Dendrochronologia 65 (2021) 125802

Contents lists available at ScienceDirect

Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

Original Article

Demystifying the age of old olive trees

J. Julio Camarero[a,*], Michele Colangelo[a,b], Adrián Gracia-Balaga[a], Miguel A. Ortega-Martínez[a], Ulf Büntgen[c,d,e,f]

[a] Instituto Pirenaico de Ecología (IPE-CSIC), Avda. Montañana 1005, 50192, Zaragoza, Spain
[b] School of Agricultural, Forest, Food and Environmental Sciences, Univ. Basilicata, Potenza, I-85100, Italy
[c] Department of Geography, University of Cambridge, Cambridge, CB2 3EN, UK
[d] Swiss Federal Research Institute (WSL), 8903, Birmensdorf, Switzerland
[e] Global Change Research Institute of the Czech Academy of Sciences (CzechGlobe), 603 00, Brno, Czech Republic
[f] Department of Geography, Faculty of Science, Masaryk University, 613 00, Brno, Czech Republic

ARTICLE INFO

Keywords:
Mediterranean trees
Monumental trees
Old trees
Olea europaea
^{14}C-dating

ABSTRACT

Iconic to the Mediterranean landscape, the age of monumental olive trees with large trunks and unique silhouettes is often considered several centuries to millennia. Here we combine tree-ring and radiocarbon dating to show that most monumental olive trees may have maximum ages between 300 and 500 years. Our example helps disentangling the tree size-longevity conundrum in a major Mediterranean cultivated tree species and important cultural heritage.

1. Introduction

The evergreen olive tree (*Olea europaea*) is a major cultivated species in areas of seasonal drought, such as the Mediterranean Basin where successive civilizations domesticated and spread the species. Olive trees, which are also widespread in other regions with Mediterranean climate (e.g. Chile, California and Australia), can become large and monumental with thick trunks of up to two meter diameter (Ninot et al., 2018). Since most people confuse tree size and age, there is the common believe that many of the magnificent olive trees are very old (Diez et al., 2011). However, scientific data supporting the assumption of millennial individuals are lacking, and the available literature reports a wide range of maximum ages of olive trees (e.g. Thomas, 2003). Here, we argue that most monumental olive trees are a few hundred rather than a few thousand years old.

When searching for the word combination "millennial, olive and tree" (www.google.com; March 2020), we found 1,140,000 results, whereas the Web of Science or Scopus only contain two scientific articles about old olive trees, though lacking any reliable age estimate (Diez et al., 2011; Delgado et al., 2013). Most web pages are touristic and refer to ancient olive trees, such as a 1,700-year old tree in Spain (https://edition.cnn.com/travel/article/millenary-olive-trees-spain/index.html), or another olive tree from Montenegro that is supposed to be at least 1,314 years old (https://www.oliveoiltimes.com/wp-content/uploads/2015/05/cert.jpg). However, none of these entries provide scientific references to how dating was performed. A more recent study characterizes genetically old olive trees in eastern Spain (Ninot et al., 2018), and reports maximum age estimates of 324–1,082 years, based on algorithms transforming stem circumference or diameter measured at 1.3 m into theoretical age (Arnan et al., 2012). Radiocarbon (^{14}C) dating of olive trees in the Garden of Gethsemane estimated maximum ages of up to 670 years (Bernabei, 2015).

To accurately date trees, a complete radius of annually formed rings from the innermost pith to the outermost bark must allow cross-dating against independent reference material. Cross-dating of olive wood is, however, challenging if not impossible (Cherubini et al., 2013, 2014), because the species often forms intra-annual wood density fluctuations and exhibits false rings. The species is also well-known for highly variable tree-ring boundaries and eccentric growth patterns (Cherubini et al., 2003). Despite these constraints, a few studies have succeeded to synchronize and measure rings in cultivated (Rossi et al., 2013) and wild olive (*Olea europaea* subsp. *cuspidate*) trees (Girmay-Siyum et al., 2019).

