Identification of the semideciduous and deciduous Oak species of the Salento Peninsula and their relevance to archaeological contexts: A metric approach

A.M. Grasso [a], E. Vacca [b], G. Fiorentino [a]

https://doi.org/10.1016/j.jasrep.2019.101924

Abstract

Oak charcoals recovered from archaeological sites can yield information of fundamental importance to our understanding of human economic and cultural development over time and the ecological setting in which this took place. To this end, the present paper describes the anatomical patterns of modern semideciduous and deciduous oaks and those of charcoals of semideciduous and deciduous oaks found in archaeological contexts in the Salento Peninsula. The preliminary results indicate that the oak species of the past could be different from those of today, and that different species seem to have been used for different purposes. For example, a post in the fortification walls probably is of a different species from the wood used to build the monumental gate in the same fortifications (Roca, Middle Bronze Age).

1. Introduction

Members of the Beech family (Fagacea), Oaks (*Quercus* spp.) include trees and shrubs found throughout the northern hemisphere (Kubitzki, 1993). Their infrageneric classification is complex because of the genus' immense size, wide distribution and frequent interspecific hybridisation, but an attempt to organise them is in process (Denk et al., 2017). During the Quaternary, oaks in the Northern Hemisphere underwent extensive migrations in response to climate change (Grivet et al., 2006; Kremer et al., 2010). Concerning Europe, the present-day oak vegetation is believed to have arisen from whatever survived in the refugia of the Southern Iberian Peninsula, Central and Southern Italy and the Southern Balkan Peninsula (Bennett et al., 1991) during the last ice-age (Brewer et al., 2002; Petit et al., 2002; Tzedakis et al., 2002; Atkinson et al., 2007). Their post-glacial migration routes have been delineated by molecular genetic investigations based on the maternally inherited cpDNA genome (Dumolin et al., 1995), and three of the six European cpDNA lineages (A, C and E) described by Petit et al. (2002) have been found in Italy (Fineschi et al., 2002; Fineschi and Vendramin, 2004). Perhaps partly as a result of all this, Italy probably hosts more *Quercus* species than any other European country: according to Pignatti (1982), up to 15 species are present, most of which are found in Puglia. Indeed, Puglia was a refugium for a broad range of European mesothermophilic vegetation during the last ice age (Fiorentino and Parra, 2015) and it hosts a large pool of biodiversity (Macchia et al., 2000; Marchiori et al., 2000) that has been preserved thanks partly to its limited size and natural borders.

Being widespread, generally large and possessing important chemical and physical properties, oaks have had numerous applications. The acorns have been used for making medicinal drinks (Pardo de Santayana et al., 2010) and for tanning hides (Flemestad, 2014), as well as in human and animal diets (Primavera and Fiorentino, 2013), while their wood has been used for carpentry (Giordano, 1981) and as firewood (Giordano, 1981). Their remains are thus frequently found in the archaeological contexts of Puglia. The most widely distributed part of the oak discovered here is the wood (most frequently charred), but it is generally possible to discern only whether it belongs to evergreen, semi deciduous or deciduous species (Cambini, 1967a; Cambini, 1967b; Feuillat et al., 1997; Schweingruber, 1990; Sousa et al., 2009). This deprives us of important information about the palaeoenvironment, since many oak species constitute distinct ecotypes. In addition, we have no data indicating whether the oak remains are from the Mediterranean region or are allochthonous/imported. Thus, our current inability to identify samples at the species level represents a serious limitation for palaeoecological and historical studies based on subfossil oaks, charcoals, or macro-samples found in archaeological contexts.

In order to answer some of these questions, the present study examines the anatomical patterns of modern semideciduous and deciduous oaks and those of the semideciduous and deciduous oak charcoals found in archaeological contexts in the Adriatic side of the Salento Peninsula (South eastern Salento subregion, see Caliandro et al., 2005), because Puglia is characterised by a variety of climate zones. Since the evergreen *Quercus* type is typical of Mediterranean plant associations, we focused our attention on the semideciduous and deciduous *Quercus* types, some of which are at the limit of their ecological range. In this way we aim to propose an approach that can potentially be applied to other homogeneous regions.

1.1. Semideciduous and deciduous Oak species of the Salento Peninsula

Puglia is the easternmost region of Southern Italy, and the Salento Peninsula is its southernmost sub-region: a flat area with low relief that extends for over 150 km between the Ionian and Adriatic seas, The Adriatic side of Salento is characterised by a Mediterranean climate and flora (Macchia, 1984; Marchiori and Tornadore, 1988; Lorenzoni and Ghirelli, 1988). The deciduous oaks growing today in the Salento peninsula include *Q. dalechampii* Ten., *Q. virgiliana* Ten., *Q. amplifolia* Guss., *Q. frainetto* Ten., while *Q. ithaburensis* subsp. *macrolepis* (Kotschy) Hedge & Yaltirik is a semideciduous one (Pignatti, 2018). However, not all the botanists are agree about these taxonomic differences and say that the first three of these are probably eco-morphotypes of *Q. pubescens* Willd. (Pubescent oak) (Viscosi et al., 2011; Wellstein and Spada, 2015; Di Pietro et al., 2016; Pasta et al., 2016), and they are therefore sometimes allocated to a single group: *Quercus pubescens* sensu *lato*.

Pubescent oak is a heliophilous and thermophilous species that is perfectly adapted to both moderate summer drought stress and low winter temperatures. It is found all over central and southern Europe. *Q. frainetto* Ten. (Hungarian oak) is a basically thermophilous species that requires appropriate atmospheric humidity. Indeed, it can be found in the Salento where rainfall exceeds 750 mm/yr (Medagli et al., 1990). It is widespread in south eastern Europe (parts of Italy, the Balkans, parts of Hungary, Romania and Turkey) and it is considered native to this area (Mauri et al., 2016). Finally, *Q. ithaburensis* subsp. *macrolepis* (Valonia oak) grows well where the local climate is semi-arid with warmer winters (Pantera et al., 2008). It is found mostly in Albania, Greece and western Anatolia, its westernmost occurrence being the Salento (Accogli et al., 2005; Accogli et al., 2008; Medagli, 2017). Some researchers suppose that it was introduced for the cupule of its acorn, which was used as a raw material for tanning hides (Scaramuzzi, 1960b). Others assert that it is spontaneous in Puglia (Bellarosa et al., 2003), deriving support for this hypothesis from the recovery of old fossil remnants in Tuscany (Tongiorgi, 1939), but those who have studied the ecological patterns of this species argue that there is no certainty about its origins (Scaramuzzi, 1960a).

