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Supplementary Material

Tasmania's giant eucalypts: discovery, documentation, macroecology and conservation status of the world's largest angiosperms

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Appendix S1. A brief history of giant tree measurement

The discovery and recording of giant trees in Australia have evolved in step with new technologies and data sets. In the 19th and 20th century tall trees were discovered by timber workers. Between the 1960s -1990s the tallest trees were recorded by chance during timber and ecological surveys (for example the Andromeda grove, Styx Valley, Tasmania) using topographic maps, compass bearings, and string lines for navigation (Kostoglou 2000). Availability of satellite imagery in the 1990s-2008 and ground-based surveys using Global Positioning Systems (GPS) enabled more accurate field- surveys. These became much more refined with the increasing availability and novel applications of LiDAR in Australia since 2008 (Nelson 2014) (Fig. S1).

Geometric methods

Prior to the advances of laser technology in the late 1990s, most tall tree heights in Australia were calculated by ground-based trigonometry (although some notable historical tall trees in Victoria were measured on the ground once they had been felled). Unfortunately, this 'tangent' method was unreliable, as it could not account for any horizontal difference between the base of the tree and the position of the perceived highest measured part of the tree, a problem that was noted as far back as 1923 (Hardy 1923). Furthermore, in irregular topped old growth eucalypt trees, the highest part of the tree is rarely directly over the base of the trunk. Consequently, many of the tallest trees measured via the tangent method were shown to be significantly shorter when later measured via laser or climber deployed tape drop. Other deficiencies of the tangent method include it being time consuming and destructive, as it requires clearing a line of sight to the base of the tree, and it is unsuitable for rugged terrain. This contributed to a historic bias to measuring trees in favourable settings. The availability of laser rangefinders from the late 1990s markedly improved the accuracy of tree height measurements. Depending on the internal accuracy of the laser in use, tree heights could be measured to within ± 30 cm. The other significant advantage of the laser rangefinder is that it enabled the user to survey many hundreds of trees in a day, regardless of vegetation and terrain. The accuracy of height measurements of very tall trees was further enhanced using a climber deployed tape drop, which was first noted in Australia in 1999 (Kostoglou 2000), although it had been used in the USA since at least 1988 (Sillett Pers. Comm.).

Measuring and ranking tree size

Historically, various methods have been used to measure and compare tree size. For example, many of the early measurements of giant trees in Victoria (especially stumps with accompanying photos) only recorded the girth of the tree, usually measured at breast height above the average ground level (Holmes 1949.) While this is the easiest measurement to make, it does not necessarily produce the best indication of tree size. A more detailed method to compare tree size is the American Forests points system (American Forests 2024): three aspects of the tree, the girth in inches, the height in feet and the average crown spread in feet divided by four, are added up to produce the total point score. This system has been used for many years in the USA and has been introduced to Australia via the National Register of Big Trees (2023b), for which it has been slightly modified in that the crown spread is no longer divided by four. Trunk wood volume was first used to compare tree size in the 1920s (Flint 2002), following a heated debate between rival counties as to which held the distinction of having the largest Giant Sequoia (*Sequoiadendron giganteum*) after the points system had not produced a clear champion. A team of engineers surveyed four trees from different counties and declared the 'General Sherman' tree both the winner and the largest known tree in the world, a title it has held to this day. Furthermore, trunk volume was measured and used by Van Pelt (2001) to rank 117 trees from 20 species in the seminal work 'Forest giants of the Pacific Coast'. The book included the Giant Sequoia, Coast Redwood (*Sequoia sempervirens*), Western Red Cedar (*Thuja plicata*), Douglas Fir (*Pseudotsuga menziesii*) and Sitka Spruce (*Picea sitchensis*) – five of the largest tree species on earth. Van Pelt (2001) considered stem volume the most appropriate method to compare very large trees (as opposed to the American forests 'Points' system) because (i) measuring diameter at breast height (as per the points system) means that for the largest trees, you are actually measuring the roots of the tree; (ii) stem volume includes multiple measurements from the entire trunk (not just at breast height) and therefore better represents the size of the tree trunk; (iii) it reduces the bias of the points system that favours trees with large buttresses or flaring at the base, but otherwise have an average sized or even small trunk above the basal flare (many tropical species for example); and (iv) it subtracts the air contained in fluting and buttressing (unlike the points system).

