest 4 regrowth layers, for which the IntCal04 and SHCal04 data sets were used. The Southern Hemisphere atmospheric calibration curves, i.e. SHCal02 and SHCal04, were derived from the general IntCal98 and IntCal04 data sets, by using measurements on contemporaneous Northern and Southern Hemisphere sample pairs. These measurements suggest a variable interhemispheric offset of several decades over the time span covered by the calibration curves (McCormac et al. 2002, 2004). However, the utilized SHCal04 data set does not contain information for low southern latitudes and includes only a few results for a short time period from South Africa, due also in part to the absence of native conifers in Africa.

For the investigated segments, the comparative calibration leads to an offset of 1 to 4 decades for 3 regrowth layers that were dated before AD 1950. For 2 segments (1c, 2c) that correspond to the oldest regrowth layer of around 300 BP, the offset is greater, of 7 to 10 decades, due to “wiggles” in the calibration curves. Consequently, when using the SHCal04 calibration, the 1-σ cal age ranges for the 2 oldest regrowth layers from around 260 and 300 BP overlap in part.

In the absence of a reliable sequence of growth rings for large and hollow baobabs, such as the Platland tree, and as no old written records exist for Africa, it was not possible to make a choice between the 2 data sets based on the accuracy of the presented comparative results.

Origin of Fires

In the arid areas around the Limpopo Basin, there is generally little build-up of biomass to fuel intense fires. Also, large baobabs with broad canopies generally have little grass cover, therefore, are less threatened (Nel 1988). However, due to high rainfall episodes during the rainy season, often mentioned in the Platland tree area, fuel loads or the build-up of green biomass becomes a more relevant factor, as does the season of fire and the prevailing weather conditions (Govender et al. 2006).

The most recent fire episode of AD 1990 is documented and was inflicted by human activity. Workers at the farm set a fire to smoke out a pair of black mamba snakes from the cavities. The fire got out of control and burned badly the inner cavities of the Platland tree. The other fire episodes evinced by the dating results could have been caused by a number of factors, such as natural veld fires ignited by lightning or by drought and excessive heat; anthropogenic veld fires caused by hunting practices, namely to stimulate early grazing; or fires started through honey gathering and as protection against wild animals at the entrance of the cavities.

Artifacts found in the cavities indicate that the Platland tree was possibly used for centuries as a shelter. The tree was along one of the old, possibly ancient ivory and gold trading routes through the region. The other 5 fire episodes within the cavities of the Platland tree could have been generated by abiotic factors (build up of biomass, possibly aided by lightning to fuel intense fires to burn also the internal cavities, natural veld fires) or biotic factors (human activity). On the basis of current field observations in Southern Africa for both abiotic and biotic causes and the archaeological and historic record, fires caused by human activity appear to be more likely.

CONCLUSIONS

The research reported here represents the first attempt of dating a live and standing baobab tree, by investigating wood samples collected from open inner cavities. AMS analysis of sample segments collected from the cavities of the Platland tree led to the following conclusions:

1. Any sizeable fire damage in the open cavity of a baobab immediately triggers a significant new growth. New growth can be several centimeters thick and covers the entire damaged cavity area.
2. Each new growth layer is partially (or totally) combusted by a subsequent fire inside the cavity; this causes further growth, yielding 1 additional young wood coating layer inside the cavity.
3. AMS results indicate that a depth of 15–20 cm in the wood inside cavities is not sufficient for reaching the original old wood of large baobabs with multiple fire episodes;
4. Dating results document 6 new growth layers in the cavities of the Platland tree. Ages of successive new growth layers allowed determining the dates when the corresponding fires occurred.
5. Age differences when using different calibration data sets for Northern and Southern hemispheres are small, with the exception of segments that correspond to the oldest new growth layer.

Results reported in this paper demonstrate that the ^{14}C dating method is suitable for evincing successive fire episodes suffered by the African baobab. This new approach is very promising for documenting, in a reliable manner, past environmental events in remote zones, lacking written records.

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