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ORIGINAL ARTICLE

Age, growth and architecture of the historic Big Tree at Victoria Falls, Zimbabwe assessed by radiocarbon dating

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ABSTRACT

The article discloses the AMS (accelerator mass spectrometry) radiocarbon dating results of the historic Big Tree at Victoria Falls, Zimbabwe. The research aimed to determine the age, growth and architecture of this renowned African baobab. The superlative baobab is composed of five main stems, three young stems and one false stem. It exhibits an open ring-shaped structure, an architecture that allows baobabs to reach large sizes and old ages. Several wood samples extracted from four stems were dated by radiocarbon. The oldest sample had a radiocarbon date of 978 ± 14 BP, corresponding to a calibrated age of 955 ± 20 calendar years. By this value, the Big Tree at Victoria Falls is 1150 ± 50 years old. We found that the eight common stems belong to three generations, which are 1000–1100, 600–700 and 200–250 years old, respectively. The false stem is 550 years old. The stems belonging to the oldest generation stopped growing over 100 years ago.

1. Introduction

By crossdating, dendrochronology determines the exact year when the growth rings of trees were formed. Solely ring counting is not sufficient and crossdating is necessary, given that the ring growth is not always annual (or seasonal). Sometimes, a ring does not grow during one year (season), therefore, it is called missing or absent ring. In other cases, more than one ring grows during a year (season) and it is referred to as false ring. According to dendrochronology, missing and false rings are only exceptions among annual (seasonal) rings (Wendland, 1975).

Classical dendrochronology, recte crossdating, cannot be used for dating certain trees, and is particularly inadequate for large angiosperms, including tropical trees (Worbes, 1995; Worbes, 2002; Patrut et al., 2010). The African baobab (*Adansonia digitata* L.), which is a tropical tree (Wickens, 1982; Baum, 1995; Wickens and Lowe, 2008), typically exhibits well-defined growth rings. Its rings correspond in many cases to a one-year period or, more precisely, to one rainy season. Nevertheless, age modelling of baobab rings demonstrated that ring-growth anomalies occur quite often and may be more frequent for baobabs than for other tree species. Thus, for certain baobabs in the Mapungubwe National Park, South Africa, which are hundreds of years old, radiocarbon dates and ring counts show that their ring formation is not annual. Hence, for three baobabs the average ring frequency varies between 0.6 and 6.7 rings/year (Woodborne et al., 2016). In Senegal, in the Dakar and Thiès regions, we found five baobabs for which the average ring frequency varies between 0,42 (for dwarf baobabs of Madeleine Island) and 2.25 (for very large baobabs) rings/year.

Beyond such significant ring-growth anomalies, African baobabs, especially monumental specimens, may exhibit some particular features, which preclude the use of crossdating for assessing the ages of their stems. Most old baobabs have large hollows, typically in the central area of their trunk/stems. These cavities can be either normal ones, i.e., formed by wood loss, or false cavities, namely natural empty spaces between fused stems of baobabs that exhibit a closed ring-shaped structure (Patrut et al., 2015a, Patrut et al., 2018). In such cases, ring counting is either incomplete (for trees with normal cavities) or excessive (for trees with false cavities) for revealing the stem(s) age.

Additionally, growth stop is a baobab-specific phenomenon that was

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discovered by radiocarbon dating. Thus, in certain cases, the outermost rings, located closest to the bark, were found to be old, with ages of several hundred years, instead of being very young. The only reasonable explanation for this anomaly is that the trunk/stems of these baobabs stopped growing centuries ago, especially due to old age or stress factors. Nevertheless, these baobabs remained alive and continued to produce leaves, flowers and even pods (Patrut et al., 2017a).

In such cases, when classical dendrochronology is not applicable for determining stem ages and growth rates, radiocarbon analysis represents the only accurate method for dating (Worbes, 2002; Swart, 1963; Patrut et al., 2007). In the customary procedure, wood samples are pretreated prior to radiocarbon dating. Pretreatment is necessary for removing non-structural mobile carbon, especially lignin. As a result, one can isolate for dating exclusively the structural non-mobile carbon components, mainly cellulose (Gaudinski et al., 2005).

