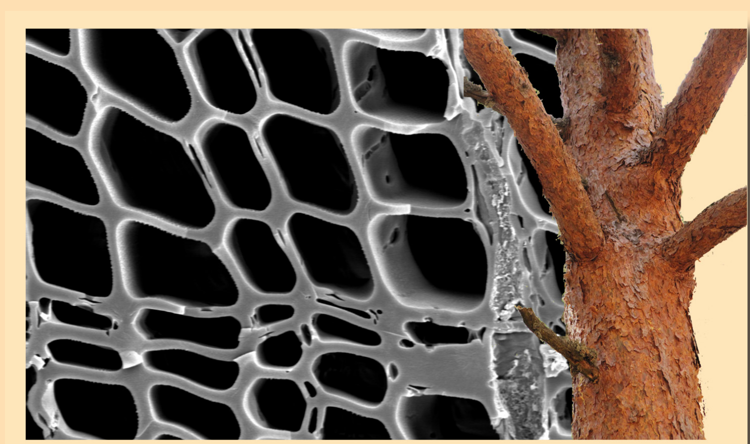
SAGVNTVM

PAPELES DEL LABORATORIO DE ARQUEOLOGÍA
DE VALENCIA
EXTRA-13

WOOD AND CHARCOAL
EVIDENCE FOR HUMAN AND NATURAL HISTORY

ERNESTINA BADAL – YOLANDA CARRIÓN – MIGUEL MACÍAS – MARÍA NTINOU
(COORDINATORS)



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FACULTAT DE GEOGRAFIA I HISTÒRIA
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Correction factors on archaeological wood diameter estimation

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***Summary**: This paper proposes two correction factors designed to improve the accuracy of dendrometric tools. The development of a referential framework on* Pinus halepensis *suggests that the "trigonometric tool" is the most appropriate technique for this estimation. The error rates associated with this tool are proposed as a first correction factor on archaeological measurements. The second correction factor is related to wood shrinkage. The percentage of radial and tangential shrinkage on* P. halepensis *sections is calculated. A test that applies this corrective factor on trigonometric measurements shows that tangential correction is more accurate than radial for treating archaeological data. Finally, an example of the application of both correction factors in the prehistoric site of Barranco de la Viuda is presented.*

***Key words**: Dendrometry, firewood,* Pinus halepensis*, Bronze Age, Iberian Peninsula.*

INTRODUCTION

Archaeological charcoals reflect management patterns of forest areas in the past. In addition to the species, an important criterion of wood selection could be the diameter, which influences aspects such as the intensity and duration of fire. Therefore, the development of dendrometric tools designed to estimate the calibre of prehistoric exploited firewood is an important line of research in anthracology.

The measurement of the radius of the curvature of growth rings involves calculating the distance between the pith (absent) and the charcoal fragment under study. Following early studies based on the degree of ring curvature (Lundström-Baudais 1986; Marguerie 1992; Ludemann and Nelle 2002; Dufraisse 2002, 2006; Marguerie and Hunot 2007), image analysis software has enabled the implementation of more accurate qualitative techniques such as the "circle tool" (Chrzazvez 2006) or others based on trigonometric principles (for a state of the art, see Dufraisse and García Martínez 2011).

The application of these tools involves a margin of error on the result. Its accuracy depends on the technique used, the distance from the pith, the wood anatomy and the intraspecific variability. This problem must be addressed through the development of referential frameworks that assess the reliability of these techniques for different species. In this research, a referential framework that evaluates the “circle tool” and the “trigonometric tool” on *Pinus halepensis* sections is presented. The percentages of error obtained serve as the first corrective factor on measurements made on archaeological charcoals (García Martínez and Dufraisse 2011).

Another factor that influences the calculation of the archaeological wood calibre is the shrinkage caused by carbonization. This shrinkage occurs in all directions (radial, tangential and longitudinal) and is influenced by physical variables such as length, thickness or density (Perstorper *et al.* 2001; Washusen and Ilic 2001; Clair *et al.* 2003) and chemical variables, such as the composition of the woody cells (Leonardon *et al.* 2010).