Method used to estimate trunk volume of Tasmanian massive trees

In our study of Tasmanian massive trees, we measured trunk wood volume to rank the most massive trees. Trunk wood volume is calculated by modelling the trunk as a series of truncated cones, measuring their height and upper and lower diameters, and calculating and summing these volumes. We acknowledge that it is possible to measure all the wood including branches down to 3 cm diameter (Kramer et al. 2018), it is extremely time-consuming to do so and requires a team of skilled climbers. We did not have the resources to do this, but present measurements or estimates of branch volume where these data are available from previous detailed surveys (Sillett et al. 2015).

To measure trunk volume, we initially assessed potential massive trees using girth measurements at 1.4 m above the high and mid points of ground, together with a preliminary measurement of trunk diameters using a handheld Relaskop (Macroscope 25/45 8x30 ocular, RF Interscience) in conjunction with a laser rangefinder (Nikon Forestry Pro I & II). From these initial measurements, if the tree was considered likely to be close to or exceed 280 m^3 in trunk wood volume, the volume was estimated in more detail:

i. A base model of the lower trunk was created using photogrammetry and / or iPhone LiDAR scanner (iPhone 12 Pro, Software: Agisoft Metashape) (Fig. 2c). Cross-sections of the 3-D model were extracted at small height intervals, and each area was then back-calculated into a circle, from which 'functional diameters' were obtained. (Fig 2b).
ii. Diameters of the trunk above the irregularly shaped basal section were measured via climber deployed tape wraps to top of the trunk (Fig 2d).
iii. All diameter figures from both the base modelling and the climber deployed tape wraps were combined to calculate create the total volume (Fig 2e).

Note that the volume of a truncated cone is given by:

$V = (1/3) * \pi * h * [r^2 + (r * R) + R^2]$,

where R is the radius of the base of the cone, r is the radius of the top surface, and h is the height of the truncated cone (Szczepanek 2024).

A worked example of this approach is provided in Table S3.

first estimating the volume of the irregular base of the tree using photogrammetry and/or LiDAR, and the upper part of the trunk by tape. Specifically:

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Table S1: Tallest known tree species in Australia. Species name, trunk measurements, condition, location and measurement notes are given for the tallest known living individual.

Tree species	Tree name (if applicable)	Height (m)	Girth at 1.4m	Diam at 1.4m	Condition of tree top	Geographic location	Notes
Eucalyptus regnans	Centurion	96.1	12	3.82	Living leaves	Arve Valley, Tasmania	First measured at 99.6 in 2008
Eucalyptus globulus	Neeminah Loggerale	90.7	13	4.14	Dead top	Denison Valley, Tasmania	First measured 2007
Eucalyptus obliqua	Princess Picabella	88.5	12	3.82	Living leaves	West Picton, Tasmania	First measured by laser January 2021
Eucalyptus tasmaniensis	n/a	86	13	4.14	Dead top	Lower Cole, Tasmania	Was 87.9 when first measured in 2004
Eucalyptus cypellocarpa	n/a	85	8	2.54	Living leaves	Errinundra NP, Victoria	Discovered by LiDAR, first measured by laser April, 2022
Eucalyptus nitens	n/a	84	8.2	2.61	Dead top	Yarra Ranges NP, Victoria	Fire damaged in 2009 Tallest live topped 81.5m
Eucalyptus viminalis	n/a	80	4	1.27	Living leaves	Yarra Ranges NP, Victoria	1939 regrowth
Eucalyptus diversicolor	n/a	78	7	2.23	Living leaves	Shannon NP, Western Australia	2020 Laser measurement
Eucalyptus denticulata	n/a	76	8.5	2.70	Living leaves	Errinundra NP, Victoria	2022 laser measurement
Eucalyptus dalrympleana	n/a	74	12.2	3.88	Living leaves	Burns Creek, Tasmania	Laser measurement
Eucalyptus grandis	The Grandis	71	10	3.18	Living leaves	Bulahdelah, NSW	Laser measurement
Eucalyptus deanei	Woodford tree	71	7.8	2.48	Living leaves	Blue Mountains, NSW	Laser measurement
Corymbia calophylla	Corymbia giant	71	10.8	3.44	Living leaves	Northcliffe, Western Australia	Laser measurement

Table S2. Australia's most massive tree species ranked by wood volume. Species name, volume of trunk, main appendages and branches, and state of origin are given for the most massive known living individual (as well as the other states in which the species occurs).