In crossdating, a single age value for a certain growth ring is obtained. The main result of radiocarbon investigation of a tiny wood sample is a radiocarbon date, which must be calibrated, to produce one or several age ranges of calendar years. We developed a method by which one can derive from the calibrated age range(s) a single age value of the dated wood sample, with a calculated error (Patrut et al., 2011).

Here we report the radiocarbon dating results of the famous historic Big Tree at Victoria Falls, Zimbabwe.

2. Material and methods

2.1. The Big Tree and its area

The historic Big Tree is located on the Zambezi Drive, at the outskirts of the Victoria Falls town, in the province of Matabeleland North, Zimbabwe. The baobab stands at only 200 m from the southern (right) bank of the Zambezi River and 2 km west from the well-known Victoria Falls, which is now officially called “Mosi-oa-Tunya” (in Lozi, “The Smoke That Thunders”) (Fig. 1). The bedrock in the Victoria Falls area is dark volcanic basalt, which was formed around 180 million years ago in the former supercontinent Gondwanaland. It is up to 300 m thick and forms a geological island in the surrounding sandveld (Hilton-Barber and Berger; 2008).

The Big Tree at Victoria Falls was sometimes called Livingstone’s tree, as an erroneous belief that this was the baobab into which Livingstone carved his name. The Scottish missionary David Livingstone was probably the first European explorer to see the waterfall in November 1855. He named it in honour of Queen Victoria of Britain.

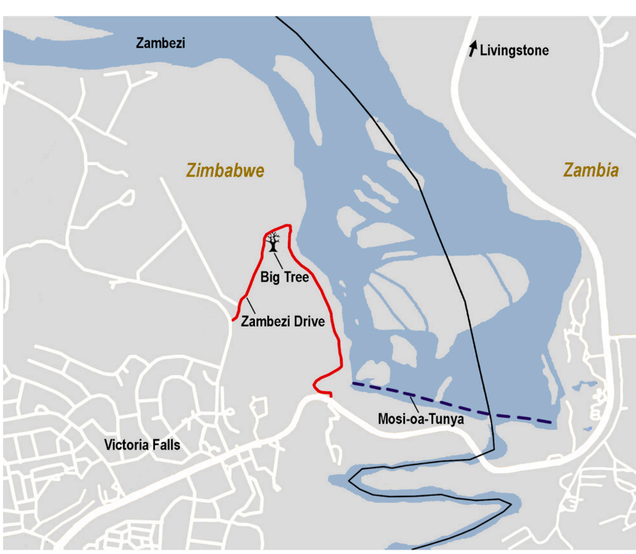

Fig. 1. Location of the Big Tree at Victoria Falls.

Livingstone carved his name on a large baobab near the waterfall, but he probably did not notice the Big Tree, which was “discovered” after 1855 by other explorers (Mullin, 2003; Wickens and Lowe, 2008). Today, the Big Tree is the most heavily visited African baobab in the world. We estimate the number of the visitors on the order of 150,000–200,000 per year.

The GPS coordinates of the Big Tree are 17º54.750’ S, 025º50.472’ E and the altitude is 894 m. The mean annual rainfall in the area is 684 mm, while the mean annual temperature reaches 22.3 °C.

The baobab has a maximum height of 25.6 m, a circumference at breast height (cbh; at 1.30 m above ground level) of 22.77 m and an overall wood volume (stems and branches) of 200 m^3. The horizontal dimensions of the canopy are 40.35 (NS) x 30.70 m (WE) (Fig. 2).

The Big Tree was severely affected by a violent storm in 1960, when the upper part of its canopy was practically destroyed. It was stated that, prior to this storm, the baobab had a height of over 45 m, which seems to be very unlikely (Cashel, 1995; Wickens and Lowe, 2008). Fortunately, there are many photographs of the Big Tree taken prior to the year 1960 (Fig. 3a and b). By comparing our recent photographs with earlier pictures taken from similar angles, we calculated that the Big Tree had a height of 33 m, which represents a record for African baobabs.

Because the Big Tree is deeply incised, it was speculated that it is composed of two or three fused stems (Mullin, 2003). In fact, this baobab exhibits a kind of open ring-shaped structure. It consists of five main stems (numbered 1–5), a large false stem (numbered 6) and three young stems (numbered 11–13), which belong to several generations (see Fig. 4a and b). The very irregular footprint of the Big Tree also demonstrates that it is a multi-stemmed specimen (Fig. 5).

