



Original Article

The Early Bronze Age dendrochronology of Sovjan (Albania): A first tree-ring sequence of the 24th – 22nd c. BC for the southwestern Balkans

Andrej Maczkowski^{a,b,*}, Matthias Bolliger^{a,b}, Ariane Ballmer^{a,b}, Maja Gori^c, Petrika Lera^{d,e}, Cécile Oberweiler^f, Sönke Szidat^{b,g}, Gilles Touchais^f, Albert Hafner^{a,b,*}

^a Institute of Archaeological Sciences, University of Bern, Switzerland

^b Oeschger Centre for Climate Change Research OCCR, University of Bern, Switzerland

^c Institute of Heritage Science, National Research Council of Italy (ISPC-CNR), Rome, Italy

^d University of Fan Noli, Korçë, Albania

^e Academy of Albanological Studies, Institute of Archaeology, Tirana, Albania

^f UMR 7041 ArScAn, CNRS, Université Paris I Panthéon Sorbonne, Université Paris Nanterre, Paris, France

^g Department of Chemistry and Biochemistry, University of Bern, Switzerland



ARTICLE INFO

Keywords:

Dendrochronology
Radiocarbon dating
Wiggle-matching
Bronze Age Balkans
Wetland archaeology
Sovjan
Apsidal house

ABSTRACT

The archaeological site of Sovjan is situated on the edge of the Korçë Basin, southeastern Albania. Its remarkably long and well investigated stratigraphic sequence, spanning from the Neolithic till the Iron Age, makes it an important type- and reference-site for the whole region. At different periods of prehistory it was located on the shores of the former Lake Maliq that once filled the Korçë Basin, but was definitely drained in the 1940's. These permanent wetland conditions on the site allowed for a high degree of preservation of organic material, especially wood. Based on the current knowledge, level 8 of Sovjan contains the best-preserved wooden material of all the Early Bronze Age sites in the Balkans. Through the combination of dendrochronology and Bayesian modelling, i.e. wiggle-matching, a floating 269-years long tree-ring chronology was constructed, with an absolute end-date range falling between 2158 and 2142 cal BC (2σ). It was possible to establish that the dwellings and the trackway associated with the last occupation phase of level 8 are contemporaneous. Additionally, with the help of the new dendrochronological data and based on previously published charcoal dates, the absolute chronology of the subsequent level 7 is being narrowed-down to a range from the mid-22nd to mid-20th c. cal BC (2σ). The Early Bronze Age layers of the archaeological site of Sovjan, which are particularly pertinent for the 3rd millennium chronology of the southwestern Balkans, can now be dated with high precision for the first time and hence offer a major chronological reference point in the region.

1. Introduction

Near the modern village of Sovjan (approx. 817 m.a.s.l.), in south-eastern Albania, a prehistoric lakeside pile-dwelling was discovered in 1988 in the course of agricultural works. The Franco-Albanian Korçë Basin Archaeological Expedition has been systematically excavating the site between 1993 and 2006 (Fig. 1). The excavations at Sovjan have revealed a long human occupation of the site dating back at least to the beginning of the 7th mill. BC and lasting up to the 8/7th c. BC, with gaps during the second half of the 4th mill. BC and the first half of the 3rd mill. BC. Sovjan is situated around 3.5 km to the north from the village of Maliq, eponymous to another important prehistoric site that was

excavated in the 1960s. The long stratigraphic sequence of Maliq made it the type-site for the relative chronology of the Albanian Bronze Age (Prendi and Bunguri, 2008). The site of Sovjan was flooded by the waters of the ancient lake Maliq and definitely abandoned around 700 BC (Touchais et al., 2005; Fouache et al., 2010a, b). Due to this event and the subsequent waterlogging, the archaeological site of Sovjan offers remarkably well-preserved organic remains. In the course of the late Holocene, the former Lake Maliq was reduced to a marsh in the north-western part of the plain of Korçë and was finally drained after 1946 during land reclamation activities (IUCN, 1992).

Level 8 of Sovjan, consisting of several archaeological strata, is particularly rich in architectural remains. Floors of at least four

* Corresponding authors at: Institute of Archaeological Sciences, Mittelstrasse 43, 3012, Bern, Switzerland.

E-mail addresses: andrej.maczkowski@iaw.unibe.ch (A. Maczkowski), albert.hafner@iaw.unibe.ch (A. Hafner).

<https://doi.org/10.1016/j.dendro.2021.125811>

Received 29 September 2020; Received in revised form 23 December 2020; Accepted 10 January 2021

Available online 19 January 2021

1125-7865/© 2021 The Authors. Published by Elsevier GmbH. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

buildings were uncovered, as well as various wooden construction elements, some *in situ* (dowels and beams) and others collapsed (fragments of wattle and daub, beams and poles). A previous radiocarbon measurement of an uncharred wooden board from the bottom part of the accumulated strata has delivered a date between the 23rd and 21st c. BC (Ly-8290) (Lera et al., 1997, 2007; see also Table 3), allowing for its chronological attribution to the Early Bronze Age (EBA). Given the fact that until recently only one single absolute date was available from level 8, some uncertainty remained regarding both the reliability of the dating and the time span of the level's sediment accumulation which could be determined with a chronological resolution of about 300 years only.

The most striking feature discovered in level 8 is a nearly complete floor of an apsidal building, measuring more than 15 m in length and over 4 m in width. Its name *Maison du Canal* (house at the canal) is due to its parallel position to the modern artificial canal that cuts the prehistoric settlement in two. Its main constructive features are the wattle and daub walls preserved up to about 50 cm in height. Oriented north-south, the building consists of a large main space and a small apsidal space to the north (Figs. 2 and 3). The entrance to the building is situated in the eastern wall and a bark bedding – interpreted as floor insulation – is

partly preserved in the northern part of the large space (Fig. 2). The floor plan of the house featuring an apsis corresponds to the common design of the time (e.g. Nola-Croce del Papa/Italy: Albore Livadie, 2007) and the region (e.g. Sitagroi/Greece: Renfrew et al., 1986; Elster, 1997; Agios Athanasios/Greece: Mavroidi et al., 2008; Arhontiko/Greece: Pilali and Papanthimou, 2002; Greek mainland: Wiersma, 2014). From an archaeological point of view, the building seems to have been erected at ground level. North of the *Maison du Canal* a wooden log trackway was uncovered (Fig. 2, 3b), which is interpreted as a connecting path between the different buildings of the settlement. To the northeast of the trackway, another building named *Maison du Pêcheur* (Fisherman's house) was unearthed, of which only the entrance area and a small section of one wall have been excavated (Lera et al., 2004; Touchais et al., 2005; Touchais, 2008).

The aforementioned good state of conservation of the wooden remains from Sovjan's level 8 motivated the sampling for dendrochronological analysis. For this purpose, a total of 34 wood samples were taken from three structures belonging to level 8: 18 samples from various elements of the *Maison du Canal* in trench A7, 2 from the wattle and daub wall of the *Maison du Pêcheur* and 14 samples from the logs and piles of



Fig. 1. Lake region at the border triangle of Albania, North Macedonia and Greece with the ancient Lake Maliq (hatched) (based on a reconstruction by Fouache et al., 2010a) situated in the Korçë basin, as well as the Lakes Ohrid and Prespa. Besides Sovjan, a series of waterlogged archaeological sites are known from the region, showing a high potential for wood preservation. Johannes Reich (EXPLO. UBern)

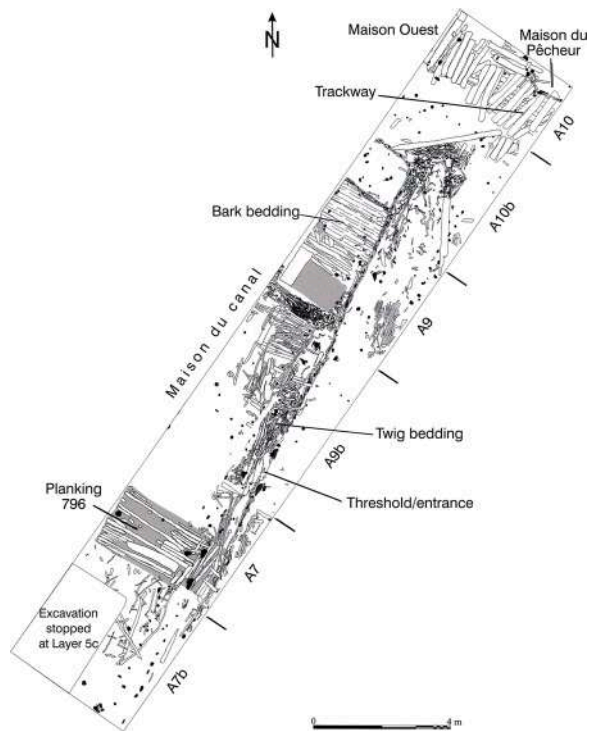


Fig. 2. Sovjan (Albania). Trench A, level 8: plan of wooden structures, featuring the *Maison du Canal*, the *Maison du Pêcheur*, and the trackway. École Française d'Athènes; Andrej Maczkowski (EXPLOR. UBern).

the trackway situated in trench A10 (Fig. 4). Based on these, we present the first floating dendrochronological mean curve of the southwestern Balkans' Bronze Age with an absolute end-date range falling in the middle of the 22nd century cal BC. Dendrochronologically cross-dated wood samples, in combination with 13 new radiocarbon dates and the application of Bayesian modelling (wiggle-matching), allow for an

absolute chronological dating in the range of decades. Sovjan's EBA level 8 is thus offering a robust absolute chronological framework for the first time, allowing for a more precise supra-regional synchronisation of the site with the EBA chronological sequence of the Balkans and the Aegean (Arvaniti and Maniatis, 2018; Bulatović et al., 2020).