2. Materials

2.1. Modern control collection

The modern control collection is composed of five specimens of each of the following species: *Q. dalechampii* Ten., *Q. virgiliana* Ten., *Q. amplifolia* Guss., *Q. frainetto* Ten. and *Q. ithaburensis* subsp. *macrolepis* (Kotschy) Hedge & Yaltirik. The sample trees were found growing in some different station of the Adriatic side of the Salento Peninsula, because there isn't now a place in which they all grow at the same time (Fig. 1, Table 1).

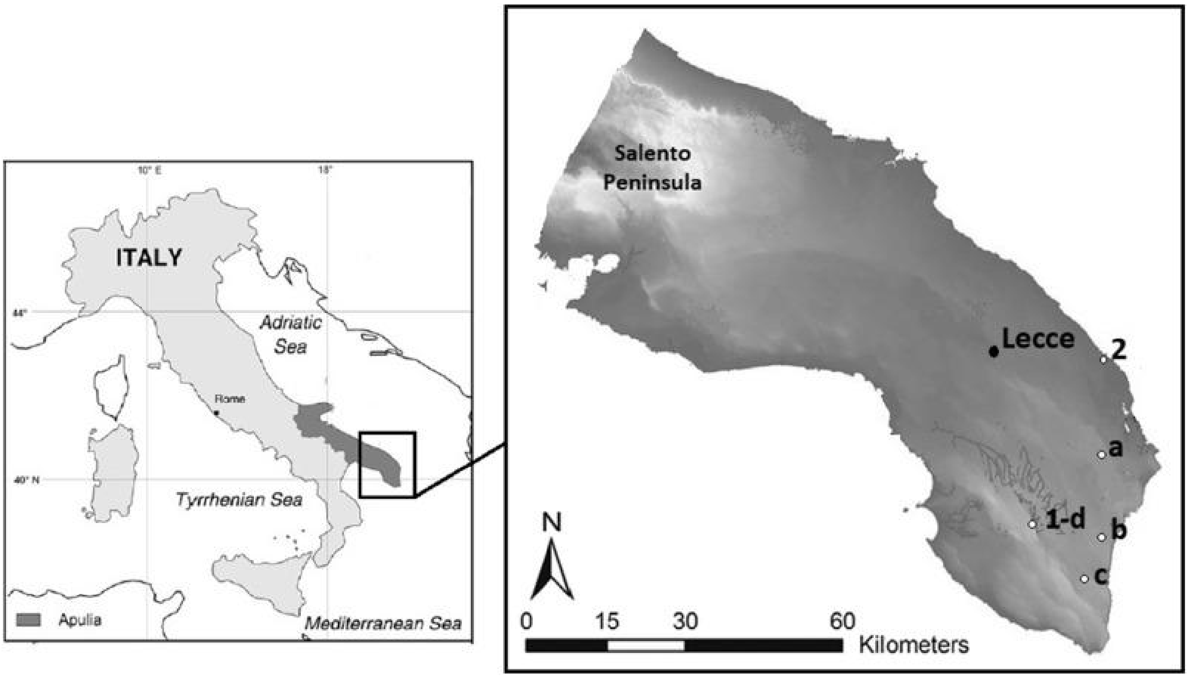


Fig. 1

Table 1. Samples included in the present study.

Samples	Species	Location	Age	Archaeological context
1–5	*Q. amplifolia*	a) Palmariggi	Modern	–
6–10	*Q. virgiliana*	b) Andrano	Modern	–

11–15	*Q. dalechampii*	b) Andrano, c) Tricase	Modern	–
16–20	*Q. frainetto*	d) Supersano	Modern	–
21–25	*Q. ithaburensis*	c) Tricase	Modern	–
RO2	?	2) Roca Vecchia	Second half of the 15th century- First half of the 14th century BCE	Fortification walls (US 451)
RO3	?	2) Roca Vecchia	Second half of the 15th century- First half of the 14th century BCE	Fortification walls (US 451)

RO4	?	2) Roca Vecchia	Second half of the 15th century- First half of the 14th century BCE	Fortification walls (US 451)
RO5	?	2) Roca Vecchia	Second half of the 15th century- First half of the 14th century BCE	Fortification walls (US 451)
RO7	?	2) Roca Vecchia	Second half of the 13th century- Last half of the 12th century BCE	Ritual hearth (US 11349)
RO8	?	2) Roca Vecchia	Second half of the 13th century- Last half of the 12th century BCE	Ritual hearth (US 11379)

RO9	?	2) Roca Vecchia	Second half of the 15th century- First half of the 14th century BCE	Post from the fortification walls (USM 453)
RO10	?	2) Roca Vecchia	Second half of the 15th century- First half of the 14th century BCE	Monumental gate (US 70)
SUP14	?	1) Supersano	7th century– First half of the 9th century CE	Sunken featured buildings (US 312)
SUP15	?	1) Supersano	7th century – First half of the 9th century CE	Abandoned layer (US 338)

SUP16	?	1) Supersano	7th century – First half of the 9th century CE	Sunken featured buildings (US 125)

In the samples' area, the mean annual temperature is 16 °C and the mean annual rainfall is 746 mm; the mean summer precipitation (from June to August) is 24 mm (Caliandro et al., 2005). The substrate is made up of calcarenites (Calcareniti di Gravina) and, in terms of pedology, the area is dominated by well-drained humus-enriched soils (luvisol type), whereas both weak-developed mineral soils (regosol) and weak-differentiated soils (cambisol) are subordinated (Costantini et al., 2013).

Sampled trees were on average 70 years-old (estimated age) at the time of sampling in sites, mean diameter at 1.30 m above the ground was 37 cm, and mean tree height was 15 m. For each plant, one sample was taken: according to the results of Gasson, 1987, that identify a negligible decrease in vessels size between the trunks and the branches (around 7%), we have selected only secondary branches; their ranging is from 5 to 12 cm in diameter.

2.2. Archaeological samples

The oak wood archaeological samples come from two sites in the Salento peninsula, Roca Vecchia and Supersano, listed in Table 1 and shown in Fig. 1.The settlement of Roca Vecchia dates back to the late Proto-Apennine phase and it was occupied until the late Middle Ages. During the Middle Bronze Age the fortifications of Roca were destroyed by a great fire, causing each area adjacent to the fortifications to collapse, burying the original contents of these spaces. Six samples are from this area, with two other samples from ritual hearths dated to the Late Bronze Age (Scarano, 2012). Lastly, three samples come from the Byzantine village of Scorpo, Supersano (LE), which was occupied mainly in the 8th century. The oak wood discovered may have been used to build dwellings (Arthur et al., 2008). The contexts were dated with reference to artefact typology and radiocarbon analysis.