2.2. Investigation of the Big Tree

2.2.1. Sample collection

Several wood samples were collected from four stems, using a long Haglöf increment borer (0.90 m long, 0.01 m inner diameter). The samples were labelled using the initials of the tree location and the corresponding stem number, i.e., VF-1, VF-3, VF-5 and VF-6. The heights of the sampling points were between 1.58 and 2.05 m above the ground. Several tiny segments, each 10^{-3} m long (named a, b, etc.) were extracted from predetermined positions along the first three samples.

2.2.2. Sample preparation

The standard acid-base-acid pretreatment method was used for removing soluble and mobile organic components (Loader et al., 1997). Pretreated samples were combusted to CO_2 via the closed tube combustion method (Sofer, 1980). Next, CO_2 was reduced to graphite on iron catalyst, under hydrogen atmosphere (Vogel et al., 1984). Finally, all obtained graphite samples were analysed by AMS.

2.2.3. AMS measurements

The AMS radiocarbon investigations were performed at the NOSAMS Facility of the Woods Hole Oceanographic Institution by using the Pelletron®Tandem 500 kV AMS system (Povinec et al., 2009; Roberts et al., 2010). The resulting fraction modern values, corrected for isotopic fractionation, were ultimately converted to a radiocarbon date. Radiocarbon dates and errors were rounded to the nearest year.

2.2.4. Calibration

Radiocarbon dates were calibrated and converted into calendar ages with the OxCal v4.4 for Windows (Bronk Ramsey, 2009), by using the SHCal20 atmospheric data set (Hogg et al., 2020).

3. Results and discussion

3.1. Radiocarbon dates and calibrated ages

Radiocarbon dates, expressed in radiocarbon years BP (before

Fig. 2. General view of the Big Tree taken from the north.

present, i.e., before the reference year 1950) and calibrated ages (expressed in calendar years CE, i.e., common era) of the ten sample segments are listed in Table 1. The 1σ probability distribution (68.3%) was selected to derive calibrated age ranges. For four sample segments (VF-1a, VF-3b, VF-5a, VF-6a) the 1σ distribution corresponds to one range of calendar years. For the other six segments (VF-1b, VF-3a, VF-5b, VF-5c,VF-5d, VF-5e) the 1σ distribution is consistent with two or three age ranges. In these cases, the confidence interval of one range is considerably greater than that of the other(s); therefore, it was selected as the cal CE range of the sample for the purpose of this discussion. In all cases, the selected age range is marked in bold in Table 1.

We derived an assigned year for each sample segment, which corresponds to the mean value of the selected age range, with the error rounded to the nearest 5 yr. Sample/segment ages, expressed in calendar years, represent the difference between the year 2021 CE and the assigned year. Sample ages and errors were rounded to the nearest 5 yr.

This approach for selecting calibrated age ranges and single values for sample ages was used in all our previous publications on AMS radiocarbon investigation of superlative angiosperm trees, mainly baobabs (Patrut et al., 2007, 2010, 2011, 2015a, 2015b, 2017a, 2017b, 2018).

3.2. Dating results of samples

As mentioned, we collected, at convenient heights, samples from four stems. Out of these samples we extracted tiny segments, which were finally dated by AMS radiocarbon.

We dated two sample segments, which originate from stem 1, namely VF-1a and VF-1b, at distances of 0.57 and 0.77 m from the sampling point. Their radiocarbon dates were found to be 757 ± 18 BP and 914 ± 38 BP, which correspond to calibrated calendar ages of 735 ± 10 yr and 835 ± 35 yr. Sample VF-1 was collected at a height of 1.66 m above ground level, where the theoretical pith of stem 1 is situated at a distance of 0.95 m from the sampling point.

We also dated two sample segments, which originate from stem 3, i.e., VF-3a and VF-3b, at depths of 0.20 and 0.57 m in the wood. These segments had radiocarbon dates of 232 ± 16 BP and 462 ± 15 BP, which correspond to calendar ages of 245 ± 15 yr and 570 ± 10 yr. Sample VF-3 was collected at a height of 1.58 m, where the theoretical pith of stem 3 is located at 0.70 m from the sampling point.