2. Materials and methods

2.1. Tree-ring widths measurement and cross-dating

For this study, the tree-ring widths of 34 subfossil wood samples from the archaeological site of Sovjan were measured (Fig. 5). The backfilled main trench at Sovjan was re-opened for dendrochronological sampling in 2018 (Oberweiler and Kurti, 2018). All of the samples were taken from architectural construction elements which were recovered in a layer of clayey peat (Lera et al., 1997). The sampling was performed by the excavation team by means of a handsaw, and the wooden disks were wrapped in plastic alimentary foil for temporary conservation. Tree-ring analysis was carried out at the Dendrochronological Laboratory of the Institute of Archaeological Sciences at the University of Bern in 2019. The segments to be measured were first prepared with a razor blade and then blackboard chalk was applied to the heartwood surface in order to increase the contrast between the anatomical features of the wood. Two to four different radii per wood sample were averaged to represent the sample. The tree-ring widths (TRWs) of the subfossil wood were measured on a mechanical *Isel LES 4* measuring platform equipped with a *Mitutoyo Digimatic* caliper with an accuracy of 0.01 mm. The measuring of the samples and the statistical cross-dating were performed in the *Dendroplus* software (Ulrich Ruoff, version 28 Nov. 2013, unpublished). Descriptive dendrochronological statistic and standardisation of the site chronology was performed in the *dplR* package in R (Bunn, 2008; Bunn et al., 2020; R Core Team, 2020).

In order to assess possible relative positions, the raw TRWs were first cross-checked using the standard dendrochronological statistical parameters, the percentage of parallel variation or *Gleichläufigkeit* (GLK) (Eckstein and Bauch, 1969) and the *t-values* (Hollstein, 1980 [t_{HO}]). Then, the cross-dated positions were visually checked in a vector



Fig. 3. Sovjan (Albania). Trench A, level 8. a: the *Maison du Canal* with preserved wattle and daub walls, at the very bottom of the image the trackway is visible. View from northeast. b: the trackway, and in the upper left corner of the trench the curved wattle and daub wall of *Maison du Pêcheur*, viewed from the northwest. École Française d'Athènes

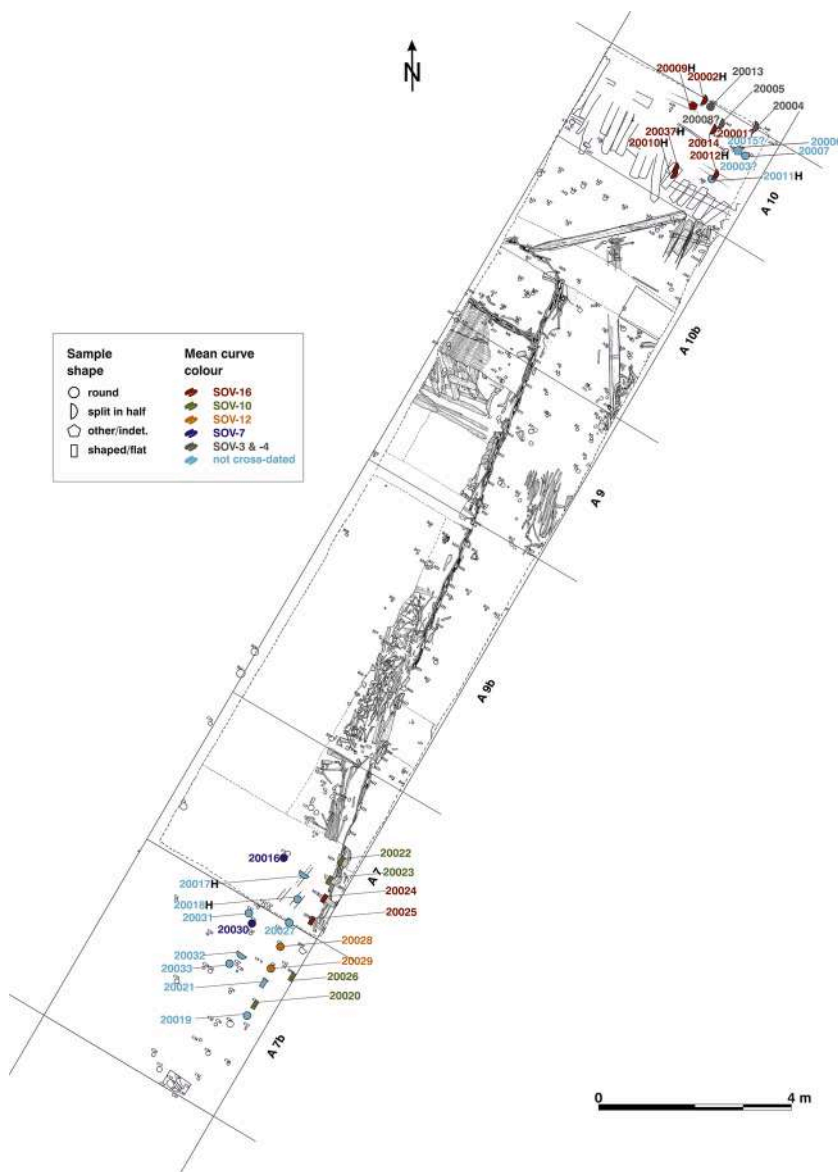


Fig. 4. Sovjan (Albania). Trench A, level 8: location of samples taken for dendrochronological measurements, as discussed in the paper. The colors refer to the curve, the numbers to the sample ID. The shapes refer to the sample form and do not reflect sample orientation. The letter 'H' next to the sample number indicates horizontal wood. Question marks indicate uncertain absolute positions within the stratigraphic unit.

École Française d'Athènes; Andrej Maczkowski (EXPLO. UBern); Ariane Ballmer (EXPLO. UBern); Matthias Bolliger (EXPLO. UBern).

graphics software. Standardisation of the main chronology was performed using a cubic smoothing spline with a 50 % frequency-response cut-off at 32 years (Cook et al., 1990), and the indices were averaged using a bi-weighted robust mean. The cross-dating was done solely with the oak samples ($n = 30$). Dendrotypological parameters, such as growth trend, cambial age and presence/absence of sapwood (Billamboz, 2008) were also taken into account during the synchronisation of the series. In order to control for the quality of the dendrochronological cross-dating and to avoid confirmation bias, the spatial relationship of the samples on the archaeological plan was not consulted until the end of the correlation work. This also serves as quality control for the prior information used for the wiggle-matching. The archaeological information was later used to test, support and/or place unsure matches and short mean curves.

Initially, for the construction of the mean curves the conventional threshold of a minimum of 40–50 rings (e.g. Pilcher et al., 1990; Haneca et al., 2009) was maintained. Two thirds of the oak samples ($n = 20$) had equal to or more than 40 rings. The ring-count of the non-oak species ($n = 4$) was below 24, therefore unsuitable for cross-dating. In the second round of cross-matching, the oak samples and mean curves with lower ring-counts were also used, coupled with the radiocarbon dates and

archaeological data if available. As there are no reference chronologies available for this area and period, there is no possibility to check the results by dendrochronological absolute dating of individual samples or groups. Therefore, in case of doubt, samples were not included in mean curves.

2.2. Radiocarbon sampling and Bayesian modelling

For the radiocarbon dating 13 sections of tree-rings from 9 cross-dated wood samples representing the different mean curves were selected, marked and cut with a razor blade under a binocular microscope. Between 7 and 10 rings were sampled, depending on the ring size (Table 2; Fig. 5). To minimize the risk of sample contamination, the area previously used for the ring-width measurement was thoroughly removed before sampling for radiocarbon dating. The samples were dated in the Laboratory for the Analysis of Radiocarbon with AMS at the University of Bern (Table 2). The cellulose was extracted from wood samples using the BABAB method, i.e. a modified ABA procedure at 75 °C for all steps: the samples were treated in 4% NaOH overnight, followed by three repeated sequential treatments in 4% HCl and 4% NaOH of 1 h each; then several bleaching steps of 30 min each using 5%