It should be further noted that high-resolution ^{14}C-dates of the outermost wood of the same olive tree may differ by several decades (Ehrlich et al., 2018), most likely due to shifts in cambial activity along the stem circumference (Liphschitz and Lev-Yadun, 1986).

Here we combine tree-ring dating in nine trees from northeastern Spain with ^{14}C analyses in wood from five monumental olive trees

* Corresponding author.
E-mail address: jjcamarero@ipe.csic.es (J.J. Camarero).

https://doi.org/10.1016/j.dendro.2020.125802
Received 8 October 2020; Received in revised form 10 November 2020; Accepted 22 December 2020
Available online 28 December 2020

Table 1
Location, diameter, number of counted rings and the age estimated through ^{14}C dating of pith wood in five monumental olive trees sampled in north eastern Spain (calendar dating using CALIB program; see Stuiver and Reimer, 1993; Reimer et al., 2013; Stuiver et al., 2020). Age was estimated with respect to the 2020 year and the two ^{14}C-dates with highest probability are presented.

Study site	Latitude N	Longitude –W, +E	Diameter at 1.3 m (cm)	No. rings	Age ± SE (years)	^{14}C cal. date	Prob. (%)
Ainzón	41.8066	−1.5344	146.0	275	151 ± 27	1803–1937	69.5
					312 ± 27	1681–1738	28.9
Barillas	41.9743	−1.6610	118.0	182	177 ± 33	1797–1891	64.5
					272 ± 33	1716–1782	30.7
Asque	42.1755	0.0497	98.0	220	371 ± 26	1631–1670	68.0
					232 ± 26	1779–1799	17.1
Valdealgorfa	40.9896	−0.0228	124.5	–	533 ± 27	1450–1526	55.9
					427 ± 27	1556–1632	44.1
Valderrobres	40.8527	0.1561	87.0	–	365 ± 26	1634–1679	62.6
					233 ± 26	1776–1800	30.6

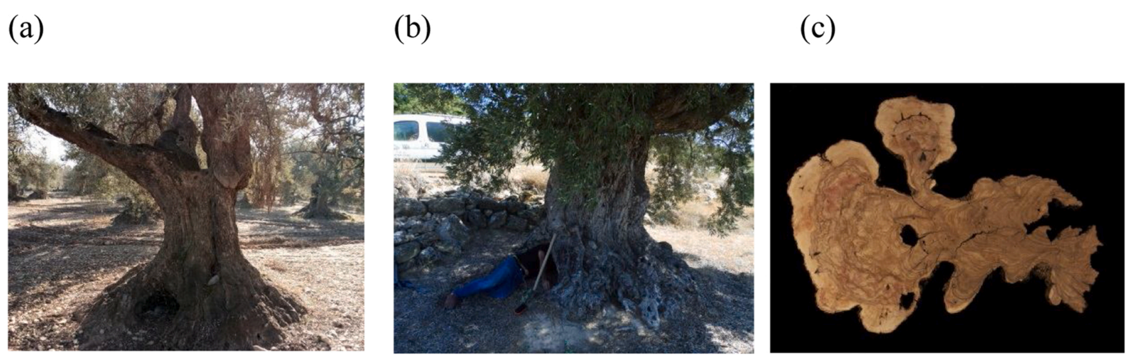

Fig. 1. View of (a) a monumental olive tree, (b) sampling of pith wood, and (c) basal cross-section (olive tree sampled in Asque, see Table 1). The first photograph (a) was taken by A. Gracia-Balaga in Barillas (north eastern Spain), and the second (b) and third images (c) correspond to J.J. Camarero and M. Ortega-Martínez, respectively.

sampled in eastern Spain and compared them with previous analyses carried out by other authors in different regions of the Mediterranean Basin. In this way, we illustrate how ^{14}C analyses improve the dating of monumental trees, particularly in the case of olive trees which show challenging tree-ring dating because of the formation of false rings (Cherubini et al., 2003, 2013, 2014).