The size of the archaeological charcoal fragments is often small, <2 cm, because taphonomic processes and recovery strategies have modified their original structure (i.e. timber, pole etc.). They had at least five rings clearly identifiable and a high degree of radial shrinkage (see Paradis-Grenouillet and Dufraisse, 2018).

3. Methods

3.1. Experimental charcoal production

Wood blocks 1.5 cm thick and 5 to 12 cm in diameter were carbonised inside a muffle furnace without oxygen. Specifically, oak samples were placed in the preheated oven and heated to 400 °C for 1 h, this temperature leaving most of the morphological characteristics of the wood's anatomy still relatively unchanged (Kim and Hanna, 2006; Braadbaart and Poole, 2008). The cross-sectional surface was exposed by manual fracture or with a scalpel and was digitised using a Nikon DIGITAL SIGHT DS-FI1 camera mounted on a Nikon SMZ1000 microscope and saved via NIS-Elements AR in .jpeg format.

3.2. Morphometric analyses

The quantitative characteristics of the wood's anatomy were determined by examining the lumen in cross-section at x8 magnification using *ImageJ* software (Schneider et al., 2012). The lumen area, perimeter, tangential diameter and radial diameter of 30 earlywood vessels and 30 latewood vessels were measured for each sample (in accordance with Wheeler et al., 1989). The shift from earlywood to latewood in semideciduous oak species is characterised by a gradual change to narrower vessels. Therefore, in order to avoid confusion, only latewood vessels located near the border of growth rings were measured (in accordance with Carlquist, 1988) (Fig. 2).

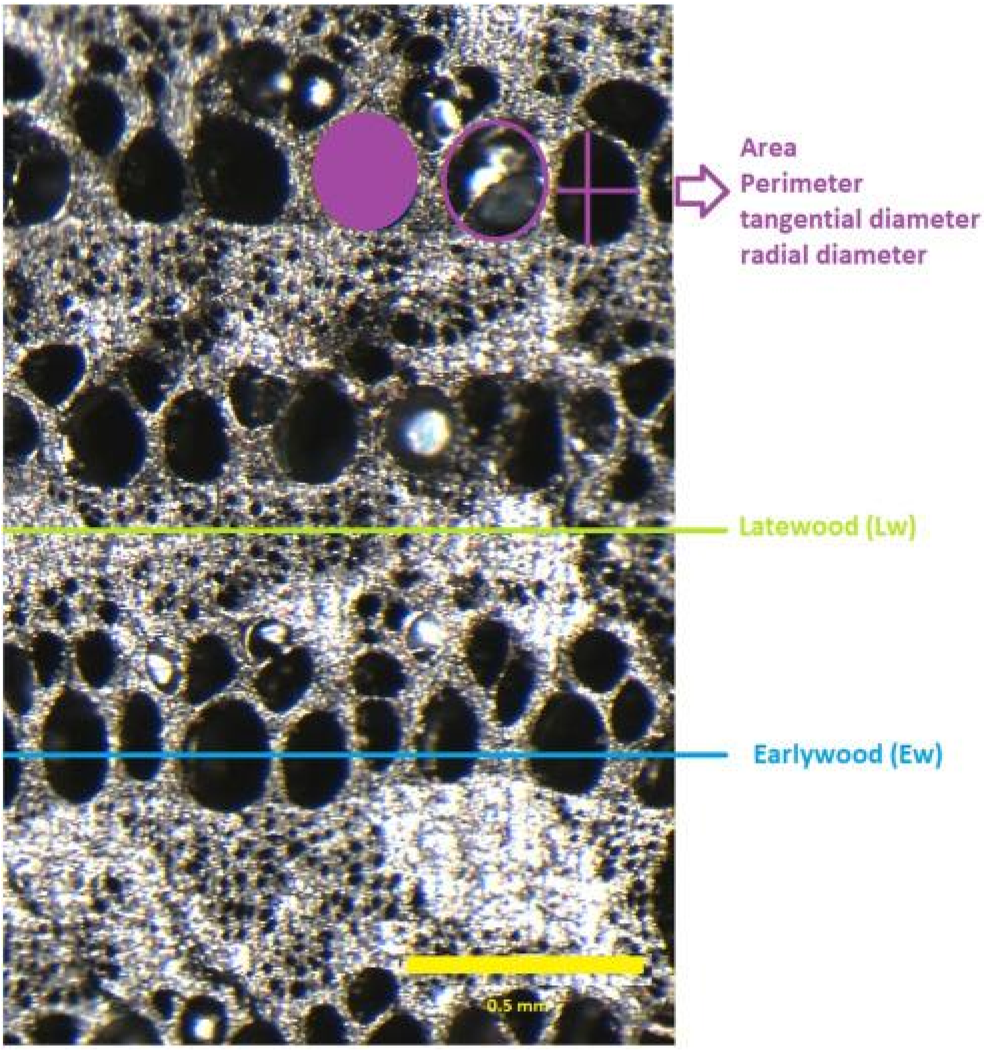


Fig. 2

3.3. Statistical analyses

In order to metrically characterise the five considered *Quercus* species, descriptive statistics were obtained for both the earlywood (ew) and latewood (lw) vessel variables.

The Shapiro-Wilk test was used to ascertain whether the data were normally distributed. Since normal distribution was not found for any of the variables, the observations were converted to logarithmic form to reduce asymmetry and stabilise variance.

Although the differences in size between earlywood and latewood vessels are obvious in all species, a comparison between the mean ew and lw measurements was carried out using a two-sample *t*-test.

One-way analysis of variance (ANOVA) was then applied to determine whether there were any statistically significant differences between the means of the five species. Where such differences were found, post-hoc testing was performed to determine between which of the samples the differences occurred. Due to the lack of homogeneity of variance, as assessed by the Levene test, the Welch test and post-hoc Tamhane test were used. Although the one-way ANOVA is considered a robust test against the normality assumption (Sokal and Rohlf, 1995), a non-parametric Kruskal-Wallis test was also added.

To combine and analyse together the information derived from the size of the vessels in the two vegetative phases, the mean values of the raw variables for each of the individual samples (5 samples per species, 30 ew and 30 lw vessels per sample) were obtained. These values underwent Principal Component Analysis, to highlight and characterise any relationships among the data. Due to differences in the raw data metrics, the analysis was performed on the correlation matrix.