It has been noted that generally this shrinkage would be around 25% (Schweingruber 1978). Some experiments at 900°C observed a radial reduction close to 30% and tangential up to 40% (Byrne & Nagle 1997). The shrinkage of the vessel diameters of early *Quercus robur* wood was between 20-25% at 400°C and 40% at 1000°C (Braadbaart and Poole 2008). Davidsson and Pettersson (2002) observed tangential shrinkage between 25-40% and radial of 15-40%, with maximum tangential shrinkage at 400ºC and radial between 500-700 °C.

The application of this second correction factor on archaeological wood calibre estimation implies addressing new questions such as (1) if the shrinkage is homogeneous in the different parts of the wood (centre / periphery, compression / opposite wood) or (2) under what criteria it is possible to integrate this correction value with the use of dendrometric tools. To demonstrate this, an exploratory approach on the shrinkage experienced by two *Pinus halepensis* sections is proposed. Subsequently, an experimental test makes it possible to evaluate the most appropriate way to combine these two correction factors on charcoals found in an archaeological context.

Finally an example of the application of these correction factors on firewood from the prehistoric site of Barranco de la Viuda (SE Spain) is presented.

METHODS

REFERENTIAL FRAMEWORK

The referential framework has been developed using two fresh and charred *Pinus halepensis* sections sampled from the Region of Murcia (SE Iberia). The section 1 (R1) belongs to a 55-year-old tree which was 19.5 x 19.5 cm in diameter (without bark). The section 2 (R2) comes from a 30 year-old pine tree and was 17 x 15.5 cm in diameter. The carbonisation was conducted in a muffle furnace at 300 °C, without oxygen supply, for 2’45’’ (R1) and 2’30’’ (R2).

Measurements were made with binocular (x10) and NIS Elements D 3.1 image analysis software, on a surface of 0.84 x 0.63 cm. The “circle tool” generates a perfect circle from several reference points positioned on the edge of the growth ring. Between 15 and 20 reference points for each ring under study were marked. The “trigonometric tool” was applied by tracing the angle formed by two wood rays and the perpendicular distance between them. The radius of growth ring curvature was calculated by using the right triangle trigonometric formula (hypotenuse = opposite side / sine α). For this tool, a preliminary series of measurements made it possible to determine the minimum angle and distance values required to avoid systematic occurrence of marginal results, 3 degrees and 3 mm. This first stage also enabled the most appropriate diameter classes for this species: [0-2] cm, [2-5] cm, [5-10] cm, [10-14] cm, > 14 cm to be established. The dataset consists of 1882 measurements (Dufraisse and García Martínez 2011).

TEST ON WOOD SHRINKAGE

The experimental test on wood shrinkage has been conducted using two *Pinus halepensis* sections. The first one (R3) was 19.6 x 19.5 cm in diameter and the second one (R4) was 6.8 x 6.1 cm. Both of them were scanned to create a cross-shaped planimetry (Fig. 1) on the surface to obtain data concerning compression, opposite and normal wood. References indicating diameter classes, preset distances (1 cm for R4 and 2 cm for R3) and reference growth rings were marked.

The carbonization was conducted in a muffle furnace at 400 °C under reduction conditions, for 2'30''. Charred sections were scanned and the planimetry was adjusted to the shrinkage incurred. Then, comparative measurements of benchmarks to calculate percentages of radial and tangential shrinkage (opposite distance and angle) were made.

Finally, a test developed to correct the trigonometric measurements with these shrinking percentages was conducted. The radial correction was calculated by adding the average shrinkage percentage to the raw result. For the application of tangential correction, we firstly corrected the raw angle and opposite distance measurements, and then the radius was calculated.

RESULTS

REFERENTIAL FRAMEWORK

The referential framework compares the actual radius of the studied growth ring with the result obtained using dendrometric tools. The difference between them has been expressed as a percentage of error.

The average percentage error of the trigonometric tool is around 25%, while the circle tool error reaches 50%. The median is also lower with the trigonometric tool (between 19-22%), whilst it exceeds 25% for the circle tool. Therefore, the trigonometric tool proves to be the most appropriate technique to calculate *Pinus halepensis* calibres.

Results of reliability graphs by diameter classes have already been described in a previous publication (Dufraisse and García Martínez, 2011). These showed that the circle tool is accurate only for diameters less than 2 cm, acceptable up to 5 cm and demonstrates predominantly marginal results for calibres exceeding 10 cm. The trigonometric tool provides very reliable measurements (above 50%) up to 10 cm in diameter. The margin of error increases for larger diameters, however unreliable measurements are a minority. In both cases, the results are reproducible across all fresh and charred sections. Consequently, trigonometry would also be better suited to estimating *Pinus halepensis* calibres considering diameter classes.