Species	Volume of trunk (m^3)	Volume of main appendages (m^3)	Branch volume (m^3)	Total (m^3)	State(s)
Eucalyptus regnans	463	20	7	490	Tas (&Vic)
Eucalyptus globulus	367	~5	N/A	372	Tas (&Vic)
Eucalyptus obliqua	297	43	N/A	337	Tas (&Vic)
Eucalyptus tasmaniensis	~240	~5	N/A	245	Tas
Eucalyptus diversicolor	187.6	33	N/A	220.6	WA
Eucalyptus jacksonii	171	33	N/A	204	WA
Eucalyptus denticulata	~200	~5	N/A	205	Vic
Eucalyptus nitens	229	~4	N/A	233	Vic
Ficus macrophylla	~140	~50	N/A	~190	NSW (&Qld)
Eucalyptus cypellocarpa	~190	~15	~5	205	Vic
Eucalyptus viminalis	180	~5	N/A	185	Tas (&Vic SA)
Eucalyptus pilularis	155	27.1	N/A	183	NSW
Ficus virens	~130	~50	N/A	~180	NSW & Qld
Eucalyptus grandis	137.6	18.7	N/A	156.3	NSW (&Qld)
Corymbia calophylla	119	20	N/A	139	WA
Corymbia gummifera	120.9	6	N/A	127	NSW
Eucalyptus mirocorys	102.4	21.6	N/A	124	NSW
Corymbia maculata	~100	~10	N/A	110	NSW
Eucalyptus gomphocephala	42.6	65.4	N/A	108	WA
Eucalyptus marginata	97.7	7.3	N/A	105	NSW
Eucalyptus fastigata	100	~5	N/A	105	Vic, NSW
Eucalyptus camaldulensis	~60	~40	N/A	100+	Vic SA NSW WA QLD NT
Lophostemon confertus	90	~20	N/A	110+	Qld (&NSW)
Eucalyptus deanei	73.7	18	~9	101	NSW
Eucalyptus dalrympleana	~90	~10		~100	Tas (&Vic SA)

Table S3. A worked example to calculate trunk volume of tree AR1 (Fig. 3). Trunk volume is calculated by modelling the trunk as a series of truncated cones, measuring their height and upper and lower diameters to calculate their volumes, then summing these. Diameters up the irregular base were estimated by software that processes data from photogrammetry and/ or LiDAR. In this instance, all measurements from -1.2m (below the high point of ground) to 17.2m in height were derived from this base model. Diameters above this were measured via climber deployed tape wrap (from this point, the trunk is assumed to be round in cross section).

Height (m)	Diameter (m)	Volume (m^3)	Notes
-1.2	0.000	1.29	Low point of ground
-0.7	3.135	6.98	
0	3.974	12.08	
0.7	5.368	11.44	
1.2	5.425	30.58	High point of ground
2.6	5.122	16.13	
3.5	4.422	13.70	
4.5	3.926	20.89	
6.5	3.359	15.88	
8.6	2.840	10.51	
10.4	2.611	18.60	
14	2.518	15.31	
17.2	2.417	17.27	End of base model
21	2.394	12.54	Start of tape wraps
23.9	2.298	18.49	
28.4	2.276	16.07	
32.7	2.085	13.79	
36.8	2.053	16.30	
42	1.942	12.80	
46.4	1.907	11.14	
50.4	1.859	9.62	
54.4	1.639	7.58	
58.3	1.506	6.71	
62.3	1.416	6.33	
66.5	1.353	4.01	
70.5	0.891	2.45	
76	0.605	0.02	
76.2	0.000	0.00	
Total		328.47	