2. Materials and methods

We sampled, measured and cross-dated nine olive trees located near the village of Ainzón in Aragón, northeastern Spain (41° 47’ 50’’ N, 1° 31’ 57’’ W and 471 m a.s.l.). The annual mean temperature and precipitation total is 12.2 °C and 420 mm, respectively, according to data from the Borja climate station (41° 50’ 05’’ N, 1° 31’ 55’’ W, 459 m a.s.l.). Water deficit occurs from June to September with minimum soil water availability in July and August. Frosts can occur from November to March.

The samples were cross-sections of basal stems or thick branches which were carefully sanded until rings were clearly visible and visual cross-dating was possible. Two radii per tree were dated and measured to the nearest 0.01 mm using a Lintab-TSAP measuring device (Rinntech™, Heidelberg, Germany). Cross-dating was only feasible for the period 1950–2017. The resulting ring-width data were detrended and standardized by using the software ARSTAN v.44 (Cook and Krusic, 2005), which allows removing age-related growth trends prior to calculating growth-climate response patterns. Each ring-width series was detrended by 32-year cubic smoothing splines. The resulting series of dimensionless ring-width indices were pre-whitened with an autoregressive model, and their bi-weight robust mean was computed to obtain residual chronologies of high-frequency variability. Calculated over the common 1950–2017 period, a mean correlation of 0.19 between trees, a mean correlation of 0.52 between radii, an EPS (Expressed Population Signal) of 0.65, and 30.1 % of variance in the first eigenvector indicate a

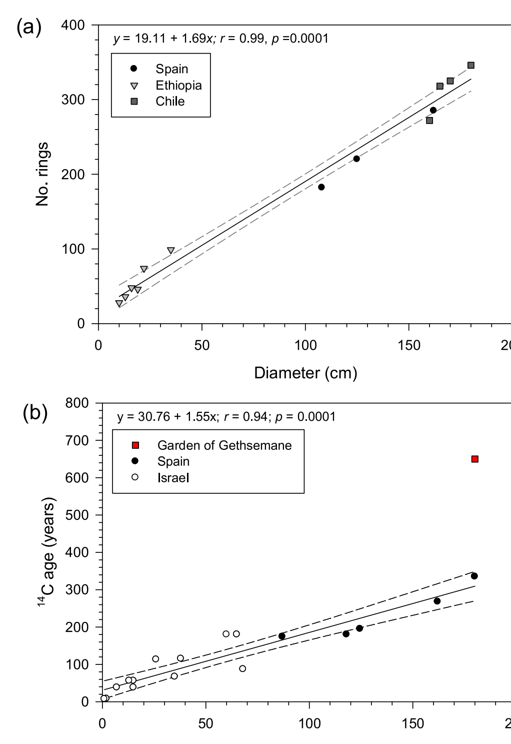

Fig. 2. Relationships between trunk diameter of olive trees and age estimated by counting annual rings (a) or through ^{14}C dating. In plot (b) the square shows the dating of an olive sampled in the garden of Gethsemane (Bernabei, 2015) which was not included in the regression. Continuous and dashed lines show the linear regressions and their 95 % confidence intervals, respectively (statistics are displayed in the plots).