TRIGONOMETRIC TOOL CORRECTION

The validity of the circle tool to estimate *Pinus halepensis* calibres being dismissed, the correction applied on archaeological charcoals will take into consideration only the trigonometric results.

We notice that the trigonometric tool involves an overestimation of small diameters (less than 10 cm) while an underestimation of the larger ones. The correction values have been established by calculating the average percentage error (including positive and negative percentages) for each diameter class studied. It is necessary to apply a different correction value on each diameter class (García Martínez and Dufraisse 2011) and the correction curve provides increased accuracy for diameters between 5 and 10 cm (Fig. 2).

WOOD SHRINKAGE

The shrinkage experienced by the wood sections following carbonization demonstrates no significant differences between compression, opposite and normal wood. R3 and R4 radial shrinkage is about 20% and similar values are given in the tangential direction. The percentage reduction of angles formed by several reference points is around 3% (Table 1).

SHRINKING CORRECTION

The criteria for applying this correction factor on trigonometric measurements were evaluated by means of an experimental test. We seek to determine which

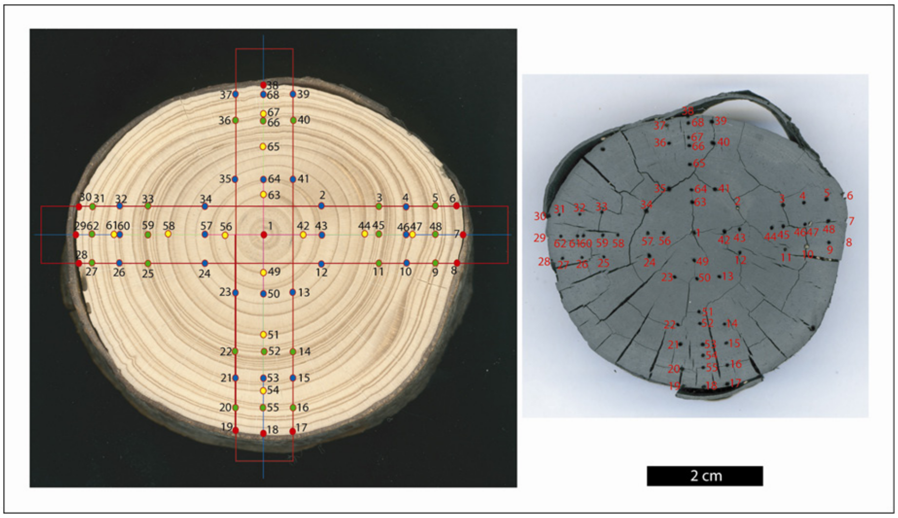

Figure 1. Cross-shaped planimetry designed on the section R4. Shrinkage is clearly noticeable in carbonised section.

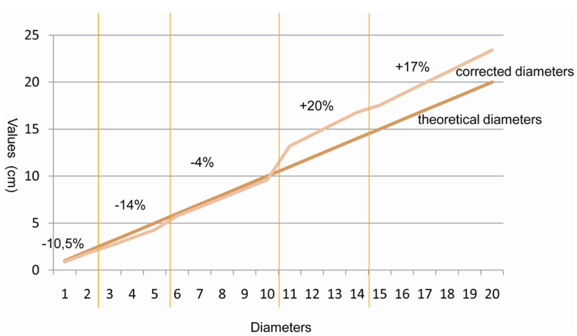

Figure 2. Correction values to be applied on the archaeological trigonometric measurements.

shrinking correction (radial or tangential) provides a more reliable approach to the initial diameter of exploited firewood.

The average percentage error of raw trigonometric measurements is around 7%, but shows very high standard deviation (Table 2). The shrinking correction applied to raw data provides the best results. The radial correction provides very accurate corrected measurements, with the average margin of error decreasing to 1.8%. The average percentage error is almost zero when applying tangential correction (0.004%). The standard deviation is similar in both cases, being slightly lower for tangential correction. Even though differences are not notable, tangential correction can be considered as the most appropriate corrective factor for measurements on archaeological charcoals, due to the slightly lower error rates (Table 2).