We investigated five segments extracted from sample VF-5, which was collected from the largest stem 5. Sample segment VF-5a, which consists of the wood layer adjacent to the bark, had a radiocarbon date of 97 ± 18 BP, which corresponds to a calendar age of 115 ± 15 yr. This result demonstrates that stem 5 and very likely the other old stems stopped growing more than a century ago (Patrut et al., 2017a). Sample segments VF-5b, VF-5c and VF-5d, which originate from depths into the wood of 0.10, 0.30 and 0.50 m, had radiocarbon dates of 231 ± 18 BP, 419 ± 21 BP and 648 ± 17 BP. These results correspond to calendar ages of 255 ± 30 yr, 545 ± 20 yr and 685 ± 15 yr. The oldest dated sample segment of the Big Tree was VF-5e, which originates at 0.85 m from the sampling point. It had a radiocarbon date of 978 ± 14 BP, which corresponds to a calendar age of 955 ± 20 yr. Sample VF-5 was extracted at a height of 1.85 m, where the theoretical pith of stem 5 is located at a depth of 1.15 m.

Eventually, we dated one segment, VF-6a, which originates from the false stem 6, at a depth of 0.60 m. Sample VF-6 was collected close to the emergence point of stem 6 from the adjacent stem 5, at a height of 2.05 m. Its radiocarbon date of 443 ± 23 BP corresponds to a calibrated age of 545 ± 30 calendar yr.

Fig. 3. Historic photographs of the Big Tree. (a) The first photo of the Big Tree taken by Frank "Zambezi" Watson in 1891; (b) The image of the Big Tree taken by Percy Clark in 1903.

3.3. Tree and stem ages

The ages of stems 1, 3 and 5 were calculated by extrapolating the age of their oldest sample segment to the calculated positions of their pith. We considered, for each stem, the mentioned distances from the sampling point to the position of the oldest segment (0.77, 0.57 and 0.85 m) and to the position of the calculated pith (0.90, 0.70 and 1.15 m), as well as an estimated growth rate. Thus, the estimated ages of stems 1, 3 and 5 are 1100 ± 50, 650 ± 50 and 1150 ± 50 calendar yr, respectively.

For the false stem 6, the dated segment's position is close to the emergence point from stem 5, which also represents the point of maximum age. Accordingly, the calculated age of the false stem 6 is 550 ± 50 calendar yr.

We stated that the Big Tree presents a kind of open ring-shaped structure, which consists of five main stems, three young stems and a false stem that belong to several generations. Radiocarbon dating results, combined with a careful inspection and measurements of stems, allow to estimate the age and the generation of each stem.

Main stems 1–5 obviously belong to two different generations. The largest three stems (1, 2 and 5), out of which two were dated (1 and 5), have dbh (diameter at beast height, i.e., at 1.30 m above ground) values of 2.15 m (stem 1), 2.10 m (stem 2) and 2.65 m (stem 5), respectively. They belong to the first generation, which is 1100–1200 years old. At least stem 5 stopped growing over a century ago. This is confirmed by photographs taken more than 100 years ago, in which the main stems seem to have the same dimensions as today (see Fig. 2b).