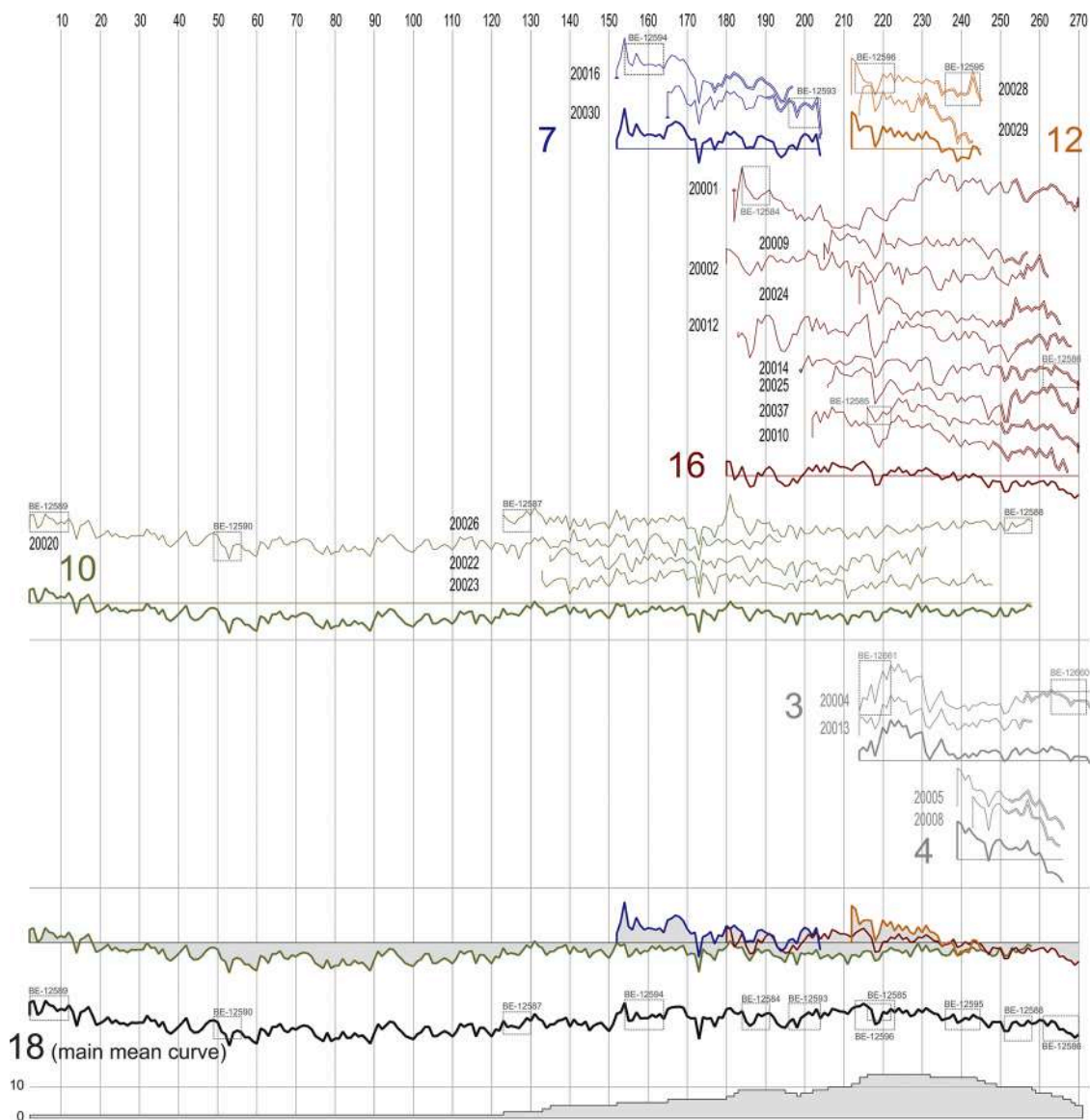


Fig. 5. Sovjan (Albania). Plotted tree-ring widths (semi-logarithmic scale) of the individual wood samples and the constructed mean curves discussed in the text. Numbers above the vertical straight lines correspond to the relative ring number. The histogram on the bottom of the image represents the sample replication in the mean curve SOV-18. The small black rectangles with 'BE-#' labels represent the positions of samples taken for radiocarbon dating. Matthias Bolliger (EXPLO. UBern).

NaClO₂ and 2 drops of 4% HCl are performed until the colour of the wood samples turns white (Szidat et al., 2014).

The obtained radiocarbon dates were analysed within Bayesian chronological models. The application of Bayesian modelling of radiocarbon dates has become a very common practice in archaeology in the last decades (Bayliss, 2015). Its importance and popularity can be mainly attributed to the high-quality chronological output information that can be extracted from groups of radiocarbon dates when calibrated and modelled with specialized software, in this study the program OxCal v.4.4 (Bronk Ramsey, 2009a). The definition of the Bayesian approach in analysing radiocarbon dates is outside the scope of this paper and its archaeological implementation has already been dealt with in detail elsewhere (e.g. Bayliss, 2007, 2009). In summary, the basic concepts and building blocks of a Bayesian statistical model are the independently obtained raw radiocarbon dates of particular samples ('standardized likelihoods') and the prior additional information we have about those particular samples such as context, stratigraphy, material characteristics etc. (i.e. the 'priors'). The modelled results ('posterior density estimates') are a quantitative, statistical calendar-age approximation of the

combined raw dates and the prior information used to define the model.

Radiocarbon samples from tree-ring sequences where the exact calendar-year intervals are known were used for wiggle-matching, a type of Bayesian radiocarbon modelling which enables a more precise chronological anchoring of 'floating' tree-ring sequences (Galimberti et al., 2004; Bronk Ramsey et al., 2001; Bayliss, 2007). The mid-point of each radiocarbon-dated tree-rings group (Table 2, col. 'Tree-rings'), rounded to an integer, was selected as a mean year for calculating the distance between consecutive tree-rings samples. The radiocarbon dates from the shorter mean curves and from the main mean curve SOV-18 were wiggle-matched using the D.Sequence command in OxCal v.4.4 (Bronk Ramsey et al., 2001; Bronk Ramsey, 2009a) and were compared to the atmospheric data from the IntCal20 calibration curve (Reimer et al., 2020), the curve resolution being set at 1 year. For the CQL code used in OxCal refer to S1 (Suppl. Material).

The new high-resolution chronological information obtained with the wiggle-matching for level 8, was further used for refining the previously published radiocarbon dates for the subsequent level 7 (Table 3) (Lera et al., 1996, 1997; Lera and Touchais, 2003; Gori and Krapf, 2015;

Gori, 2015). Like level 8, level 7 also comprises several archaeological layers. All of the radiocarbon measurements from level 7 were performed on charcoals and the metadata available for these radiocarbon measurements is not in all cases complete. However, considering the regional archaeological importance of Sovjan, we decided to utilize the available resources for a preliminary chronological model refining the absolute chronology of level 7. Charcoal samples most frequently are the remains of trees, i.e. relatively long-lived organisms. Therefore, when it is not known from which part of a tree the charcoal remains come from, it is assumed that they are older than the context they are found in. To account for this inbuilt age of the charcoal samples, special Bayesian models have been proposed. The ‘Charcoal Outlier Model’ (COM) allows for the samples to have a distribution longer than a year, but shorter than a thousand years (Bronk Ramsey, 2009b; Dee and Ramsey, 2014). The wiggle-matched end-date of the main site mean curve SOV-18 was defined as a *terminus post quem* boundary for the level 7 radiocarbon dates. For the CQL code used in OxCal refer to S1(Suppl. Material).

3. Results

3.1. Wood anatomy

The macro- and microscopic analysis of the wood anatomical features revealed that the majority of the examined samples ($n = 30$) are oak, while the remaining species are represented by *Abies* sp. ($n = 1$), *Fraxinus* sp. ($n = 1$) and *Ulmus* sp. ($n = 2$). Today, there are at least 12 different evergreen and deciduous oak species found among the contemporary arboreal flora of Albania, such as *Quercus cerris*, *Quercus trojana*, *Quercus petraea* and others, with *Quercus frainetto* being the most common one (Dida, 2003). At least seven of these oak species were employed as construction timber in modern and historical times (Westphal et al., 2010). The deciduous species are categorized either to the section *Cerris* (red oaks) or *Quercus* (white oaks). All the wood samples from Sovjan belong to a deciduous oak type. Yet, since wood anatomical distinction between the different deciduous species of oak is not possible (Schweingruber, 1990; Akkemik and Yaman, 2012), the material in this study is broadly defined as *Quercus* spp.

The presence of the outermost growth ring under the bark (waney-edge) is of great importance for dendrochronological dating and conclusions on relative sequences in settlement history. It enables the precise annual, or even sub-annual, determination of the felling year. If the waney-edge is missing, remains of sapwood can be used to estimate the missing rings. The sapwood is the outer, physiologically active part of the tree stem and in the case of oak it is lighter in colour than the inner heartwood. Considering the depositional conditions on a prehistoric wetland site, discriminating features on organic remains based on their colour is not always a reliable method. Another criterion usually used in discriminating sap- from heartwood is the presence/absence of oily secondary metabolites, so-called tyloses (Robert et al., 2017) which appear as membranes filling the large early-wood pores. However, in the case of the oak samples with preserved waney-edge from Sovjan, most of the sapwood rings, except for the last 1–3 rings, were filled with tyloses (Fig. 7). Thus, a small degree of error in defining the sapwood where only a low amount of it was present, might not have been avoided. Numerous methods for sapwood reconstruction exist (e.g. Hughes et al., 1981; Ruoff, 1995; Haneca et al., 2009; Bleicher et al., 2020), however no missing sapwood estimates were attempted on our material. Considering the above-mentioned issues, but also because of the sapwood’s highly variable, region-specific ring number (Rybníček et al., 2006; Sohar et al., 2012) and the low number of pith-to-bark samples in the present collection (S2, Suppl. Material), the development of a regional sapwood estimate reference was not attempted in this study and will be dealt with when more samples are available.