In this step of the analysis, the archaeological samples were also examined, in order to evaluate their morphological affinities with the sampled modern specimens.

Descriptive statistics and comparative analyses were carried out with common spreadsheet software. The analysis of variance and principal component analysis were performed with the Past (Hammer et al., 2001) and Systat (Wilkinson, 1989; Systat, 2007) packages.

4. Results

4.1. Descriptive and comparative statistics

Table 2 shows the descriptive statistics for earlywood and latewood vessels belonging to the five species analysed, while the data for vessels in the archaeological samples are shown in Table 3. The physiological differences between the vessels in the two vegetative phases were found to be “highly significant” by both the parametric test (*t*-test, $p < 0.001$) and the non-parametric test (*U* Mann-Whitney, $p < 0.001$).

Table 2. Descriptive statistics. Dimensions of the earlywood and latewood vessels in the five species (150 ew and 150 lw vessels for each species); N.B. ew = earlywood, lw = latewood. Area in µm2, perimeter and diameters in µm.

Species	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
	Area – ew				Area – lw			
Q. amplifolia	27,398.7	15,340.5	4465.0	71,112.8	268.5	143.8	73.1	972.3
Q. virgiliana	26,535.1	15,771.7	3819.0	67,506.6	297.7	172.4	34.0	1041.0
Q. dalechampii	21,915.4	8928.4	6089.4	48,589.9	362.0	227.7	63.8	1450.0
Q. frainetto	13,204.1	6175.8	2423.7	32,798.1	344.2	160.8	85.6	1171.2

Q. ithaburensis	15,970.9	7997.6	3456.0	38,152.1	1216.6	728.4	130.6	4632.0
	Perimeter - ew				Perimeter - lw			
Q. amplifolia	590.4	164.0	240.9	990.7	57.1	15.5	30.4	112.1
Q. virgiliana	569.9	177.0	223.7	961.5	59.6	17.3	22.2	115.6
Q. dalechampii	539.4	112.6	299.1	781.6	65.6	19.8	28.0	136.4
Q. frainetto	417.1	91.7	182.2	646.7	64.7	14.5	32.6	123.6
Q. ithaburensis	448.8	113.7	218.1	698.1	122.2	35.8	40.6	247.1

	Major diameter - ew			Major diameter - lw				
Q. amplifolia	226.3	62.8	85.1	402.0	20.6	6.3	10.1	40.9
Q. virgiliana	212.7	67.7	82.3	374.6	21.4	6.2	7.7	41.5
Q. dalechampii	207.7	43.9	113.6	299.1	23.4	7.6	10.3	49.1
Q. frainetto	159.7	35.0	70.7	223.9	22.5	5.6	11.4	45.6
Q. ithaburensis	167.0	43.1	83.2	262.6	45.4	13.7	15.3	92.4

	Minor diameter - ew				Minor diameter - lw			
Q. amplifolia	144.0	46.7	53.7	252.5	15.7	4.0	8.6	30.2
Q. virgiliana	146.1	49.5	59.1	250.6	16.4	5.2	5.5	32.9
Q. dalechampii	130.1	36.8	63.1	248.7	18.2	5.4	7.9	37.6
Q. frainetto	101.5	31.3	43.7	186.5	18.7	4.0	9.4	32.7
Q. ithaburensis	115.4	33.9	47.2	201.6	31.7	10.1	10.9	70.3

Table 3. Archaeological samples, dimensions of earlywood and latewood vessels (30 ew and 30 lw vessels for each sample); N.B. ew = earlywood, lw = latewood. Area in µm2, perimeter and diameters in µm.

Archaeological sample	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**

	Area – ew				Area – lw			
RO2	32,482.6	13,009.5	14,040.11	52,932.33	384.8	110.4493	243.2146	580.3984
RO3	31,143.8	18,253.62	67,486.29	7280.814	493.7	275.2791	1168.848	156.7171
RO4	24,470.6	8414.217	46,147.64	16,996.66	444.5	150.0974	774.7767	203.3789
RO5	24,551.0	15,605.88	49,068.32	9090.457	250.6	118.8123	671.7086	128.7442
RO7	9930.3	3574.9	19,218.75	3955.078	1608.4	804.7636	3437.5	449.2188
RO8	7501.2	3482.929	14,990.7	2268.592	1376.4	715.9619	2384.566	341.4519
RO9	44,922.2	15,642.36	57,762.1	19,137.66	361.3	310.5983	1262.173	68.35752

RO10	98,963.2	30,420.33	14,416.6	56,751.87	803.4	203.8399	1217.943	448.7158
SUP14	33,089.9	8917.958	46,426.23	16,545.21	261.3	203.3966	837.2992	87.74539
SUP15	90,763.4	29,845.63	124,549.4	55,037.18	727.4	357.2717	1579.417	232.0048
SUP16	24,927.7	9130.637	42,654.67	9503.272	327.2	180.9646	826.8888	86.25818

	Perimeter - ew				Perimeter - lw			
RO2	639.0	132.3782	425.5919	821.486	69.1	10.14464	54.59702	85.82918
RO3	610.2	183.6368	925.977	305.3417	76.4	22.0613	123.4705	44.35717

RO4	557.4	89.39039	774.7185	466.2818	74.4	13.16539	98.93491	52.21956
RO5	533.7	173.2891	786.2772	343.266	55.2	11.89357	92.32139	40.34891
RO7	353.5	63.41274	493.1199	231.4142	139.1	37.09218	211.9987	76.7738
RO8	309.9	68.45763	440.5599	179.9409	128.8	39.0338	174.6404	66.29012
RO9	759.7	147.6895	878.2318	503.9918	61.8	27.33315	126.6287	28.44081
RO10	1118.0	172.4971	1360.249	860.8027	100.0	13.02892	125.4817	75.17512
SUP14	663.1	96.76652	808.395	470.5431	54.6	20.15834	102.5885	34.35358
SUP15	1074.9	167.2548	1253.719	879.0375	93.5	22.88025	141.6289	54.12889

SUP16	563.9	110.1558	749.227	352.9575	62.6	18.00842	103.9408	33.57585
	Major diameter - ew				Major diameter - lw			
RO2	232.6	47.07952	153.0893	286.5251	25.1	3.412775	20.46139	30.88252
RO3	220.3	65.02933	319.8383	108.7474	26.8	7.927214	44.29758	15.61504
RO4	200.5	33.69644	281.8832	161.2934	27.0	4.941161	36.44221	18.73351
RO5	180.9	53.84516	257.1199	123.9056	20.1	4.24354	33.6592	15.36327
RO7	127.4	21.50631	168.9307	89.78764	49.5	13.86434	77.25738	28.03026