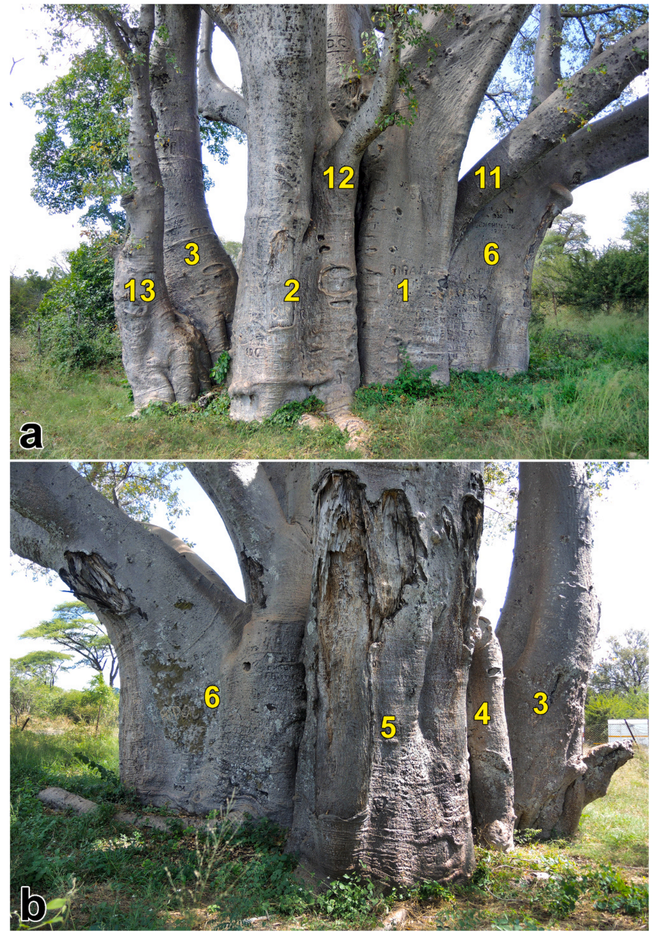

Fig. 4. Images of the Big Tree with stem numbering. (a) taken from the north; (b) taken from the south.

The other two main stems (3 and 4), out of which one was dated (3), are smaller and have close dbh values, i.e., 1.40 m (stem 3) and 1.30 m (stem 4). These stems belong to the second generation, which is 600–700 years old.

The young stems (11, 12 and 13) are much smaller, with dbh values of 0.50–0.80 m, and too young to be accurately dated by the radiocarbon method. Comparing current pictures of these stems with older photographs, we estimate the three young stems to be 200–250 years old. These stems, which belong to a third generation, are not a part of the ring.

Stem 6 is a false one. Consequently, it emerged from the large adjacent stem 5 and has a particular structure that is triangular or trapezoidal in the horizontal section (Patrut et al., 2017b). The length of the horizontal section of stem 6 is 3.64 m. This is a special type of buttress that plays the role of an anchor and provides better stability to the tree. The age of stem 6, namely 550 years, is close to the age of the main stems, which belong to the second generation.

The age of the Big Tree is identical with the age of its oldest stems, i.e., 1100–1200 years or 1150 ± 50 years. One can state that the Big Tree at Vic Falls started growing around the year 870 CE.