3.2. Dendrochronological cross-dating and wiggle-matching

It is remarkable, that 21 individual oak TRWs (62 %) of the randomly sampled wooden construction elements could be cross-matched. Six working groups consisting of individual samples were defined and for each of them a mean curve from the raw TRW was constructed (Fig. 5). The raw means of the working groups SOV-7, 10, 12 and 16 were averaged in a site chronology SOV-18. Additionally, standardisation of the ring-width series using cubic smoothing spline was performed for the main chronology SOV-18, using a spline with a 50 % frequency-response cut-off at 32 years (Cook et al., 1990; Fig. S3, C (Suppl. Material)). The summary statistics of the raw working-group mean curves and the standardised chronology are presented in Table 1. The running expressed population signal value (EPS; Wigley et al., 1984) and the subsample signal strength (SSS) are presented in the Supplementary Material (Fig. S3 A, B). The mean EPS of the site chronology SOV-18 is below the conventionally used threshold of 0.85 (Table 1 (but see Buras, 2017)). However, since the EPS and the SSS are above all a function of the sample replication (Briffa and Jones, 1990, p. 147; Fig. S3) it is expected that for our, as of now limited, deciduous wood sample they will not reach high values. Moreover, the presence of few different deciduous oak species in the sample (see 3.1) which may have been sourced from different stands, can lower the common signal. The EPS, Rbar and SNR for the raw SOV-18 (Table 1) achieve comparable values to the detrended SOV-18 when sample No. 20001 is removed from the raw chronology. Nevertheless, cross-dating decisions relied on the visual match, as it is still primarily a visual process (Black et al., 2016). For the same reason, to account for the quality of the cross-dating, the mean curves were treated separately. Therefore, only two mean curves contain more than three samples. Five of these mean curves were sampled for radiocarbon dating (Table 2). The results of the radiocarbon dating

Table 1

In the upper part of the table some of the conventional dendrochronological summary statistics. AR1 = mean first-order autocorrelation; Interser. Corr. = the mean interseries correlation, the leave-one-out principle, each series against its working-group or the chronology; Rbar = average pairwise correlation between the series; EPS = Expressed Population Signal; SNR = signal-to-noise ratio; Avg. Seg.Length = average segment length in each group (meancurve). All the values refer to the raw TRW, except for the detrended version of the site chronology SOV-18; Lower part of the table presents the cross-dating matrix, the GLK (% of parallel variation) and t-values after Hollstein (1980) between the different means described in the paper (cf. Fig. 5). [Note: SOV-3 and -4 are not part of SOV-18].

Meancurve	AR1	Interser. Corr.	Rbar	EPS	SNR	Avg. Seg. Length
SOV-18 <i>detrend</i>	0.32	0.55	0.34	0.714	2.49	77.2
SOV-18	0.66	0.54	0.29	0.668	2.01	77.2
SOV-16	0.74	0.50	0.37	*	1.34	69.0
SOV-12	0.63	0.49	0.66	*	0.45	32.0
SOV-10	0.53	0.46	0.36	*	1.14	135.5
SOV-7	0.63	0.72	0.82	*	1.48	43.0
SOV-4	0.66	0.88	low	*	low	25.5
SOV-3	0.76	0.74	ring no. 0.78	*	ring no. 1.37	52.5
GLK/ t _{HO}	SOV-3 SOV-4	SOV-7	SOV-10	SOV-12	SOV-16	SOV-18
SOV-3	*	*	70 % / 2.6	*	75 % / 3.8	70 % / 3.8
SOV-4	*	*	*	*	63 % / 3	70 % / 3
SOV-7	*	*	62 % / 6.8	*	*	*
SOV-10	*	*	*	62 % / 3.8	69 % / 5.5	*
SOV-12	*	*	*	*	79 % / 5.4	*
SOV-16	*	*	*	79 % / 5.4	*	*

Table 2

Uncalibrated and modelled dates for the radiocarbon measurements from dendro-chronologically cross-dated Sovjan mean curves from level 8. Shown is the modelled individual sample calibration, and in bold the wiggle-matched posterior density estimates of the last measured rings of each short mean curve. The 'tree-ring' column lists the tree-ring ranges of each individual wood sample that was selected for radiocarbon measurement. The calibration of the data was performed in OxCal 4.4 (Bronk Ramsey et al., 2001; Bronk Ramsey, 2009a,) with the atmospheric data from IntCal20 (Reimer et al., 2020).

Sovjan, Korçë, Albania						
Dendro-Lab Sample No.	14C Lab No.	Mean curve	Tree-rings	BP uncal	±1 s (y)	calBC modelled (95.4 %)
20001	BE-12584.1.1	16	3–9	3831	23	2310–2213
20037	BE-12585.1.1	16	35–41	3767	24	2278–2181
20014	BE-12586.1.1	16	80–89	3775	23	2231–2134
		SOV-16				2227–2130
20020	BE-12589.1.1	10	1–11	3944	23	2469–2397
20020	BE-12590.1.1	10	48–55	3897	23	2423–2351
20026	BE-12587.1.1	10	122–129	3842	24	2349–2277
20026	BE-12588.1.1	10	250–257	3762	24	2221–2049
		SOV-10				2218–2146
20016	BE-12594.1.1	7	3–13	3803	23	2335–2196
20030	BE-12593.1.1	7	45–53	3815	23	2294–2155
		SOV-7				2290–2151
20028	BE-12596.1.1	12	2–12	3787	24	2226–2139
20028	BE-12595.1.1	12	25–34	3724	23	2203–2116
		SOV-12				2199–2112
20004	BE-12661.1.1	3	1–9	3771	28	2289–2186
20004	BE-12660.1.1	3	50–59	3786	27	2239–2136
		SOV-3				2235–2132

showed no contradictions with the dendrochronological cross-dating (Fig. 6).

3.2.1. SOV-10 mean curve and corresponding shorter means

Four oak TRW series from samples taken from the southeastern limit of the trench (sectors A7 and A7b) (Fig. 4) were cross-matched into the longest site mean curve SOV-10, which spans 257 calendar years. All of the samples have between 97 and 193 annual rings; however, the first

Table 3

Previously published radiocarbon dates from the levels 9–7. The data of sample DEM-2353 was in press during the preparation of this paper. Only the dates from level 7 were used in the chronological model of the present paper. The calibration of the data was performed with the calibration program OxCal 4.4 (Bronk Ramsey, 2009a) and the calibration curve IntCal20 (Reimer et al., 2020).

Sovjan, Korçë, Albania							
Level	Sector	SU	Locus	14C-Lab No.	14C BP	calBC (95.4 %)	Reference
7	A9b	99/ 475.6		DEM-2353	3821 ± 30	2450–2144	<i>In press</i>
7	A7	94/ 280.2	776	Ly-7012	4035 ± 55	2865–2411	Lera et al.(1996), p. 1006
7	A7	96/ 312.3	775	Ly-8287	3695 ± 45	2204–1949	Lera et al. (1997), p. 874
7	A7	96/ 315.2	775	Ly-8288	3770 ± 45	2341–2034	Lera et al. (1997), p. 874
7	A9	96/ 356.6		Ly-8289	3760 ± 45	2338–2030	Lera et al. (1997), p. 874
7	A9			Ly-11918	3770 ± 40	2339–2036	Lera et al. (2003), p. 606
8	A7	96/ 362.1	above 796	Ly-8290	3765 ± 45	2341–2032	Lera et al. (1997), p. 874
9	A9	99/ 489.2	below 870	Ly-11919	3935 ± 30	2564–2302	Lera et al. (2003), p. 606

half of the mean curve is represented by only one sample (No. 20020). It is a flat-shaped piece coming from a pile line ca. 0.5 m to the west from the wattle and daub wall of the *Maison du Canal* (Fig. 4, green). The absence of sapwood on all of these samples does not permit a precise specification of the temporal succession of building phases in this case. All of the samples in SOV-10 have been deliberately split and shaped into flat forms, which is probably the reason for the sapwood's absence. However, considering that No. 20020's preserved heartwood rings end at least 37 years before the heartwood of the next closest sample-ending within the mean curve (Fig. 5, No. 20022) there is a possibility that it represents an earlier building event (together with SOV-12), as has already been assumed in the field (Oberweiler and Kurti, 2018). The end-date range of mean curve SOV-10 obtained by wiggle-matching of four radiocarbon dates is between 2218 and 2146 cal BC (95.4 % probability, (Table 2)).

A group of two samples with well-developed sapwood from the sector A7, merged in the mean curve SOV-7, cross-dates well to the relative year 203 on mean curve SOV-10 (t_{HO} 6.8; GLK 62 %). Mean curve SOV-7 was not initially included in the mean curve SOV-10 on the account of its specific growth pattern and almost complete sapwood presence. Its correct chronological placement is further confirmed by the radiocarbon calibrated end-date relative to the SOV-10 end-date (Table 2, Fig. 6), thus indicating an earlier building activity around this time (Fig. 5; 4).