RO8	116.2	22.06996	157.0532	72.70845	47.4	14.3459	64.90607	24.14488
RO9	283.3	57.78483	334.1197	189.0707	20.9	9.158704	42.591	10.09591
RO10	398.3	58.1565	480.1089	316.5273	34.9	5.168465	47.52622	27.84689
SUP14	250.9	41.75365	337.7507	177.7991	19.7	7.099441	35.25539	12.34417
SUP15	385.7	45.92253	434.0035	319.1954	31.7	8.025539	50.03328	17.20757
SUP16	205.8	45.93131	284.5213	130.1203	22.4	6.548297	38.32383	12.1794

Minor diameter - ew

Minor diameter - lw

RO2	171.7	39.35525	116.7712	235.2169	19.2	2.89328	15.10439	23.92895
RO3	166.1	53.0551	268.6552	85.24542	21.8	6.004665	33.59605	12.7786
RO4	152.1	24.40416	208.4445	123.1401	20.4	3.580341	27.06961	13.82283
RO5	158.0	57.79583	242.9829	93.41244	15.2	3.263309	25.40898	10.54782
RO7	96.4	20.65164	144.8528	56.08525	38.9	9.880587	56.65169	20.4052
RO8	78.7	24.86175	121.5305	39.72663	34.1	10.5494	49.05814	16.93854
RO9	196.0	38.16292	230.3007	128.8768	18.5	8.190628	37.73212	8.300212
RO10	310.2	56.1683	400.5344	228.2859	29.0	4.669217	37.61255	19.68292

SUP14	166.1	29.44311	208.9089	118.4821	15.0	5.849256	30.23885	8.320983
SUP15	294.4	69.78473	379.4577	200.9735	27.7	6.870638	43.65738	17.16672
SUP16	150.3	30.27837	195.4484	92.9904	17.2	5.006049	27.47188	9.017468

The proportions differ considerably in the various species. For example, the ratio of the major diameter of the lw vessels to the major diameter of the ew vessels is 9.1% in *Q. amplifolia*, 10.1% in *Q. virgiliana*, 11.3% in *Q. dalechampii*, 14.1% in *Q. frainetto* and rises to 27.2% in *Q. ithaburensis*.

The same trend can be seen in the ratio of the mean area of lw vessels to the mean area of the ew vessels, as shown in Fig. 3.

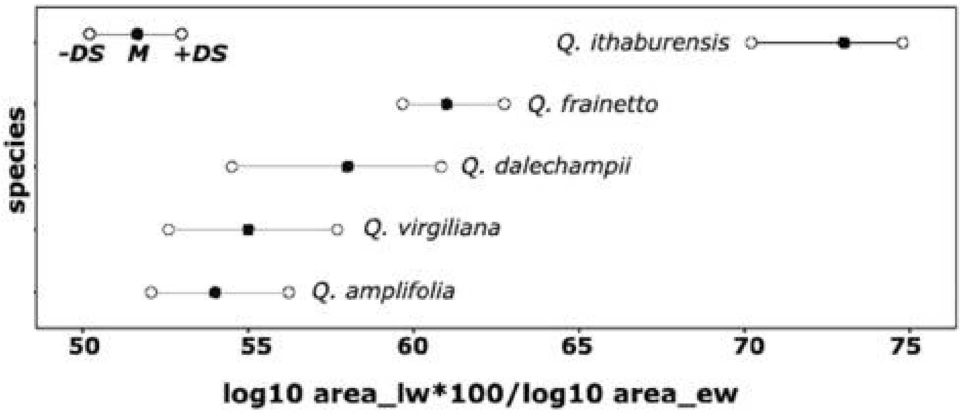


Fig. 3

It also seems possible to define some constant characteristics in the dimensions of the earlywood and latewood vessels in the various species, as evident in Fig. 4.In ew, *Q.*

amplifolia and *Q. virgiliana* always have higher mean values, while the *Q. dalechampii* values are not far behind, and *Q. frainetto* constantly presents smaller values, comparable with those of *Q. ithaburensis*. In lw, *Q. amplifolia* and *Q. virgiliana* have lower, comparable mean values, *Q. frainetto* and *Q. dalechampii* have slightly higher, comparable values, while the *Q. ithaburensis* values are always considerably higher.