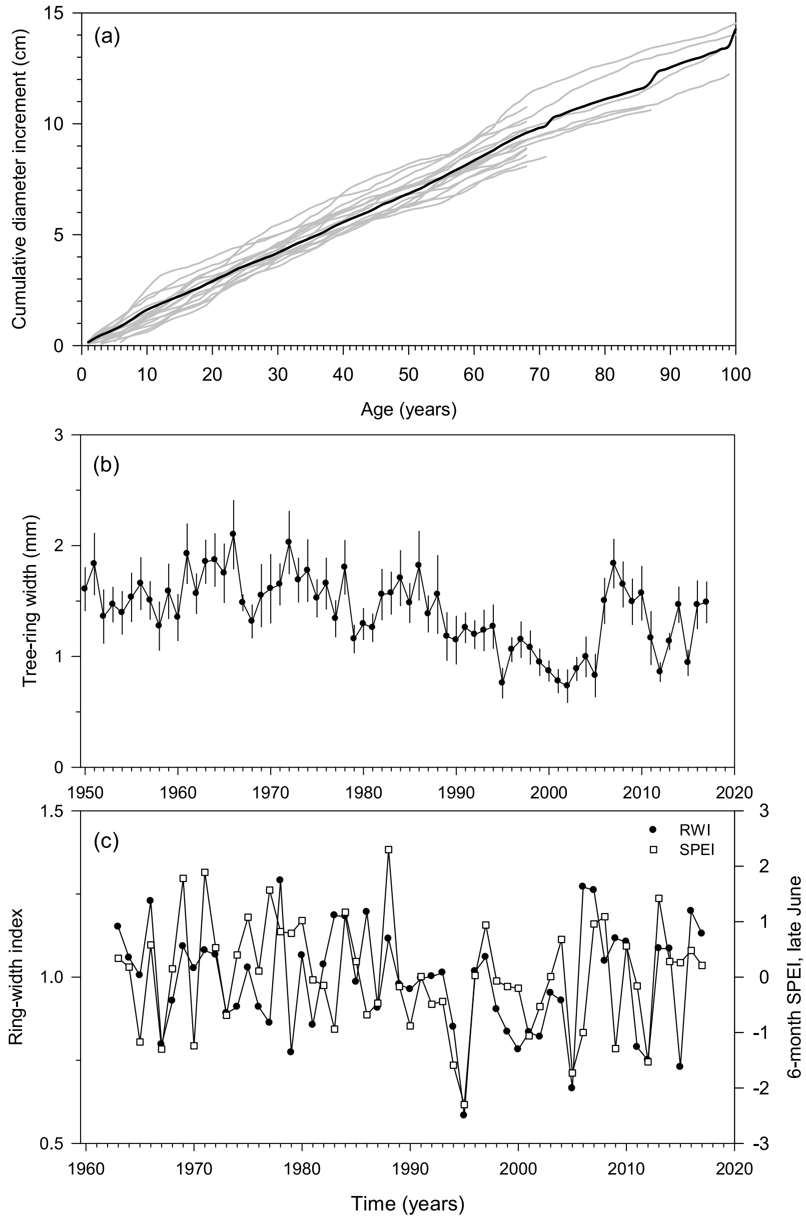

Fig. 3. Different components of radial growth in olive trees sampled in Ainzón, north eastern Spain (see location in Table 1). (a) Cumulative diameter increment as a function of tree age, (b) inter-annual growth variability (values are mean ring widths ± SE), and (c) drought-growth relationships. In plot (c) the mean series of ring-width indices (RWI) or residual chronology was found to be positively correlated with the 6-month SPEI drought index calculated for the last week of June.

weak common signal and a high tree-to-tree variability.

We calculated Pearson correlations between the mean series of the pre-whitened ring-width indices (residual chronology) and the Standardized Precipitation Evapotranspiration Index (SPEI), a multi-scalar drought index that explicitly considers the effect of temperature on the water balance (Vicente-Serrano et al., 2010, 2017). The SPEI data for the period 1963–2017 were downloaded at weekly resolution and at 1.1-km^2 spatial resolution for the grid box over the study site (https://monitordesequia.csic.es/).

In order to assess the relationships between trunk diameter and tree age, we compiled data on trunk diameter and number of rings from monumental olive trees. This information was obtained for trees from Spain (Arnan et al., 2012; and this study), Chile (Contreras et al., 2018), and Ethiopia (Girmay Siyum et al., 2019). Moreover, we collected data on tree diameter and ^{14}C dates of ring formation from several analyses carried out in Israel (Bernabei, 2015; Ehrlich et al., 2017, 2018), as well as from five selected monumental olive trees from eastern Spain (this study; Table 1, Fig. 1). All trees presented in this study contain pith wood samples, which contained between 10 and 30 rings, taken either by sampling cross-sections or partially rotten stumps (Fig. 1**b** and **c**).