3.2.2. SOV-16 mean curve and corresponding shorter means

The mean curve SOV-16 is composed of nine samples, of which seven come from the feature interpreted as a trackway and two are part of the eastern wall of the *Maison du Canal*. This mean curve is the best replicated and dendrochronologically most robust, as all of the constituent woods have at least few or all of the sapwood rings present. Four of them have clearly preserved waney-edge. The last growth rings on these samples end with a well-developed latewood which points to a felling date after the growing season, sometime between autumn and early spring (Fig. 7). Most probably all the wood samples in mean curve SOV-16 come from one felling event. The wiggle-matching points to an absolute felling-date range of SOV-16 between 2227 and 2130 cal BC (95.4 % probability) (Table 2). SOV-16 cross-dates reliably to mean curve SOV-10, both visually and statistically (t_{HO} 5.5, GLK 69 %) with 78 overlapping rings and extends it for 13 calendar years (Fig. 5).

The short mean curve SOV-12, encompassing two samples, was cross-dated to SOV-16. Its relative placement was initially more problematic because of the short overlap and the much higher mean TRW. However, guided by the fair visual matching and supported by the vicinity of these piles to the piles from the wattle wall of the *Maison du Canal* (which are part of SOV-16), SOV-12's last measured ring can be placed at the relative year 244 of SOV-16. The absolute end-date range of mean curve SOV-12 falls between 2199 and 2112 cal BC (95.4 % probability; Table 2).

Short mean curves were also constructed for the smaller sample groups from sector A10 – SOV-3 and SOV-4 – consisting of two samples

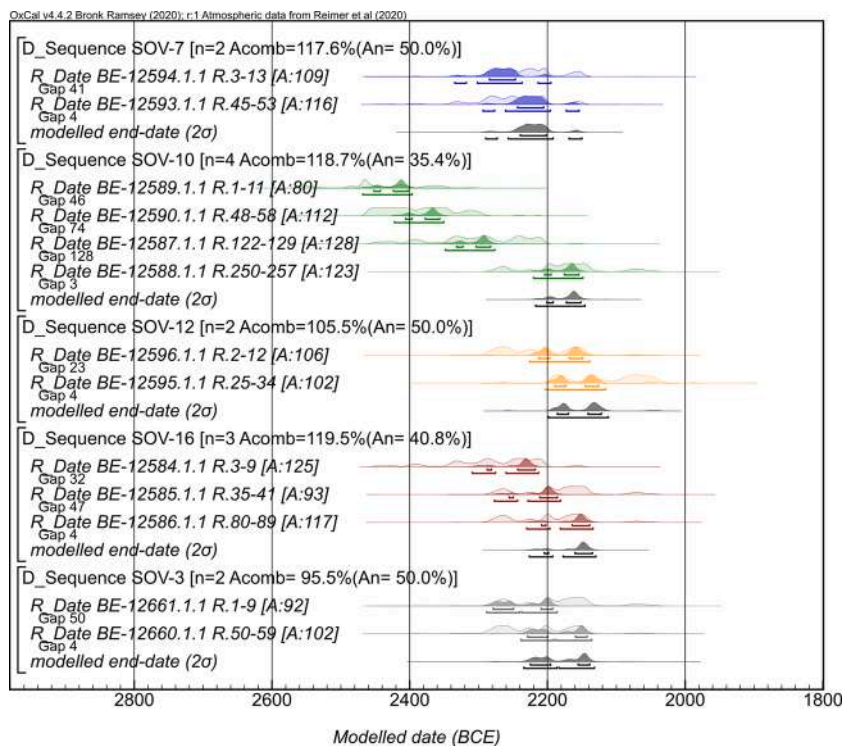


Fig. 6. Sovjan (Albania). Wiggly-matched date ranges of the individual mean curves (SOV-3,-7,-10,-12,-16), before integrating them into the wiggly-matched main site chronology (SOV-18). Colours and labels correspond to the curves in Fig. 4-5. The calibration of the data was performed with the calibration program OxCal 4.4 (Bronk Ramsey et al., 2001; Bronk Ramsey, 2009a) with the atmospheric data from IntCal20 (Reimer et al., 2020). [Note: SOV-3 is not part of the main site chronology SOV-18.].

Andrej Maczkowski (EXPLO. UBern).

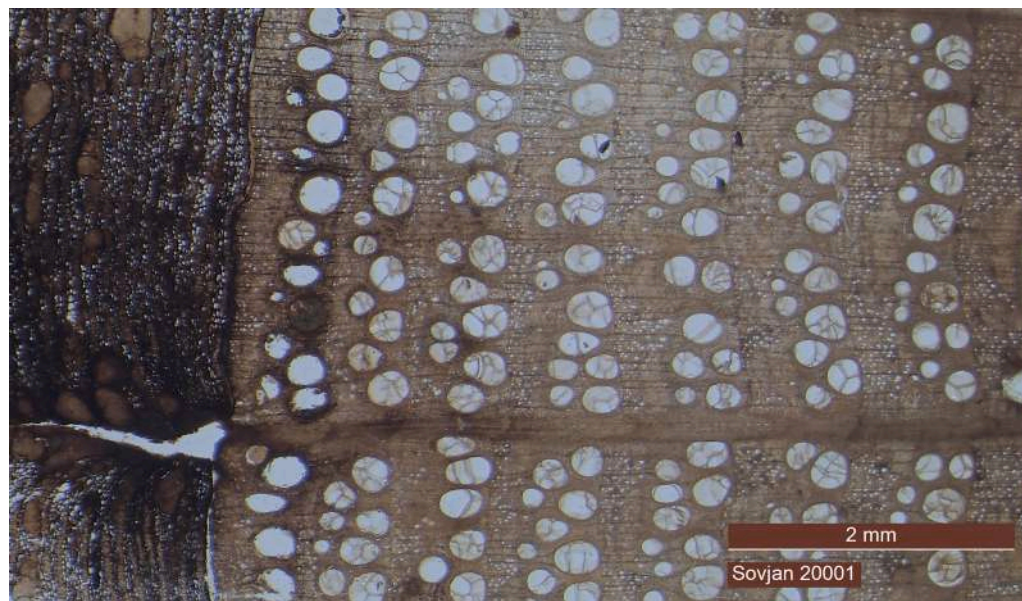


Fig. 7. Sovjan (Albania). Photograph of the last outer rings of sample No. 20001 (oak). Secondary growth direction from right to left. Note the presence of tyloses (wiggly membranes filling the large pores) in all the rings except the last ring before the bark. Developed late-wood suggests a felling date after the growing season (autumn to early spring).

Matthias Bolliger (EXPLO. UBern).

each. Based on the growth pattern of the former (probably the same tree) and the small number of rings of the latter, they were not included in any of the above mentioned longer mean curves (Fig. 5). Nevertheless, they show a good visual cross-match with mean curve SOV-16, albeit the statistical values are not as coherent (Table 1). The relative positioning of SOV-4 can be assumed to be correct considering also the spatial vicinity of its samples in the field (being close to the trackway) to those from SOV-16 (Fig. 4). The same can be said for the mean curve SOV-3, although it surpasses the SOV-16 by at least 3 years. The end-date range of mean curve SOV-3 falls between 2235 and 2132 cal BC (95.4 % probability; Table 2). The samples from mean curve SOV-4 were not sampled for radiocarbon dating.

3.3. Absolute chronology of level 7

The new dendrochronological and modelled radiocarbon data from level 8 was used to revise the absolute chronology of level 7, which was previously based only on individually calibrated radiocarbon measurements on charcoal samples from hearths and building debris (Lera et al., 1997; Lera et al., 2004). The older calibrations have yielded a wider absolute date range of ca. 2300–1950 cal BC for level 7 (Gori and Krapf, 2015). Of the six available radiocarbon measurements from level 7 (Table 3) one has been cited as an outlier (Ly-7012), falling in the first half of the 3rd mill. cal BC. Considering the new high-resolution posterior density estimates for level 8, a Bayesian chronological model was

constructed using them as a prior information setting the end-date as a Boundary, i.e. *terminus post quem* for the beginning of level 7. The time span output for level 7, using the 'Charcoal Outlier Model' – advised for use when dealing with larger charcoal datasets (Dee and Ramsey, 2014) – yielded results pointing to a calendar age range from the second half of the 22nd c. cal BC to the beginning of the 20th c. cal BC (2157–1962 cal BC (95.4 % probability)) (Fig. 8).

4. Discussion

4.1. Sovjan main chronology and absolute dating

For a main site reference and as a basis for a local oak chronology, the mean curves 10, 16, 7 and 12 are averaged into a main Sovjan chronology SOV-18 (Fig. 5). This site chronology encompasses a span of 269 years with a total replication of 17 samples. The Bayesian modelling based on wiggle-matching of tree-ring sequences leads to a much more

precise end date of the chronology. The wiggle-matching of 11 of the 13 radiocarbon dates from level 8, as described in section 2.2 with exact known year intervals between them, yields a resulting end-date range for mean curve SOV-18 between 2158 and 2142 cal BC (95.4 % probability; Acomb = 198.1 %) (Fig. 8, inset). At the present moment there are no correlations to other prehistoric oak chronologies from the region (e.g. from the lakes Ohrid and Kastoria), most probably due to the non-contemporaneity of the relevant sites.

The individual mean curves will be kept for further work, as they represent individual growth patterns, the so-called dendrogroups (Billamboz, 2008).