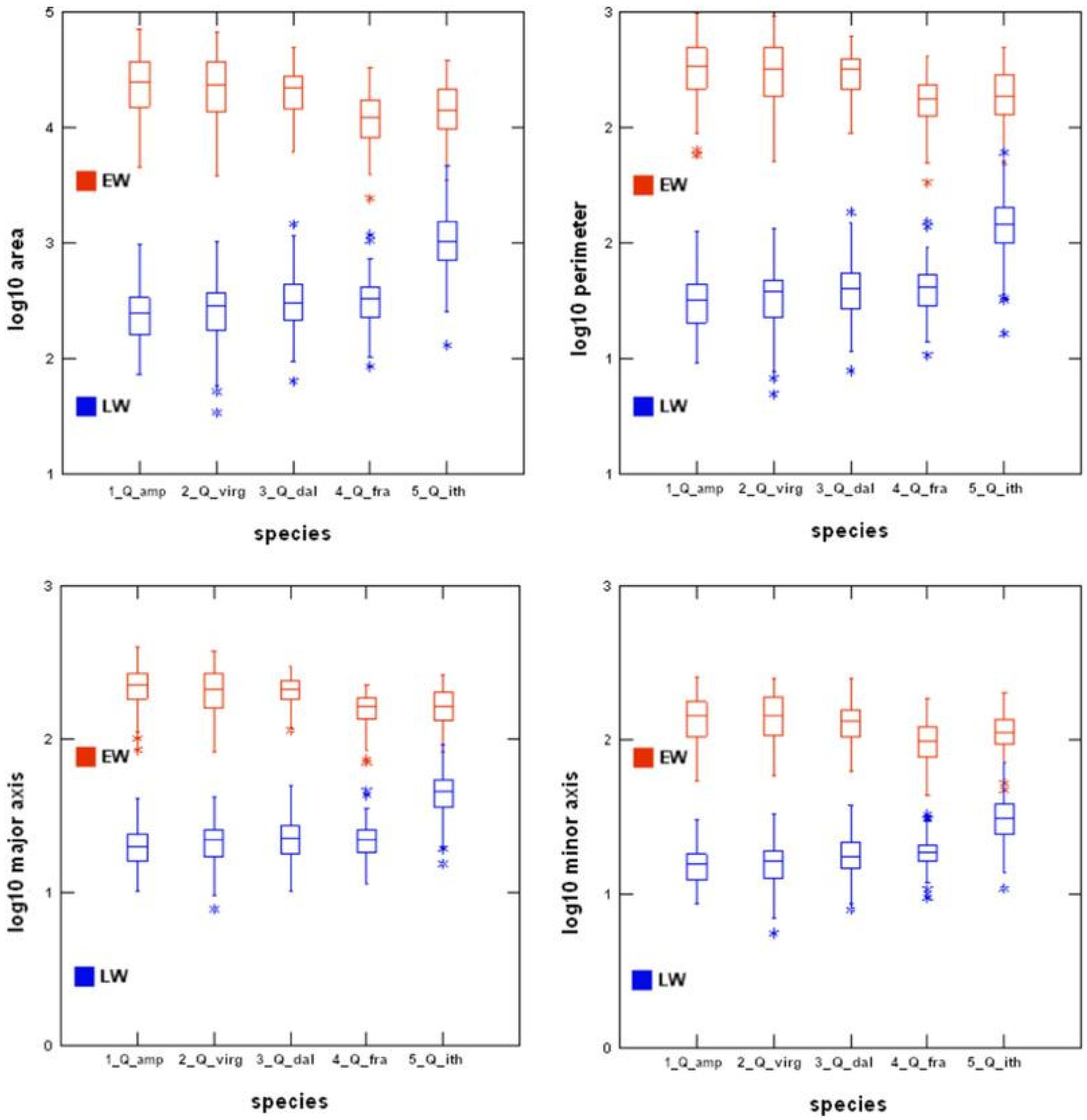


Fig. 4

4.2. ANOVA

The one-way ANOVA of *Quercus* average dimensions revealed highly statistically significant effects ($p < 0.001$) for all variables (Table 4). The Kruskal-Wallis test also provided strong evidence of a difference ($p < 0.001$) between the mean values of at least one pair of groups.

Table 4. Welch's adjusted F ratio-based Equality of Means test.

Measure	Welch's F	df1, df2	P
Area ew	45.70	4, 370.99	***
Perimeter ew	48.39	4, 370.81	***
Major diameter ew	49.93	4, 370.91	***
Minor diameter ew	31.27	4, 371.88	***
Area lw	153.56	4, 370.57	***

Perimeter lw	158.95	4, 370.69	***
Major diameter lw	169.42	4, 371.29	***
Minor diameter lw	118.49	4, 369.79	***

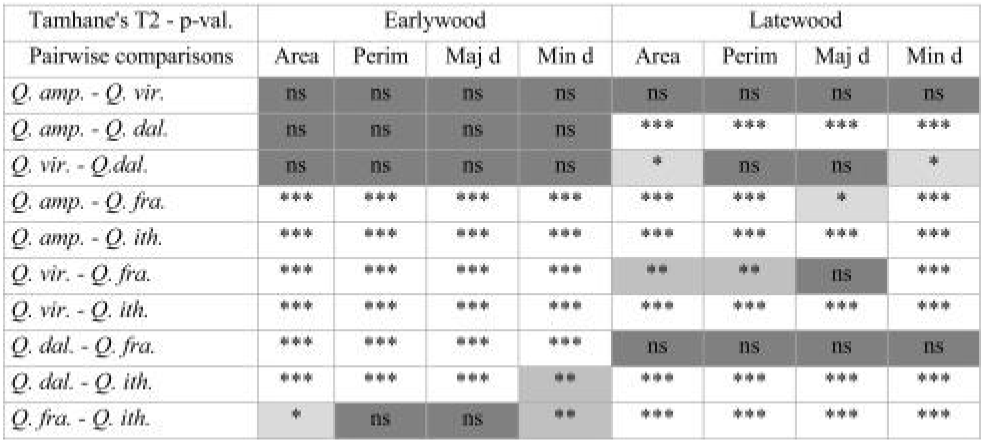
Significance value:

***

$p < 0.001$.

According to the post-hoc test (Table 5), none of the *Q. amplifolia* and *Q. virgiliana* variables differ significantly in either earlywood or latewood. Indeed, in most of the comparisons the associated *p* value is close to 1, so they can therefore be considered a homogeneous subset. *Q. dalechampii* does not differ from either *Q. amplifolia* or *Q. virgiliana* in terms of ew variables. However, it differs from *Q. amplifolia* and partially also from *Q. virgiliana* in terms of the lw variables. *Q. amplifolia* and *Q. virgiliana* are also always differentiated from *Q. frainetto* and *Q. ithaburensis* in terms of both earlywood and latewood variables. *Q. dalechampii* is differentiated from *Q. frainetto* in terms of ew variables but not lw variables, but is differentiated from *Q. ithaburensis* in terms of both ew and lw variables. *Q. frainetto* partly differs from *Q. ithaburensis* in terms of ew variables but not lw variables.

Table 5. Pairwise multiple comparisons, *p*-values obtained by Tamhane's T2 post-hoc test.



Tamhane's T2 - p-val.	Earlywood				Latewood			
Pairwise comparisons	Area	Perim	Maj d	Min d	Area	Perim	Maj d	Min d
Q. amp. - *Q. vir.*	ns	ns	ns	ns	ns	ns	ns	ns
Q. amp. - *Q. dal.*	ns	ns	ns	ns	***	***	***	***
Q. vir. - *Q.dal.*	ns	ns	ns	ns	*	ns	ns	*
Q. amp. - *Q. fra.*	***	***	***	***	***	***	*	***
Q. amp. - *Q. ith.*	***	***	***	***	***	***	***	***
Q. vir. - *Q. fra.*	***	***	***	***	**	**	ns	***
Q. vir. - *Q. ith.*	***	***	***	***	***	***	***	***
Q. dal. - *Q. fra.*	***	***	***	***	ns	ns	ns	ns
Q. dal. - *Q. ith.*	***	***	***	**	***	***	***	***
Q. fra. - *Q. ith.*	*	ns	ns	**	***	***	***	***

Significance values: ns = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Basically, *Q. amplifolia* and *Q. virgiliana* seem to be characterised by a substantially overlapping pattern, shared at least in part, by *Q. dalechampii*. In fact, while *Q. amplifolia* and *Q. virgiliana* differ from *Q. frainetto* in terms of both ew and lw variables, *Q. dalechampii* differs from *Q. frainetto* only in terms of lw variables.