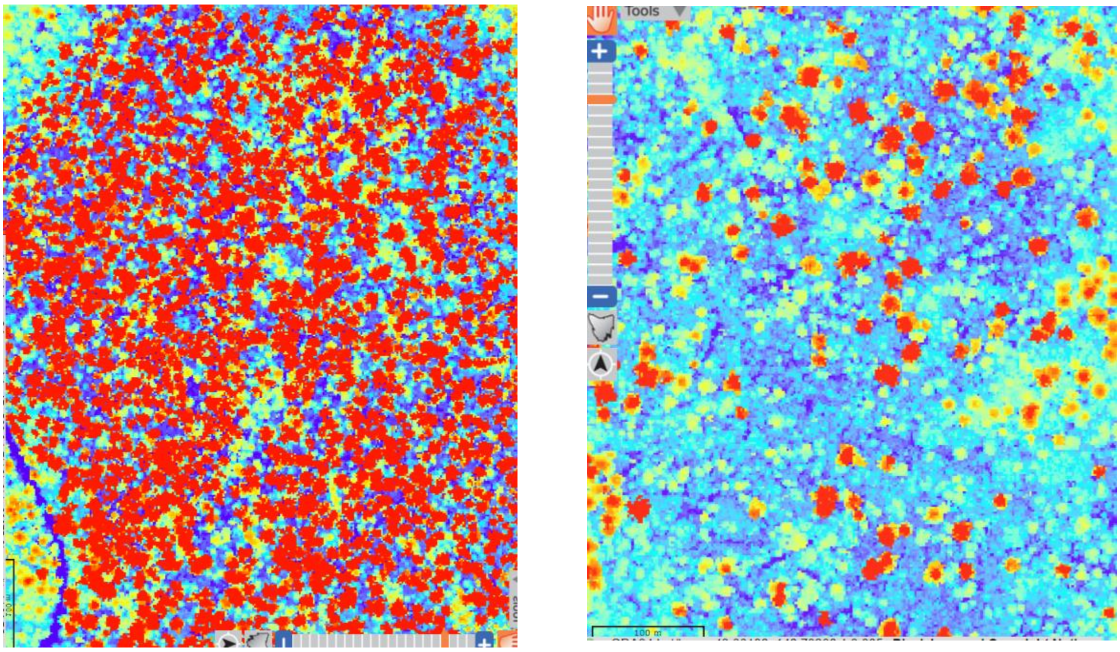

Fig. S1. LiDAR representation of two areas of tall forest, with red indicating height ≥ 50 m. On the left is the densely stocked, 220 years old. Three Huts stand in the Florentine Valley. On the right is an area of mostly rainforest of lower stature (blue) with the occasional older eucalypt tree (red). Forest of this type is usually 450-500 years old.