4.2. Woodworking and construction events

Half of the oak samples analysed in this study (n = 15) are clearly split in half along the grain of the wood. More invasive woodworking is evident on the upright stakes from the *Maison du Canal*, which are

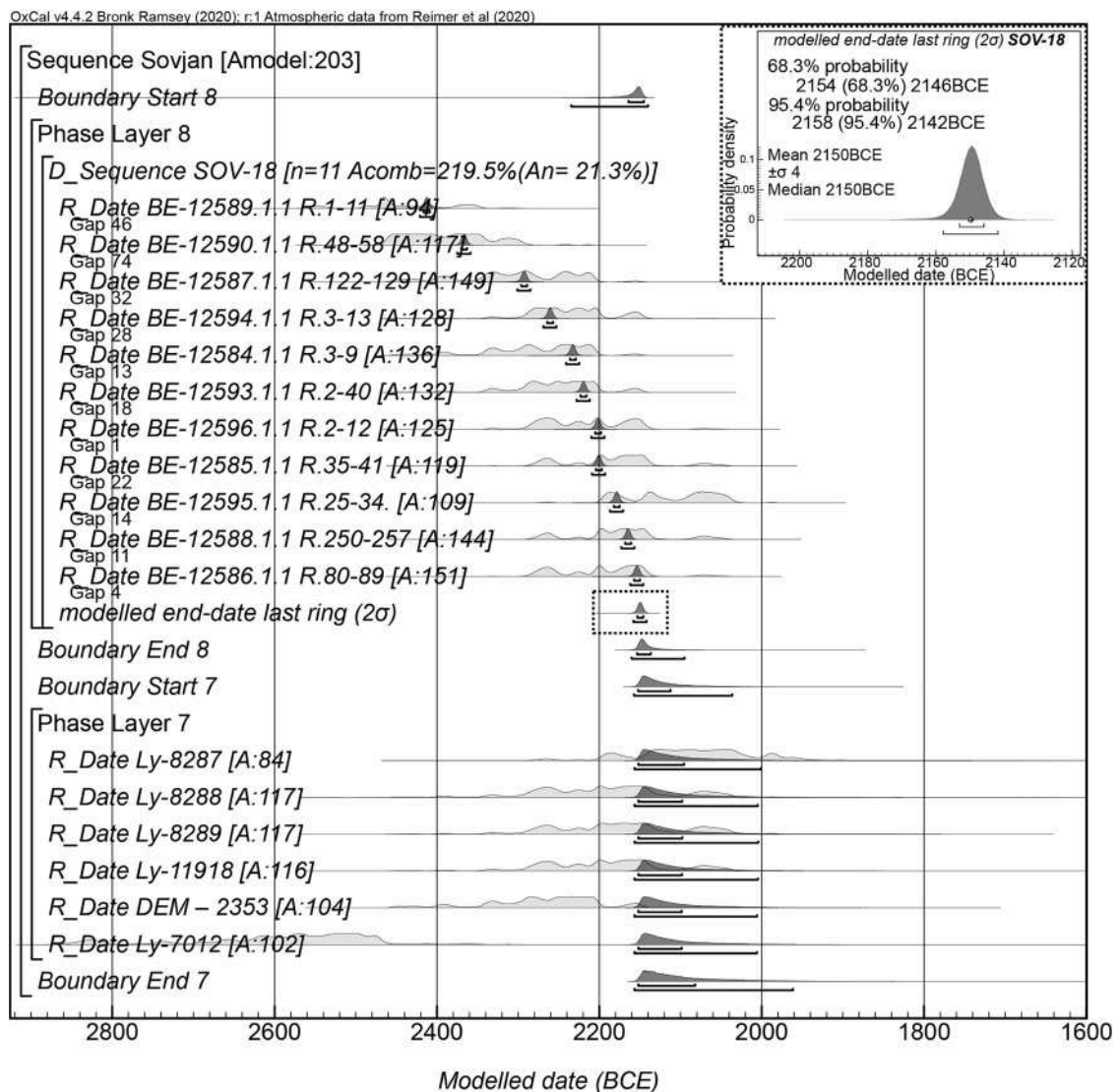


Fig. 8. Sovjan (Albania). The wiggle-matching output of the SOV-18 mean curve used as a boundary for the Charcoal Outlier Model (Bronk Ramsey, 2009b; Dee and Ramsey, 2014) applied to the previously published radiocarbon dates for level 7. The Bayesian modelling results indicate an occupation of level 7 between the second half of the 22nd c. BC and the beginning of the 20th c. BC at 2σ (2157–1962 cal BC (95.4 % probability); or 2152–2080 cal BC (68.3% probability)). The end-date of the mean curve SOV-18 from level 8 represents the boundary, i.e. a *terminus post quem* for layer accumulation of level 7. The light-gray outlines show the individually calibrated dates; the dark shaded areas indicate the modelled age-ranges. The brackets on the left define the model. Inset shows a close-up plot of the highest posterior density (hpd) range for the last ring of SOV-18, mean, median and $\pm\sigma$ also indicated. Andrej Maczkowski (EXPLOR. UBern).

shaped into a flat form with visible working marks. With the exception of a few samples, bark is absent. It is not clear whether this is the result of intentional debarking or a matter of preservation. A feature in sector A7b, contemporaneous with the *Maison du Canal*, contains a substantial number of wood shavings and splinters and hence has been defined as woodworking area (Lera and Touchais, 2004; Gori, 2015). Furthermore, the diameter of the sampled unworked timbers of round and half-round shape used for the construction of the trackway is moderately larger (12–21 cm) compared to that of the wood employed in the construction of the houses (8–16 cm).

The oldest construction layer in level 8, defined as sub-phase IV (Gori, 2015), is outlined by the wooden planking from the excavation locus 796 (Fig. 2), represented by the mean curve SOV-7. It is assumed that it dates roughly 40 years anterior to the next felling event represented by the mean curve SOV-12 based on the high incidence of sapwood. Yet, the absence of the terminal rings on the samples from the mean curves SOV-7 and SOV-12 impedes a more detailed relative dating.

The ontogenetically oldest sample No. 20020, though from a dendrochronological perspective included in SOV-10, is archaeologically part of the pile row situated ca. 0.5 m to the west from the wattle and daub wall of the *Maison du Canal*, therefore in line with the samples from SOV-12 (Fig. 4). This pile row has been interpreted as contemporaneous with the wattle and daub wall (Lera and Touchais, 2004; Gori, 2015). Based on the dendrochronological results (Fig. 4–5, SOV-12 and No. 20020) it appears that this row is made of trees felled earlier than those used for the construction of the wattle wall, the trackway and the *Maison du Pêcheur* – possibly by more than 10 years, but not more than 24 years (assuming that a terminal ring would be present on SOV-12 samples one year later after the last measured ring). Although this would fit the previous assumptions on an average occupation-phase duration of about 20 years (Lera and Touchais, 2004), it is difficult to assess these assumptions since the dendrochronological data they have been based on has never been published.

A definite relative felling-date could only be determined for the group of piles represented in the mean curve SOV-16. Considering that it includes samples from all the different structures, it is apparent that the trackway, the *Maison du Pêcheur* and the wattle and daub wall of the *Maison du Canal*, or at least parts of them, were built in the same event.

The groups of SOV-4 and SOV-3 are not included in the main site mean curve on the account of low statistical cross-dating values. Nevertheless, their stratigraphic position as well as the results of the radiocarbon dating support the visual cross-dating and considering the high presence of sapwood on all of these samples (Fig. 5) it can be assumed that the terminal rings date within the range of a couple of years. This means that some of the trees were felled not much later than those employed for the construction of the *Maison du Canal* and it may represent a slightly later repair/construction event or be the result of a different timber-seasoning practice.

According to the archaeological information, the wattle and daub wall of the *Maison du Canal* belongs to the most recent stratum or sub-phase I of level 8 (Gori, 2015). Thus, the modelled end-dates of SOV-18 correspond to the last instance of occupation of level 8.

4.3. Revisiting the absolute chronology of level 7

The new dendrochronological data from level 8, allowed for the modelling and revision of the existing radiocarbon dates of level 7. The stratigraphic boundary between the levels 8 and 7 was clearly identifiable during the excavations (Lera and Touchais, 2004). Therefore, it is assumed that the calibrated end-date of the main mean curve SOV-18 from level 8 is a *terminus post quem* for the onset for the anthropic accumulation of level 7. Consequently, the modelled time span of the occupation of level 7 resulting from the Charcoal Outlier Model applied in OxCal 4.4, narrows down to a range between the second half of the 22nd c. cal BC and the beginning of the 20th c. cal BC in the 2σ range (2157–1962 cal BC (95.4 % probability); or 2152–2080 cal BC in the 1σ

range (68.3% probability)) (Fig. 8). This time span is consistent with the previous relative dating of level 7 at the end of the EBA and the beginning of MBA (Gori, 2015). The metadata of the charcoal samples from level 7 is not in all cases detailed enough to allow for a more specific interpretation of the chronological model of the level. Also, stratigraphic identification of two strata or sub-phases within level 7 in some sectors of the excavations could not be incorporated into the model on account of the uncertain attribution of the radiocarbon samples to any of the strata or sub-phases of the level.