These three species always differ from *Q. ithaburensis* in terms of both ew and lw variables.

4.3. Principal components analysis

The earlywood and latewood vessel size data were combined for the principal components analysis, considering the mean values of the raw variables of five samples per species. The archaeological samples were also added, in order to evaluate their morphological affinities with respect to modern samples.

Due to differences in metrics, the analysis was performed on the correlation matrix. By the Kaiser-Meyer-Olkin measure (0.658), the dataset is adequate, and the correlation matrix is suitable for structure detection (Bartlett's test, sig. < 0.001). The principal component method was used, followed by a varimax rotation.

Only the first two components displayed eigenvalues >1, therefore, only these two components were retained for rotation. Combined, components 1 and 2 accounted for about 98% of the total variance (Table 6).

Table 6. Principal component analysis results: eigenvalues and percentages of variance associated with each component, and loading matrix of component solution before and after varimax rotation.

	Variance distribution			Loadings			
pc	Eigenvalues	% of var.	Variable	Components		Rotated components	
				1	2	1	2
1	4.369	54.610	Area ew	−0.671	0.729	0.013	0.991
2	3.519	43.984	Perim. ew	−0.743	0.667	−0.083	0.995
3	0.056	0.702	Major d. ew	−0.758	0.630	−0.119	0.979
4	0.030	0.372	Minor d. ew	−0.696	0.699	−0.026	0.986
5	0.016	0.196	Area lw	0.773	0.624	0.991	−0.076

6	0.011	0.135	Perim. lw	0.764	0.645	0.998	−0.055
7	0.000	0.000	Major d. lw	0.780	0.618	0.991	−0.086
8	0.000	0.000	Minor d. lw	0.720	0.685	0.993	0.004

The first component has positive associations with lw variables and negative associations with ew variables. The second component has positive associations with all variables. Considering the rotated matrix, the first component is primarily related to the “latewood” features, whereas the second component is associated with “earlywood” features.

In the score-plot shown in Fig. 5, two main areas of variability are highlighted. The *Q. ithaburensis* specimens lie within a well-defined area. A second area originates from the large overlap of the *Q. amplifolia*, *Q. virgiliana* and *Q. dalechampii* species. The two areas diverge mainly with respect to the second component, i.e. the differences in terms of ew, but partly due to the differences in terms of lw. A third minor area originates from the *Q. frainetto* specimens, separate from *Q. amplifolia* and only partially overlapping with *Q. virgiliana* and *Q. dalechampii*, from which it is distinguished mainly by the differences in the “earlywood” component.

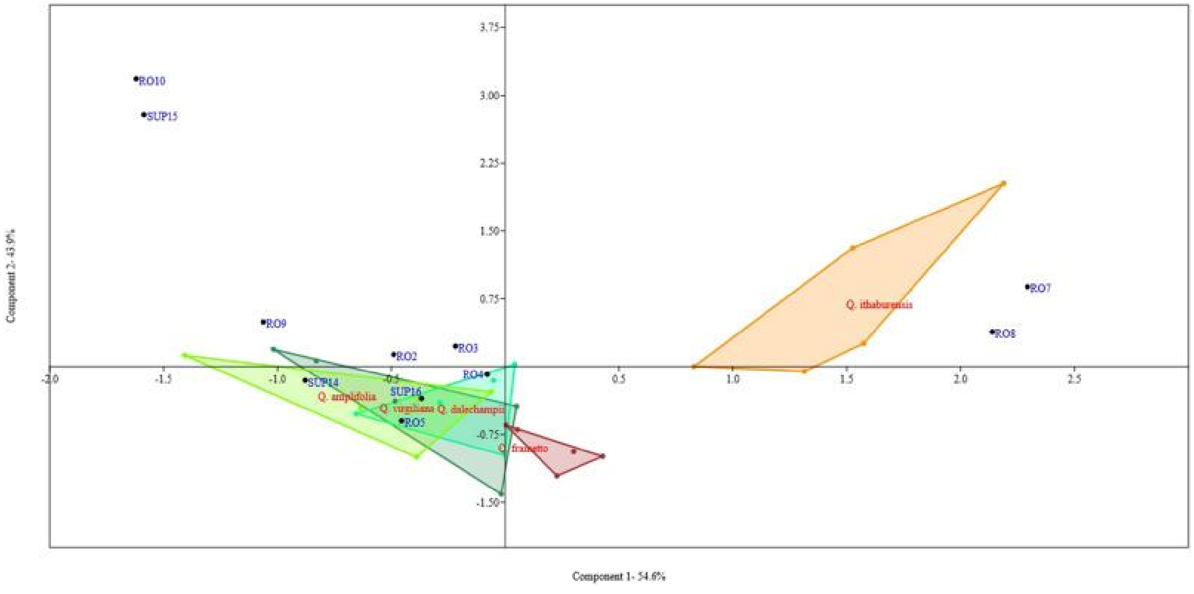


Fig. 5

The complex model suggested by the univariate analysis is therefore substantially confirmed by the multivariate approach. On the basis of this model it seems possible to establish some morphological affinities of the archaeological samples with respect to the modern sample (Table 7).

Table 7. Euclidean distances between the pca centroids of modern and archaeological samples; the minimum distances are in bold.

Euclidean distances	***Q. amplifolia***	***Q. virgiliana***	***Q. dalechampii***	***Q. frainetto***	***Q. ithaburensis***
Q. virgiliana	0.098				
Q. dalechampii	0.373	0.275			
Q. frainetto	0.943	0.849	0.596		
Q. ithaburensis	1.695	1.605	1.357	1.131	

RO7	2.373	2.280	2.021	1.688	0.693
RO8	2.337	2.241	1.972	1.571	0.743
RO2	0.316	0.364	0.569	1.164	1.717
RO3	0.365	0.349	0.436	1.007	1.488
RO4	0.391	0.307	0.180	0.715	1.306
RO5	0.186	0.130	0.267	0.780	1.624
RO9	0.911	0.996	1.243	1.837	2.344
RO10	2.984	3.059	3.273	3.860	4.029

SUP14	0.396	0.491	0.759	1.339	2.010
SUP16	0.165	0.069	0.211	0.797	1.536
SUP15	2.709	2.785	3.003	3.592	3.796

The scores of five Roca specimens (RO2, RO3, RO4, RO5, RO9) and two Supersano specimens (SUP14, SUP16) fall within, or very near, the area of the "*pubescens*" subset. In contrast, the two specimens RO8 and RO7 seem to be related to the *Q. ithaburensis* forms. Two archaeological specimens (RO10 and SUP15) fall within none of the above-mentioned areas of the modern sample. Indeed, they have the highest ew vessel dimensions, with lw values between those of *Q. ithaburensis* and *Q. dalechampii*.