3. Results and discussion

We establish relationships between trunk diameter and tree age based on ring counting (Fig. 2a) or ^{14}C-dating (Fig. 2b). These regressions emphasize that the diameter-age relationships could be described using linear regressions up to ages of about 400 years. The ^{14}C-inferred ages of some monumental olive trees, as those sampled in the Garden of Gethsemane (Bernabei, 2015) do not fit with the derived regression. Predictions based on ring counting or ^{14}C dating yield similar estimates. For instance, an olive tree with a 2-m diameter trunk should have an age between 340 and 361 years according to ring counts and ^{14}C dates, respectively.

The ^{14}C-inferred mean (± SE) age of monumental olive trees from northern Spain is 307 (± 37) years with a maximum age of 560 years (Table 1). These estimates agree with findings by Ehrlich et al. (2017), who concluded that most monumental olive trees are not older than 300–500 years based on ^{14}C-dating of olive cross-sections.

The cross-dating and measuring of rings in the nine individuals sampled in Ainzón, northeastern Spain, suggest that the oldest dated tree is circa 100 years old and the mean cumulative radial increment rate is 0.13 cm yr^{-1} (Fig. 3a), which agrees with previous analyses (Arnan et al., 2012). The mean ring-width is 1.38 mm (Fig. 3b). The mean series of ring-width indices (chronology) and the 6-month long SPEI calculated for the last week of June are positively correlated ($r = 0.44$, $p = 0.0008$, period 1963–2017; Fig. 3c). This shows that cumulative drought stress from January to June drives radial growth of olive trees which is supported by phenological analyses of cambium activity showing a peak in early spring (Liphschitz and Lev-Yadun, 1986). However, these results must be taken with caution given the weak common signal based on dendrochronological statistics.

In summary, age estimates based on ring counting and ^{14}C dating are within the range of 300–500 years; and cross-dating of olive samples is feasible, but the resulting tree-ring data reveal a high variability between trees despite coherent growth responses to drought. We therefore conclude that almost all monumental olive trees that have been dated so far have maximum estimated ages of between 300 and 500 years. The fact that the age of some of these trees has often been overestimated, however, does not preclude their protection as agricultural, cultural, patrimonial, and spiritual goods.

Even if most monumental olive trees are not millennia old, they provide historical, ecological, aesthetic, ornamental, eco-touristic, spiritual and scientific values to society. These impressive, large trees play fundamental roles as historical components of Mediterranean agricultural landscapes and deserve further recognition and special protection through legal actions. The existing acts on the protection of monumental olive trees, already approved in some Spanish and Italian regions, give similar importance to the large size and unique shape of these trees and their ages. Our results suggest modifying these laws by considering monumental olive trees those with ages higher than 150 years.

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.

Acknowledgments

We thank all people interested in old and monumental olive trees, and particularly those who helped and contributed to sampling old olive trees in northeastern Spain: Gracia-Balaga and Baigorri families, and forest guards of the Aragón Regional Govt. (José Luis Roda and Fernando Zorrilla). This study was funded by project RTI2018-096884-B-C31 (Spanish Ministry of Science). UB received funding from the SustES project - Adaptation strategies for sustainable ecosystem services and food security under adverse environmental conditions (CZ.02.1.01/0.0/0.0/16_019/0000797).

References

Arnan, X., Lopez, B.C., Martínez-Vilalta, J., Estorach, M., Poyatos, R., 2012. The age of monumental olive trees (*Olea europaea*) in northeastern Spain. Dendrochronologia 30, 11–14.

Bernabei, M., 2015. The age of the olive trees in the Garden of Gethsemane. J. Archaeol. Sci. 53, 43–48.

Cherubini, P., Gartner, B.L., Tognetti, R., Bräker, O.U., Schoch, W., Innes, J.L., 2003. Identification, measurement and interpretation of tree-rings in woody species from Mediterranean climates. Biol. Rev. 78, 119–148.

Cherubini, P., Humbel, T., Beeckman, H., Gärtner, H., Mannes, D., Pearson, C.L., Schoch, W., Tognetti, R., Lev-Yadun, S., 2013. Olive tree-ring problematic dating: a comparative analysis on Santorini (Greece). PLoS One 8, e54730.