It is acknowledged that the old-wood effect may substantially influence the dating of archaeological layers through radiocarbon dates of charcoals, however, recently developed controlled models on big datasets confirm the robustness of charcoal-based absolute dating of events (Schmid et al., 2018; Dee and Ramsey, 2014). From the simple calibration of individual radiocarbon samples from level 7 (Fig. 8, light-gray outlines) it is clear that they fall within the time span of the calibrated ranges of the younger rings of SOV-18 samples, while the substantially older sample (Ly-7012) may be an ‘old-wood representative’ in the vicinity of the calibrated calendar range of the oldest sampled tree-rings from level 8. It is plausible that given the availability of a population of trees from the region whose tree-ring sequences have been cross-dated dendrochronologically and absolutely through wiggle-matching (SOV-18), we can further support the Charcoal Outlier Model arguing that the charcoal from level 7 comes from a plant material that was growing at a time either contemporaneously or not too long after the trees felled for the constructions in level 8.

5. Conclusion

With the combination of dendrochronological analysis of the wooden construction elements and the wiggle-matching method, we were able to clarify the temporal relationship between different archaeological features within Sovjan’s level 8, containing the so far best-preserved wooden building structures from the EBA of the southwestern Balkans. The obtained results corroborate previous findings based on archaeological material, in particular pottery typical of the final stages of the EBA (EBA III) (Gori and Krapf, 2015) and improve the absolute chronological dating of this regionally important site in high resolution, placing the building activity related to level 8 at around the middle of the 22nd c. BC, with the modelled end-date range pointing to 2158 and 2142 cal BC (95.4 % probability) (Fig. 8, inset). The new results coincide with the revised dating of the Balkans Armenochori-group of the EBA (Bulatović et al., 2020). In addition to the general chronological allocation of level 8, conclusions were also drawn regarding the temporal sequence of different construction events within the level. The fact that two separate dwellings and the trackway were built in one event, or at least the timber used for the construction was felled in the same year, represents a rare direct evidence of the contemporaneous collective effort in settlement construction in the Balkan EBA. Thanks to the new dendrochronological data from level 8, the chronology of the subsequent transitional level 7 could be refined to the later part of the last century of the 3rd, or the beginning of the 2nd mill. BC.

Furthermore, this is the first published dendrochronological oak mean curve from the southwestern Balkans that covers the period from around the 24th till the mid-22nd century BC. The common climatic signal and the potential for dendrochronological cross-dating of various tree species in the Balkans and the wider Eastern Mediterranean area has been frequently attested (e.g. Čufar et al., 2008; Hughes et al., 2001; Kuniholm et al., 1998; Kuniholm and Striker, 1983), yet a coherent multimillennial oak master chronology for the region is still lacking. Taking into account the promising results of recent investigations (Čufar et al., 2015; Pearson et al., 2014; Ważny et al., 2014; Westphal et al., 2010; Durman et al., 2009; Botić, 2014), the present work will contribute to the establishment of a Balkan oak master chronology.

CRedit authorship contribution statement

Andrej Maczkowski: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Matthias Bolliger:** Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision. **Ariane Ballmer:** Conceptualization, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration. **Maja Gori:** Writing - review & editing. **Petrika Lera:** Investigation, Supervision. **Cécile Oberweiler:** Investigation, Resources, Writing - original draft, Writing - review & editing, Project administration. **Sönke Szidat:** Investigation, Resources. **Gilles Touchais:** Investigation, Resources, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition. **Albert Hafner:** Conceptualization, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Supervision, Funding acquisition.

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.

Acknowledgements

The dendrochronological analysis was performed at the Institute of Archaeological Sciences of the University of Bern. This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No. [810586]). The Franco-Albanian Korçë Basin Archaeological Expedition is a joint-project of the Archaeological Institute of Tirana, the University of Paris I, CNRS UMR 7041 laboratory, and the French Archaeological School in Athens. It is supported by the French Ministry of Foreign Affairs.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.dendro.2021.125811>.

References

- Akkemik, Ü., Yaman, B., 2012. Wood Anatomy of Eastern Mediterranean Species. Verlag Kessel, Remagen-Oberwinter.
- Albore Livadie, C., 2007. A first Pompeii. The Early Bronze Age village of Nola-Croce del Papa (Palma Campania Phase). *Antiquity* 16, 941–942.
- Arvaniti, T., Maniatis, Y., 2018. Tracing the absolute time-frame of the Early Bronze Age in the Aegean. *Radiocarbon* 60, 751–773.
- Bayliss, A., 2007. Bayesian buildings: an introduction for the numerically challenged. *Builld. Landsc. J. Vernac. Archit. Forum* 38, 75–86. <https://doi.org/10.1179/174962907X248074>.
- Bayliss, A., 2009. Rolling out revolution: using radiocarbon dating in archaeology. *Radiocarbon* 51, 123–147. <https://doi.org/10.1017/S0033822200033750>.
- Bayliss, A., 2015. Quality in Bayesian chronological models in archaeology. *World Archaeol.* 47, 677–700. <https://doi.org/10.1080/00438243.2015.1067640>.
- Billamboz, A., 2008. Dealing with heteroconnections and short tree-ring series at different levels of dating in the dendrochronology of the Southwest German pile-dwellings. *Dendrochronologia* 26, 145–155. <https://doi.org/10.1016/j.dendro.2008.07.001>.
- Black, B.A., Griffin, D., van der Sleen, P., Wanamaker, A.D., Speer, J.H., Frank, D.C., Stahle, D.W., Pederson, N., Copenheaver, C.A., Trouet, V., Griffin, S., Gillanders, B. M., 2016. The value of crossdating to retain high-frequency variability, climate signals, and extreme events in environmental proxies. *Glob. Chang. Biol.* 22, 2582–2595. <https://doi.org/10.1111/gcb.13256>.
- Bleicher, N., Walder, F., Gut, U., Bolliger, M., 2020. The Zurich method for sapwood estimation. *Dendrochronologia* 64, 125776. <https://doi.org/10.1016/j.dendro.2020.125776>.
- Botić, K., 2014. Wood sampling – fifth season 2013. *Ann. Instituti Archaeol.* X, 154–157. <https://hrack.srce.hr/128706>.