AN ARCHAEOLOGICAL EXAMPLE: BARRANCO DE LA VIUDA (SE SPAIN)

The dendrometric measurements and correction factors proposed have been tested on the Bronze Age site of Barranco de la Viuda (*c.* 3400 BP). Here, the anthracological spectrum is dominated by *Pinus halepensis* (García Martínez *et al.* 2010, 2011). 384 charcoal fragments from two archaeological levels (I and II) and two structures associated with level II (a vessel-ashtray and a fireplace) were measured (Fig. 3).

Level I, Level II and the vessel-ashtray provide similar raw measurements. Small calibres are dominant; especially between 2 and 5 cm. Diameters between 5 and 10 cm have acceptable percentages while large diameters are a minority. None of these contexts show charcoals larger than 14 cm in diameter. The fireplace shows some differences compared with the other contexts. Firewood between 2 and 5 cm was also mainly used, but diameters between 0-2 cm are not well represented. For this structure, medium and large calibres have notable percentages and raw data show the presence of wood over 14 cm in diameter.

Diameter classes (cm)	R3 Radial Shrinkage (%)	R4 Radial Shrinkage (%)	R3 Tangential Shrinkage (Distance) (%)	R4 Tangential Shrinkage (Distance) (%)	R3 Tangential Shrinkage (Angle) (%)	R4 Tangential Shrinkage (Angle) (%)
[0-2]	22.9	21.25	18.9	20.25	0.76	3.36
[2-5]	17.63	23.32	19.58	22	6.97	2.34
[5-10]	17.79		22.41		3.17	
[10-14]	20.94		19.67		1.71	
[>14]	22.38		20.97		4.25	
Average Shrinkage	20.328	22.285	20.306	21.125	3.372	2.85

Table 1. Percentages of radial and tangential shrinkage experienced by *Pinus halepensis* sections.

Diameter classes (cm)	Raw data - Percent error	Corrected data - Percent error	
		Radial correction	Tangential correction (distance + angle)
[0-2]	163.9161961	8.564297085	2.629656031
	-8.560718894	1.07594019	6.409961156
	-18.8	-10.19073721	-6.215135623
	1.290130885	13.05725543	17.37234018
	-4.427394294	5.78044635	13.49521115
[2-5]	17.45732643	16.63399444	0.379964597
	6.721853593	5.631636891	0.250854678
	11.5339181		1.319274422
	-15.35870986	-0.90689968	-2.006457473
	-11.44144771	3.581313065	7.628330829
	-14.4558236	3.242803003	2.330492623
	-19.07458572	-7.943372759	-2.665990228
[5-10]	5.272752085	-2.203774391	-7.427471243
	15.31667139	-10.87972745	-5.433260499
	10.56905128	-1.261300024	-3.663267027
[10-14]	-6.75568934	1.686532077	-2.070385846
	-4.063044736	-5.120717076	-5.515868927
	22.95336833	5.869721595	-4.609488265
	9.682938091	-2.487278811	-2.395795689
[>14]	-7.175084958	2.768009026	
	17.31929505	5.472365732	0.959572517
	3.522599781	5.629975431	-9.432214487
	-1.453592416	2.341492748	-1.246553608
Mean	7.56478	1.83373	0.00426224
Median	1.29013	2.55475	-1.62651
Standard Deviation	36.2101	6.80777	6.54108

Table 2. Results of the test designed to combine shrinking correction with trigonometric measurements.

Corrected data show some changes with respect to the raw measurements. In general, the distribution of the different diameter classes is similar, with a dominance of small calibres. 5-10 cm diameter class is also well represented. The correction of the results has highlighted the emergence of firewood larger than 14 cm in diameter in all studied contexts. This correction could also increase the percentage of diameters between 10 and 14 cm where they were weak.