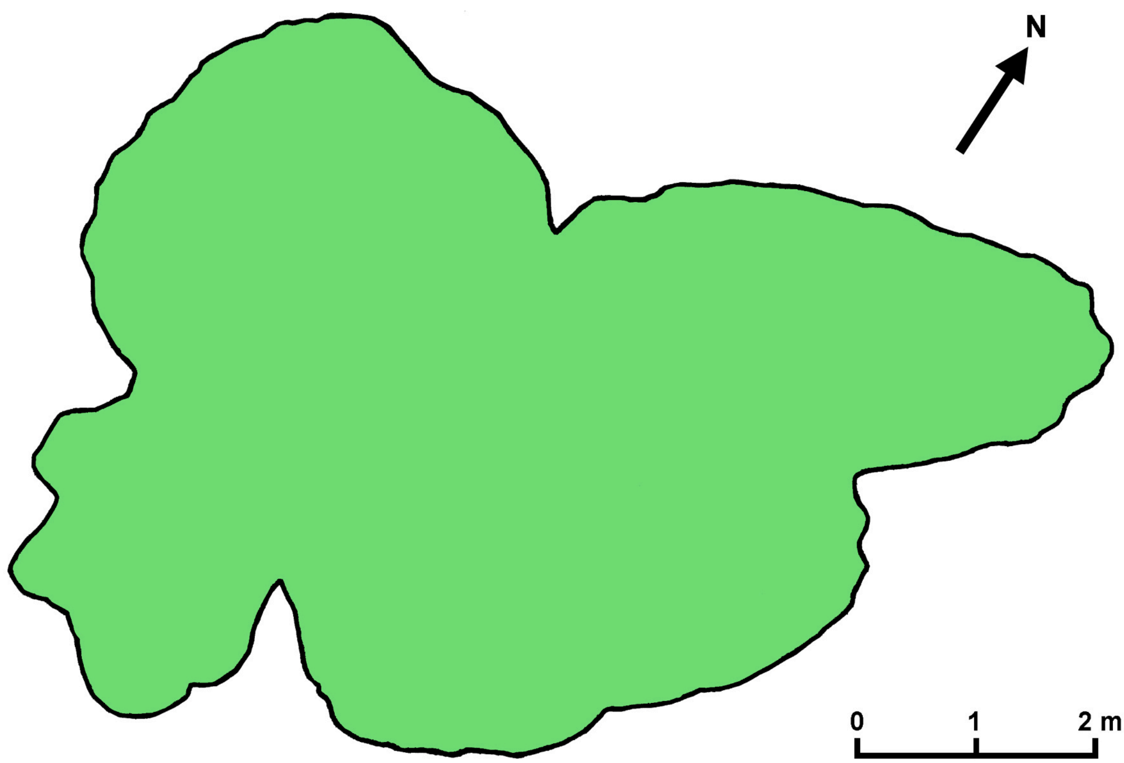

Fig. 5. The footprint of the Big Tree. Calculating the diameter of the entire trunk (stem) of a monumental African baobab, which is always multi-stemmed, devised from the circumference of the tree, is meaningless; however, this practice is used by the majority of scientists.

Table 1
Radiocarbon dating results and calibrated ages of sample segments collected from the Big Tree at Victoria Falls.

Sample/ segment code (stem)	Depth[a] [height[b]] (m)	Radiocarbon date [error] (^{14}C yr BP)	Cal CE range 1σ [confidence interval]	Assigned year [error] (year CE)	Sample/ segment age [error] (calendar years)	NOSAMS Accession #
VF-1a	0.57			1286	735	
(1)	[1.66]	757 [± 18]	**1276–1296 (68.3%)**	[± 10]	[± 10]	OS-125230
VF-1b	0.77		1072–1078 (3.0%)	1185	835	
(1)	[1.66]	914 [± 38]	**1151–1220 (65.3%)**	[± 35]	[± 35]	OS-110645
			1668–1673 (6.6%)			
VF-3a	0.20		1739–1757 (22.4%)	1775	245	
(3)	[1.58]	232 [± 16]	**1762–1798 (39.3%)**	[± 15]	[± 15]	OS-119877
VF-3b	0.57			1453	570	
(3)	[1.58]	462 [± 15]	**1446–1461 (68.3%)**	[± 10]	[± 10]	OS-120510
VF-5a	0			1907	115	
(5)	[1.85]	97 [± 18]	**1892–1922 (68.3%)**	[± 15]	[± 15]	OS-125226
VF-5b	0.10		1668–1674 (6.6%)	1768	255	
(5)	[1.85]	231 [± 18]	**1738–1798 (61.6%)**	[± 30]	[± 30]	OS-125227
VF-5c	0.30		**1458–1499 (56.8%)**	1478	545	
(5)	[1.85]	419 [± 21]	1601–1610 (11.4%)	[± 20]	[± 20]	OS-110647
VF-5d	0.50		**1322–1352 (57.3%)**	1337	685	
(5)	[1.85]	648 [± 17]	1388–1394 (10.9%)	[± 15]	[± 15]	OS-126137
			1046–1088 (38.6%)			
VF-5e	0.85		1108–1121 (11.0%)	1067	955	
(5)	[1.85]	978 [± 14]	1132–1152 (18.7%)	[± 20]	[± 20]	OS-119976
VF-6a	0.60			1478	545	
(6)	[2.05]	443 [± 23]	**1450–1496 (68.3%)**	[± 30]	[± 30]	OS-110644

[a] Depth into wood from the sampling point.
[b] Height above ground level.

4. Conclusions

The research reports the AMS radiocarbon investigation results of the Big Tree at Victoria Falls, Zimbabwe. The main goal of the research was to determine the age, growth and structure of this impressive historic African baobab.

The Big Tree exhibits a kind of open ring-shaped structure, which consists of five main stems, three young stems and a false stem. Radiocarbon dating results, associated with the inspection and measurement of stems, allowed to estimate the age and the generation to which each stem belongs.

Several wood samples were collected from four different stems. Segments extracted from these samples were processed and dated by AMS radiocarbon. The oldest dated sample segment had a radiocarbon date of 978 ± 14 BP, which corresponds to a calendar age of 955 ± 20 years. This value indicates that the Big Tree at Victoria Falls is 1150 ± 50 years old.

The eight common stems of the baobab belong to three different generations, which are 1000–1100, 600–700 and 200–250 years old, respectively. The three young stems, which are part of the third generation, are not included in the ring.The large false stem, which acts as an anchor, is around 550 years old. We also found that the oldest stems stopped growing more than a century ago.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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