5. Discussion

Studies of wood anatomy show that although widening of earlywood vessels is probably affected by ecological factors (Carlquist, 1988; Terral, 1997; Wheeler et al., 2007; Castagneri et al., 2017; Limier et al., 2018), the broader range of phenotypic plasticity, characterised by the ability of producing larger or smaller vessel, occurs mainly when the species does not grow in its ecological range (Fonti et al., 2013). Furthermore, it seems that the size of latewood vessels hasn't a reaction to fluctuating environmental conditions (García-González et al., 2016) and the oak vessel tangential diameter seems to be specie- specific (Cambini, 1967). So, our study confirms the results obtained by Robert et al. (2017) that has demonstrated the relationship between vessel diameter and taxonomic section (see Denk et al., 2017), given that *Q. ithaburensis*, *Q. pubescens*, *Q. frainetto* belong to three different sections, that are respectively: *Cerris*, *Quercus* and *Mesobalanus*.

Thus, *Q. ithaburensis* is clearly differentiated, *Q. frainetto* is less differentiated but still distinguishable, whereas *Q. amplifolia*, *Q. virgiliana* and *Q. dalechampii* overlap. This did not surprise us, since previous taxonomical studies of the latter three oak species have reported difficulties in species recognition and these species have been the subject of various contradictory interpretations in Europe (for a summary see Viscosi et al., 2011). Thus, our research into wood anatomy is also able to identify only the *Q. pubescens* sensu *latu* macro-group.

The anthracological and pollen data available for Puglia paint a rather homogeneous picture in which the Mediterranean maquis vegetation is characterised by the presence of deciduous oaks with alternating phases (Fiorentino, 1998; Di Rita and Magri, 2009; Primavera et al., 2017). The anthracological data generated by this study enable us to determine the oak species richness in Puglia in the past, and to determine whether the species represent natural vegetation or the result of human intervention. However, in order to achieve these goals, there is a need to expand both the modern collection and the archaeological database. Indeed, what emerges is an environmental framework slightly different from the current one, but whose details still elude us. In the meantime, we have discovered that probably pubescent oak was present in Puglia from the Middle Bronze Age (1500–1300 BCE) and has characterised deciduous oak vegetation since medieval times. The results also demonstrate that another, unidentified deciduous oak grew during the Middle Bronze Age and during the early Middle Ages but has disappeared here now. Finally, we cannot say with certainty whether the Valonia oak has been present in Puglia since the Middle Bronze Age, but certainly there was a semideciduous species (Fig. 5) at that time.

The results regarding the archaeological samples show that the pubescent oak was probably the most widespread deciduous species in Puglia in the past. Perhaps as a consequence of this and also because of its mechanical properties (it is more easily workable than evergreen oak wood), it was used for carpentry: the Middle Bronze Age fortifications of Roca and the Early Medieval sunken-featured buildings of Supersano were made of this species. As shown by other archaeobotanical studies (Breglia and Fiorentino, 2017), deciduous oak wood was often preferred as a building material, so these data allow us to speculate about the ancient inhabitants' knowledge of the mechanical properties of wooden materials and how and why they selected specific wood types from a wide spectrum of available forest resources. This aspect is also elucidated by our results. Indeed, we are now able to say that the deciduous oak used to build the monumental gate of the fortifications of Roca was different from the type used for fencing posts, perhaps more valuable or with more suitable physical and mechanical characteristics. The species used for the monumental gate was still present in the early Middle Ages in Supersano and it may have grown into the nearby “Bosco di Belvedere”, a local forest that supplied the timber for the Castle of Lecce even in the mid 15th century (Fiorentino, 2004).

Lastly, the samples from the ritual hearth in Roca, dated to the Late Bronze Age, do not allow us to take a position in the complex debate regarding the presence of Valonia oaks in the Salento Peninsula. Certainly, it is known that a semideciduous species was chosen for the hearth, but only further studies will be able to clarify what species it was and the possible reasons for its selection.

6. Conclusion and perspectives

In conclusion, the results set out here indicate that the *Quercus* species identified in archaeological deposits could be differentiated by their wood anatomy, specifically by comparing the characteristics of earlywood and latewood vessels. Certainly, there is a need to expand the modern collection, adding other species, since the study of the archaeological samples seems to indicate that the species present in antiquity may be different from modern ones. Moreover it cannot be excluded that some “outliers” archaeological samples results could be related to other variables, so it could be necessary to verify the influence of ecological conditions on wood anatomy, especially for *Q. frainetto* which is in the intermediate position; measuring vessel dimensions in stems and branches of the same oak individuals, to verify if the vessel characteristics are really quite similar (measurements on branches are extremely rare, see Robert et al., 2017); constitute the reference framework of oak charcoals in a wider range of temperatures in order to integrate the combustion temperatures of fireplaces (fuel) and fires (carpentry) from which could depend the variability of size of the vessels.

Finally, it is also necessary to construct a database of semideciduous and deciduous *Quercus* charcoals discovered in archaeological contexts, in order to enable comparison of samples with a certain geographical and temporal contiguity, and thereby to gain a fuller understanding of the history of certain *Quercus* species. This includes determining whether the oak remains discovered are from the Mediterranean region or are allochthonous/imported, and whether there were particular reasons that led the ancient communities to select one species rather than another.

Acknowledgements

This work was supported by the Consorzio Universitario Interprovinciale Salentino - Lecce - Italy 2014 program "*Archeologia dei Querceti. Ricerche archeo-paleobotaniche per una storia dei querceti nel territorio del Parco Naturale costa Otranto-S.M. di Leuca e Bosco di Tricase*". We are grateful to Francesco Minonne (Parco naturale Costa Otranto-S.Maria di Leuca e Bosco di Tricase), for providing modern oak samples, Piero Medagli (Università del Salento) for his help in recognising modern oak species, Paul Arthur (Università del Salento) and Teodoro Scarano (Università del Salento) for providing archaeological material and Milena Primavera (Università del Salento) for her constructive comments. Finally, we thank the anonymous reviewers for their constructive remarks and suggestions which have greatly improved this manuscript.

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