Therefore, firewood exploitation in Barranco de la Viuda was primarily directed towards small-calibre branches, and especially up to 5 cm in diameter. These

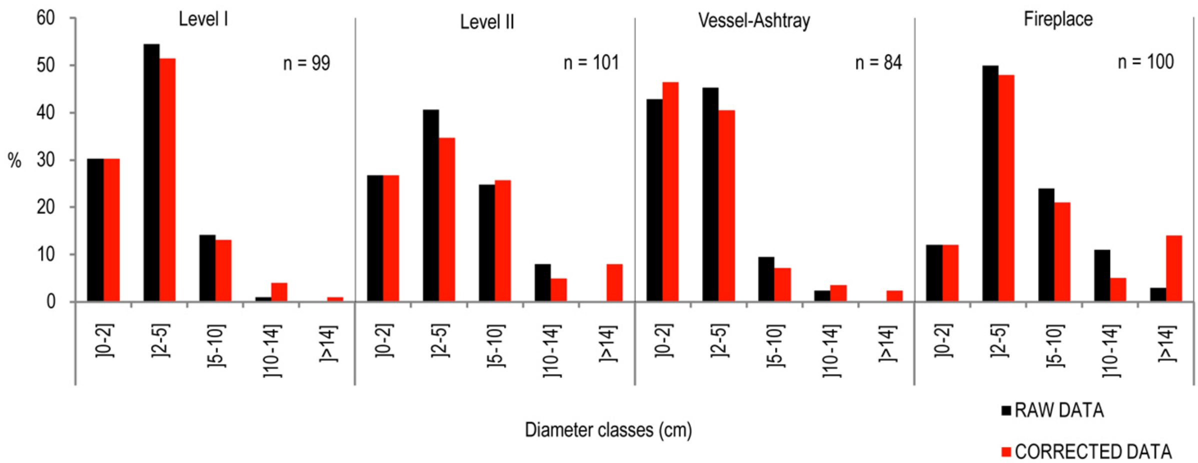

Figure 3. Raw and corrected measurements made on Barranco de la Viuda charcoal fragments.

branches were possibly dead branches recovered from the ground or damaged branches ripped straight from the trees. The presence of saproxylophagous species of Buprestidae, Cerambycidae and Siricidae families in some of these branches would confirm this hypothesis. Conversely, in the studied contexts there is a less significant presence of high calibre wood, while data correction reveals some trunk fragments larger than 14 cm in diameter, but less than 20 cm. This can suggest occasional but not systematic felling of whole trees. This activity could be linked to the periodic supply of firewood to the combustion structures associated with roasting and processing of cereal activities documented in the site. The presence of trunks of this size is also a possible indicator of the opening stage of the surrounding vegetation, which could have reduced the range of exploitable resources.

CONCLUSIONS

In this paper, we have proposed two correction factors that expand the accuracy limits of methods for estimating the radius of growth ring curvature on archaeological charcoals.

The development of a referential framework on *Pinus halepensis* sections has confirmed that the circle tool is inappropriate for this estimation. In contrast, the trigonometric tool provides reliable results. The error rates associated with the application of this tool for each diameter class studied have been proposed as a first correction factor on raw archaeological measurements.

The second correction factor is related to wood shrinkage. The experimental carbonisation of pine sections made it possible to calculate the percentage of radial and tangential shrinkage. A test designed to apply this corrective factor on trigonometric measurements shows that tangential correction is more accurate than radial for treating archaeological data.

Finally, an example of the archaeological application of both correction factors has been presented. In the prehistoric site of Barranco de la Viuda the patterns of firewood exploitation were focused on collection of thin branches. Correction of the raw data has highlighted the minority use of firewood larger than 14 cm in diameter.

This paper opens up new research perspectives. A more complete understanding of prehistoric patterns of wood calibre exploitation requires the development of referential frameworks for other tree species. The test of wood shrinkage presented here is exploratory. In the future, it will be necessary to increase and diversify experimental criteria, such as temperature, species and wood properties.

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REFERENCES

BRAADBAART, F.; POOLE, I. (2008): Morphological, chemical and physical changes charcoalification of wood and its relevance to archaeological contexts. *Journal of Archaeological Science* 35, 2434-2445.

BYRNE, C.E.; NAGLE, D.C. (1997): Carbonisation of wood for advanced materials applications. *Carbon* 35, 59-266.

CHRZAVZEZ J. (2006): *Collecte du bois de feu et paléoenvironnements au Paléolithique. Apport méthodologique et étude de cas: La grotte de Fumane dans les Pré-Alpes Italiennes*. Mémoire de Master II, Université Paris I.