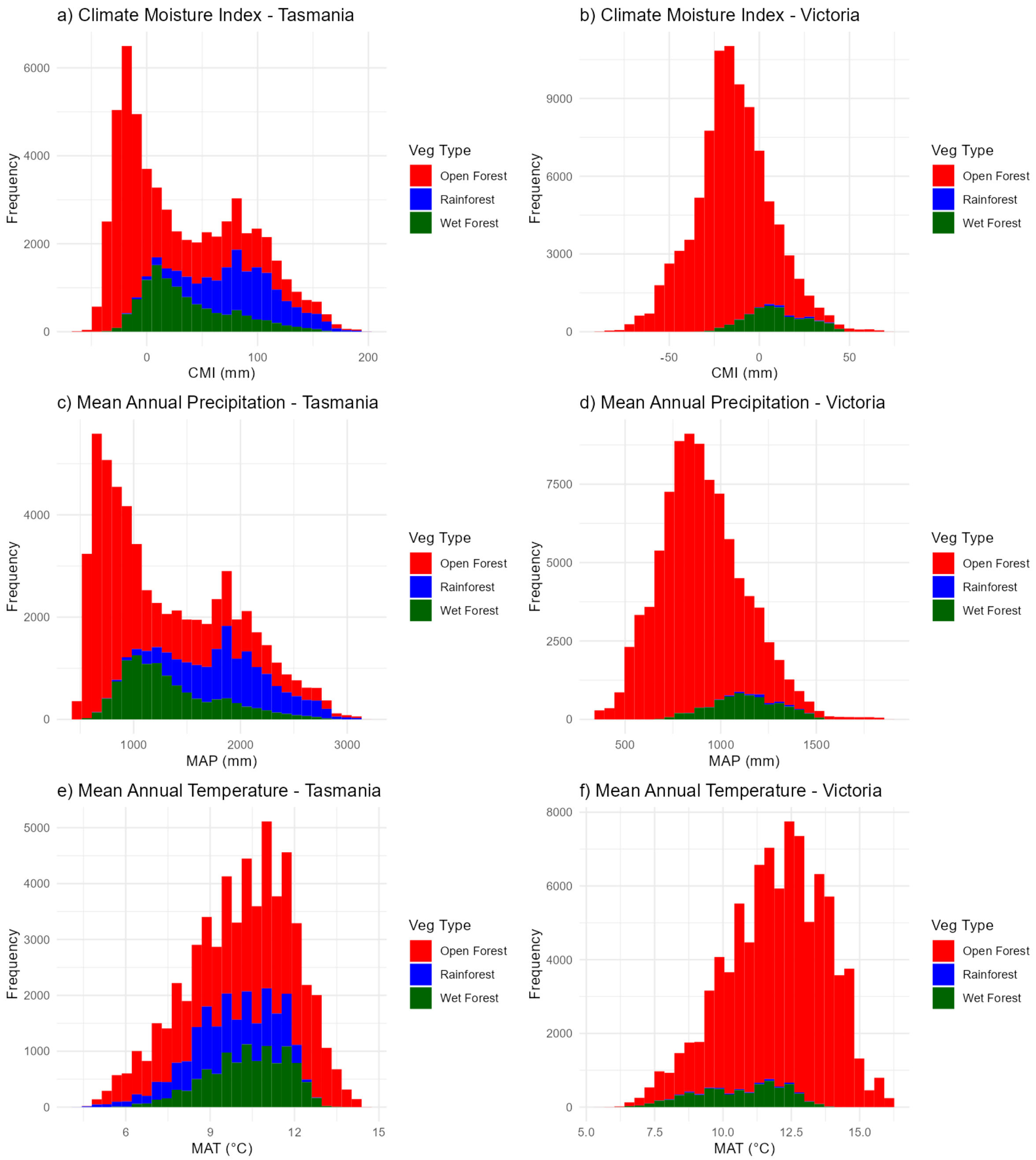

Fig. S2. Frequency distribution of open forest, rainforest and wet forest in Tasmania and Victoria in relation to climate moisture index, mean annual precipitation and mean annual temperature. Note the different scales for Tasmania and Victoria. Each cell represents 0.5 km^2.