Cherubini, P., Humbel, T., Beeckman, H., Gärtner, H., Mannes, D., Pearson, C., Schoch, W., Tognetti, R., Lev-Yadun, S., 2014. The olive-branch dating of the Santorini eruption. Antiquity 88, 267–291.

Contreras, R., Aguayo, F., Guerra, A., Tapia, F., Porcile, V., 2018. Genetic characterization of centennial olive trees from northern Chile: the case of extra virgin olive oil from Huasco in the process of designation of origin. Chilean J. Agric. Anim. Sci. 34, 126–139.

Cook, E.R., Krusic, P., 2005. A Tree-ring Standardization Program Based on Detrending and Autoregressive Time Series Modeling, with Interactive Graphics. Tree-Ring Laboratory, Lamont Doherty Earth Observatory, Columbia University, New York.

Delgado, B., Ojeda, J.F., Amate, J.I., Andreu, C., 2013. The olive groves of Andalucía and their distinctive landscapes of mediterranean. Revista de Estudios Regionales 96, 267–291.

Diez, C.M., Trujillo, I., Barrio, E., Belaj, A., Barranco, D., Rallo, L., 2011. Centennial olive trees as a reservoir of genetic diversity. Ann. Bot. 108, 797–807.

Ehrlich, Y., Regev, L., Kerem, Z., Boaretto, E., 2017. Radiocarbon dating of an olive tree cross-section: new insights on growth patterns and implications for age estimation of olive trees. Front. Plant Sci. 8, 1918.

Ehrlich, Y., Regev, L., Boaretto, E., 2018. Radiocarbon analysis of modern olive wood raises doubts concerning a crucial piece of evidence in dating the Santorini eruption. Sci. Rep. 8, 11841.

Girmay Siyum, Z., Ayoade, J.O., Onilude, M.A., Tolera Feyissa, M., 2019. Climate forcing of tree growth in dry Afromontane forest fragments of Northern Ethiopia: evidence from multi-species responses. For. Ecosyst. 6, 15.

Liphschitz, N., Lev-Yadun, S., 1986. Cambial activity of evergreen and seasonal dimorphics around the Mediterranean. IAWA Bull 7, 145–153.

Ninot, A., Howad, W., Aranzana, M.J., Senar, R., Romero, A., Mariotti, R., Baldoni, L., Belaj, A., 2018. Survey of over 4, 500 monumental olive trees preserved on-farm in the northeast Iberian Peninsula, their genotyping and characterization. Sci. Hortic. 231, 253–264.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk Ramsey, C., et al., 2013. IntCal13 and MARINE13 radiocarbon age calibration curves 0-50000 years calBP. Radiocarbon 55, 1869–1887.

Rossi, L., Sebastiani, L., Tognetti, R., d'Andria, R., Morelli, G., Cherubini, P., 2013. Tree-ring wood anatomy and stable isotopes show structural and functional adjustments in olive trees under different water availability. Plant Soil 373, 567–579.

Stuiver, M., Reimer, P.J., 1993. Extended 14C data base and revised CALIB 3.0 14C age calibration program. Radiocarbon 35, 215–230.

Stuiver, M., Reimer, P.J., Reimer, R.W., 2020. Calib 7.1 [WWW program] at: http://calib.org, Accessed 2 March 2020.

Thomas, H., 2003. Do green plants age, and if so, how? In: Nyström, T., Osiewacz, H.D. (Eds.), Model Systems in Aging. Springer-Verlag, Berlin, pp. 145–171.

Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I., 2010. A multi-scalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index –SPEI. J. Clim. 23, 1696–1718.

Vicente-Serrano, S.M., Tomás-Burguera, M., Beguería, S., Reig-Gracia, F., Latorre, B., Peña-Gallardo, M., Luna, Y., Morata, A., González-Hidalgo, J.C., 2017. A high resolution dataset of drought indices for Spain. Data 2, 22.