CLAIR, B.; JAOUEN, G.; BEAUCHÊNE, J.; FOURNIER, M. (2003): Mapping radial, tangencial and longitudinal shrinkages and relation to tension wood in discs of the tropical tree *Symphonia globulifera*. *Holzforschung* 57, 665-671.

DAVIDSSON, K.O.; PETTERSSON, J.B.C. (2002): Birch wood particle shrinkage during rapid pyrolisis. *Fuel* 81, 263-270.

DUFRAISSE, A. (2002): *Les habitats littoraux néolithiques des lacs de Chalain et Clairvaux (Jura, France): collecte du bois de feu, gestion de l'espace forestier et impact sur le couvert arboréen entre 3700 et 2500 av. J.-C. Analyses anthracologiques.* Ph.D. Thesis. Université de Franche-Comté, Besançon.

DUFRAISSE, A. (2006): Charcoal anatomy potential, wood diameter and radial growth. In: Dufraisse, A. (ed.), *Charcoal analysis: new analytical tools and methods for archaeology. Papers from the Table-Ronde held in Basel 2004*. BAR International Series S-1483, Oxford, 47-60.

DUFRAISSE, A.; GARCÍA MARTÍNEZ, M.S. (2011): Mesurer les diamètres du bois de feu en anthracologie. Outils dendrométriques et interprétation des données. *Anthropobotanica* 02. http://www.mnhn.fr/museum/foffice/science/science/DocScientifique/publications/presentation.xsp?i=1.

GARCÍA MARTÍNEZ, M.S.; DUFRAISSE A. (2011): Bronze Age firewood exploitation in South-eastern Iberia: a study focusing on an estimation of wood diameter. *Saguntum-Extra* 11, 187-188.

GARCÍA MARTÍNEZ, M.S.; MEDINA RUIZ, A.J.; GALLEGO CAMBRONERO, D. (2010): Formaciones forestales en la cuenca del Guadalentín durante la Edad del Bronce a partir del estudio antracológico de Barranco de la Viuda (Lorca, Murcia). *Saguntum* 42, 43-57.

GARCÍA MARTÍNEZ, M.S.; MEDINA RUIZ, A.J.; GALLEGO CAMBRONERO, D. (2011): Leña y madera de construcción en el poblado argárico de Barranco de la Viuda (Lorca, Murcia). *Zephyrus* 67, 129-143.

LEONARDON, M.; ALTANER, C.M.; VIHERMAA, L.; JARVIS, M.C. (2010): Wood shrinkage: influence of anatomy, cell wall architecture, chemical composition and cambial age. *European Journal of Wood and Wood Products* 68, 87-94.

LUDEMANN T.; NELLE O. (eds) (2002): *Die Wälder am Schauinsland und ihre Nutzung durch Bergbau und Köhlerei*. Forstwissenschatliche Fakultät der Universität Freiburg und Forstlische Versuchs- und Forschungsanstalt Baden-Württemberg, Freiburg.

LUNDSTRÖM-BAUDAIS K. (1986): Etude paléoethnobotanique de la station III de Clairvaux. In: P. Pétrequin ed. *Les sites littoraux néolithiques de Clairvaux-les-Lacs (Jura). I,* *Problématique générale, l'exemple de la station III*. Maison des Sciences de l'Homme, Paris, 311-391.

MARGUERIE, D. (ed.) (1992): *Evolution de la végétation sous l'impact anthropique en Armorique du Mésolithique au Moyen Âge: études palynologiques et anthracologiques des sites archéologiques et des tourbières associées*. U.P.R. n° 403 du C.N.R.S, Rennes.

MARGUERIE D.; HUNOT J.-Y. (2007): Charcoal analysis and dendrology: data from archaeological sites in north-western France. *Journal of Archaeological Science* 34, 1417-1433.

PERSTORPER, M.; JOHANSSON, M.; KLIGER, R.; JOHANSSON, G. (2001): Distortion of Norway spruce timber. Part 1. Variation of relevant wood properties. *European Journal of Wood and Wood Products* 59 (1-2), 94-103.

SCHWEINGRUBER F. H. (1978): *Microscopic wood anatomy*. Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf.

WASHUSEN, R., ILIC, J., 2001. Relationship between transverse shrinkage and tension wood from three provenances of *Eucalyptus globulus* Labill. *European Journal of Wood and Wood Products* 59 (1-2), 85-93.

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