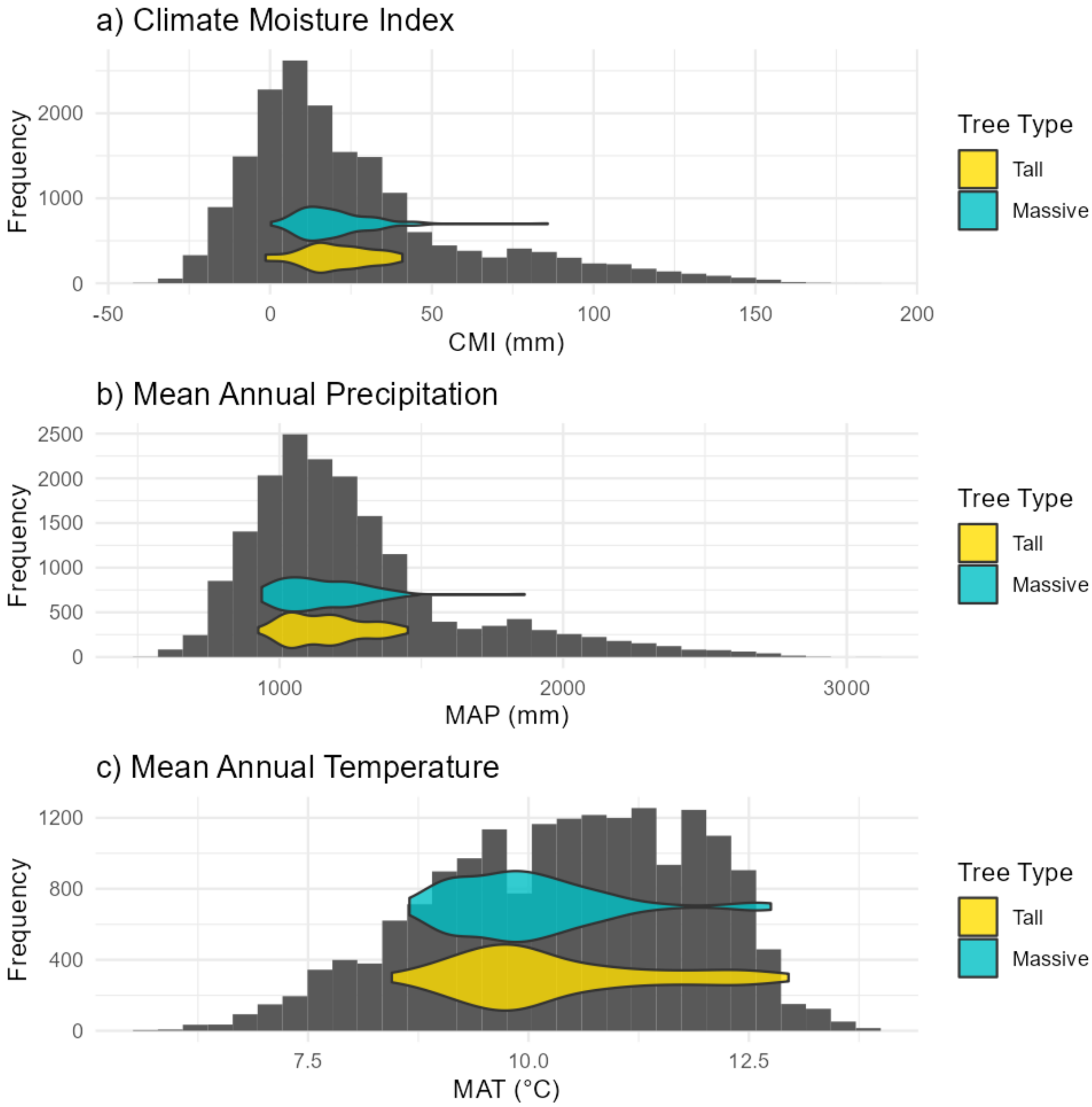

Fig. S3. The frequency distribution of the climatic variables climate moisture index (CMI), mean annual precipitation (MAP) and mean annual temperature (MAT) for wet forest in Tasmania and Victoria (black histograms). Violin plots show the distribution of exceptionally tall (≥85 m; yellow) and massive (≥200 m^3 for Tasmania, ≥170 m^3 for Victoria) for comparison. There was no significant difference in climate between tall and massive trees.

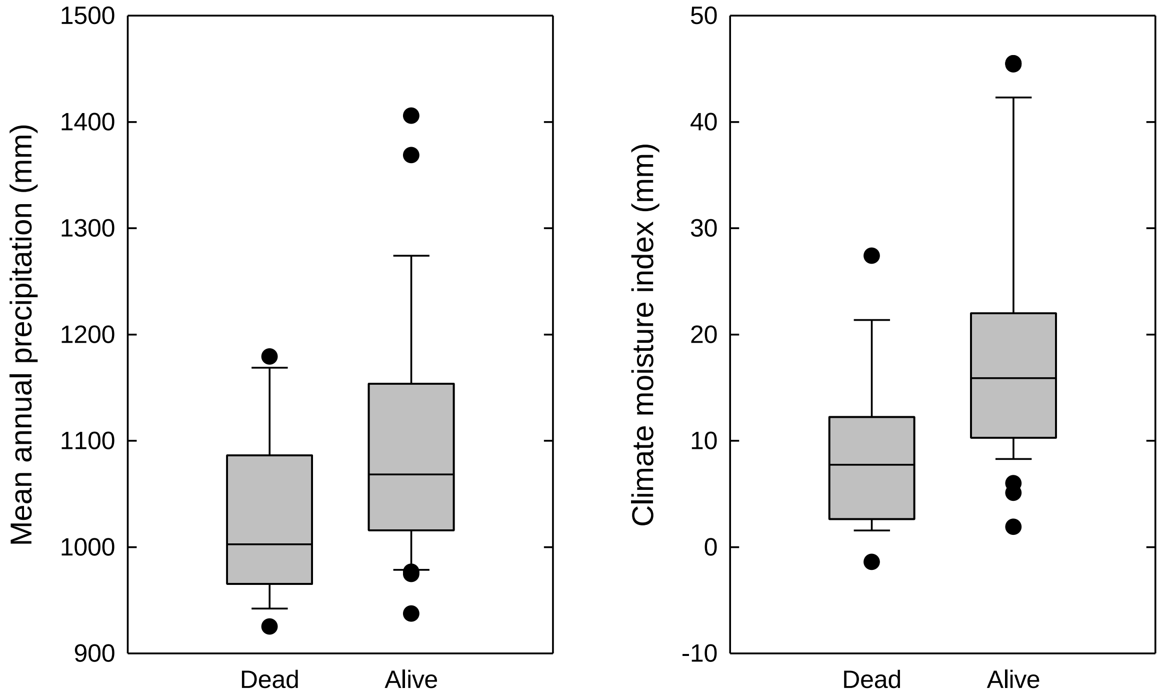

Fig. S4. Mean annual precipitation and climate moisture index for the massive trees (≥ 250 m^3) alive in the year 2000, according to whether they were alive (n = 39) or dead (n = 18) in 2023. The dead trees were all killed by fire (the massive tree that was logged in 2012 was omitted from this dataset).