- Briffa, K., Jones, P., 1990. Basic chronology statistics and assessment. In: Cook, E.R., Kairiukstis, L.A. (Eds.), *Methods of Dendrochronology. Applications in the Environmental Sciences*. Dordrecht, pp. 137–152.
- Bronk Ramsey, C., 2009a. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51, 337–360. <https://doi.org/10.1017/S0033822200033865>.
- Bronk Ramsey, C., 2009b. Dealing with outliers and offsets in radiocarbon dating. *Radiocarbon* 51, 1023–1045. <https://doi.org/10.1017/S0033822200034093>.
- Bronk Ramsey, C., van der Plicht, J., Weninger, B., 2001. 'Wiggle matching' radiocarbon dates. *Radiocarbon* 43, 381–389. <https://doi.org/10.1017/S0033822200038248>.
- Bulatović, A., Gori, M., Vander Linden, M., 2020. Radiocarbon dating the 3rd millennium BC in the Central Balkans: a re-examination of the Early Bronze Age sequence. *Radiocarbon* 62 (5), 1163–1191. <https://doi.org/10.1017/RDC.2020.61>.
- Bunn, A.G., 2008. A dendrochronology program library in R (dplR). *Dendrochronologia* 26, 115–124. <https://doi.org/10.1016/j.dendro.2008.01.002>.
- Bunn, A., Korpela, M., Biondi, F., Campelo, F., Merian, P., Qeadan, F., Zang, C., 2020. dplR: Dendrochronology Program Library in R.
- Buras, A., 2017. A comment on the expressed population signal. *Dendrochronologia* 44, 130–132. <https://doi.org/10.1016/j.dendro.2017.03.005>.
- Cook, E., Briffa, K., Shiyatov, S., Mazepa, V., 1990. Tree-ring standardization and growth-trend estimation. In: Cook, Edward, Kairiukstis, L. (Eds.), *Methods of Dendrochronology: Applications in the Environmental Sciences*. Kluwer, Dordrecht, pp. 104–123.
- Čufar, K., De Luis, M., Zupancić, M., Eckstein, D., 2008. A 548-Year tree-ring chronology of oak (*Quercus* spp.) for Southeast Slovenia and its significance as a dating tool and climate archive. *Tree-Ring Res.* 64, 3–15. <https://doi.org/10.3959/2007-12.1>.
- Čufar, K., Tegel, W., Merela, M., Kromer, B., Velušček, A., 2015. Eneolithic pile dwellings south of the Alps precisely dated with tree-ring chronologies from the north. *Dendrochronologia* 35, 91–98. <https://doi.org/10.1016/j.dendro.2015.07.005>.
- Dee, M.W., Ramsey, C.B., 2014. High-precision Bayesian modeling of samples susceptible to inbuilt age. *Radiocarbon* 56, 83–94. <https://doi.org/10.2458/56.16685>.
- Dida, M., 2003. State of Forest Tree Genetic Resources in Albania (No. FGR/62E). Forest Genetic Resources Working Papers.
- Durman, A., Gaspari, A., Levanić, T., Novsak, M., 2009. The development of the regional oak tree-ring chronology from the Roman sites in Celje (Slovenia) and Sisak (Croatia). In: Manning, S.W., Bruce, M.J. (Eds.), *Tree-Rings, Kings and Old World Archaeology and Environment: Papers Presented in Honor of Peter Ian Kuniholm*. Oxbow Books, pp. 57–64.
- Eckstein, D., Bauch, J., 1969. Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. *Forstwissenschaftliches Centralblatt* 88, 230–250. <https://doi.org/10.1007/BF02741777>.
- Elster, E.S., 1997. Construction and use of the Early Bronze Age Burnt House at Sitagroi: craft and technology. In: Betancourt, P., Laffineur, L. (Eds.), *Texnh: Craftsmen, Craftswomen and Craftsmanship in the Aegean Bronze Age. Proceedings of the 6th International Aegean Conference*. (Aegaeum, 16). Université de Liège, pp. 19–35.
- Fouache, E., Desruelles, S., Magny, M., Bordon, A., Oberweiler, C., Coussot, C., Touchais, G., Lera, P., Lézine, A.M., Fadin, L., Roger, R., 2010a. Palaeogeographical reconstructions of Lake Maliq (Korça Basin, Albania) between 14,000 BP and 2000 BP. *Journal of Archaeological Sciences* 37, 525–535. <https://doi.org/10.1016/j.jas.2009.10.017>.
- Fouache, E., Desruelles, S., Magny, M., Bordon, A., Oberweiler, C., Coussot, C., Touchais, G., Lera, P., Lezine, A.-M., Fadin, L., Roger, R., 2010b. Les variations de l'extension du lac Maliq (Bassin de Korçë, Albanie) en relation avec l'occupation humaine entre 14000 BP et 2000 BP. In: Lamboley, J.-L., Castiglioni, M.P. (Eds.), *L'Illyrie Méridionale et l'Épire Dans l'Antiquité V. Actes Du Ve Colloque International de Grenoble, 8–11 Octobre 2008, Grenoble (France)*. De Boccard, Paris., V. De Boccard, pp. 1–9. hal-01292374.
- Galimberti, M., Bronk Ramsey, C., Manning, S.W., 2004. Wiggle-match dating of tree-ring sequences. *Radiocarbon* 46, 917–924. <https://doi.org/10.1017/S0033822200035967>.
- Gori, M., 2015. Along the Rivers and Through the Mountains a Revised Chrono-cultural Framework for the South-western Balkans During the Late 3rd and Early 2nd Millennium BCE. *Universitätsforschungen Zur Prähistorischen Archäologie* 268. Dr. Rudolf Habelt Verlag, Bonn.
- Gori, M., Krapf, T., 2015. The Bronze and Iron Age pottery from Sovjan. *Iliria* 39, 91–135. <https://doi.org/10.3406/iliri.2015.2500>.
- Haneca, K., Čufar, K., Beekman, H., 2009. Oaks, tree-rings and wooden cultural heritage: a review of the main characteristics and applications of oak dendrochronology in Europe. *J. Archaeol. Sci.* 36, 1–11. <https://doi.org/10.1016/j.jas.2008.07.005>.
- Hollstein, E., 1980. *Mitteleuropäische Eichenchronologie. Trierer dendrochronologische Forschungen zur Archäologie und Kunstgeschichte*. Verlag Philipp von Zabern, Mainz am Rhein.
- Hughes, M.K., Milsom, S.J., Leggett, P.A., 1981. Sapwood estimates in the interpretation of tree-ring dates. *J. Archaeol. Sci.* 8, 381–390. [https://doi.org/10.1016/0305-4403\(81\)90037-6](https://doi.org/10.1016/0305-4403(81)90037-6).
- Hughes, M.K., Kuniholm, P.I., Eiseheid, J.K., Garfin, G., Griggs, C.B., Latini, C., 2001. Aegean tree-ring signature years explained. *Tree-Ring Res.* 57, 67–73.
- IUCN, 1992. *Protected Areas of the World: a Review of National Systems. Volume 2: Palaearctic*, IUCN Conservation Library. IUCN - The World Conservation Union, Gland, Switzerland & Cambridge, UK.
- Kuniholm, P.I., Striker, C.L., 1983. Dendrochronological investigations in the aegean and neighboring regions, 1977-1982. *J. F. Archaeol.* 10, 411–420. <https://doi.org/10.1179/009346983791504165>.
- Kuniholm, P.I., Kromer, B., Tarter, S.L., Griggs, C.B., 1998. An Early Bronze Age settlement at Sozopol, near Burgas, Bulgaria. Dated by dendrochronology and radiocarbon. In: Stefanovich, M., Todorova, H., Hauptmann, H. (Eds.), *James Harvey*

- Gaul in Memoriam (In The Steps of James Harvey Gaul, Volume 1). The James Harvey Gaul Foundation, Sofia, pp. 399–409.
- Lera, P., Touchais, G., 2003. Sovjan (Albanie). Bull. Corresp. Hellénique 127, 578–609. <https://doi.org/10.3406/bch.2003.7337>.
- Lera, P., Touchais, G., 2004. Sovjan. Bull. Corresp. Hellénique 128, 1096–1147. <https://doi.org/10.3406/bch.2004.7387>.
- Lera, P., Prendi, F., Touchais, G., 1996. Sovjan (Albanie). Bull. Corresp. Hellénique 120, 995–1026. <https://doi.org/10.3406/bch.1996.7038>.
- Lera, P., Prendi, F., Touchais, G., 1997. Sovjan (Albanie). Bull. Corresp. Hellénique 121, 871–879. <https://doi.org/10.3406/bch.1997.7065>.
- Lera, P., Touchais, G., Oberweiler, C., 2007. Ndihmesa e gjermimeve të Sovjanit për kronologjinë absolute të prehistorisë shqiptare / La contribution des fouilles de Sovjan à la chronologie absolue de la préhistoire albanaise. Iliria 33, 39–50. <https://doi.org/10.3406/iliri.2007.1065>.
- Mavroidi, I., Andreou, S., Pappa, M., 2008. Οικισμός της πρώιμης εποχής χαλκού στον Άγιο Αθανάσιο Θεσσαλονίκης. Το Αρχαιολογικό Έργο στη Μακεδονία και Θράκη 20 (2006), 479–490.
- Oberweiler, C., Kurti, R., 2018. Rapport sur les travaux de l'École française d'Athènes en 2018. Albanie. Sovjan, Bassin de Korçë, Kallamas. Unpublished report. <http://www.sovjan-archeologie.net/mission/documentation/rapports.html>.
- Pearson, C.L., Ważny, T., Kuniholm, P.I., Botić, K., Durman, A., Seufer, K., 2014. Potential for a New Multimillennial Tree-Ring Chronology from Subfossil Balkan River Oaks. Radiocarbon 56, S51–S59. https://doi.org/10.2458/azu_rc.56.18342.
- Pilali, A., Papanthimou, A., 2002. Die Ausgrabungen auf der Toumba von Archontiko. Prähistorische Zeitschrift 77 (2), 137–147.
- Pilcher, J.R., Schweingruber, F.H., Kairiukstis, L., Shiyatov, S., Worbes, M., Kolishchuk, V.G., Vaganov, E.A., Jagels, R., Telewski, F.W., 1990. Primary Data, in: Methods of Dendrochronology. Springer, Netherlands, Dordrecht, pp. 23–96. https://doi.org/10.1007/978-94-015-7879-0_2.
- Prendi, F., Bunguri, A., 2008. Bronzi i Hershëm në Shqipëri. The Early Bronze Age in Albania. Prishtina: The Albanological Studying Center. The Institute of Archaeology.
- R Core Team, 2020. R: A Language and Environment for Statistical Computing. <https://www.r-project.org/>.
- Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The Intcal20 Northern Hemisphere Radiocarbon Age Calibration Curve (055 Cal Kbp). Radiocarbon 1–33. <https://doi.org/10.1017/rdc.2020.41>, 00.
- Renfrew, C., Gimbutas, M., Elster, E., 1986. Excavations at Sitagroi: A Prehistoric Village in Northeast Greece, Vol. 1. Cotsen Institute of Archaeology Press, Los Angeles.
- Robert, E.M.R., Mencuccini, M., Martínez-Vilalta, J., 2017. The anatomy and functioning of the xylem in Oaks. In: Gil-Pelegrín, E., Peguero-Pina, J.J., Sancho-Knapik, D. (Eds.), Oaks Physiological Ecology. Exploring the Functional Diversity of Genus Quercus L. Springer International Publishing, Cham, pp. 261–302. https://doi.org/10.1007/978-3-319-69099-5_8.
- Ruoff, U., 1995. Neues von der Dendrochronologie: Ein Bericht aus dem 25jährigen Zürcher Labor für Dendrochronologie. Bericht Zürcher Denkmalpflege. Stadt Zürich, pp. 126–130.
- Rybníček, M., Vavřík, H., Hubený, R., 2006. Determination of the number of sapwood annual rings in oak in the region of southern Moravia. J. For. Sci. 52, 141–146. <https://doi.org/10.17221/4496-JFS>.
- Schmid, M.M.E., Dugmore, A.J., Foresta, L., Newton, A.J., Vésteinnsson, O., Wood, R., 2018. How 14C dates on wood charcoal increase precision when dating colonization: the examples of Iceland and Polynesia. Quat. Geochronol. 48, 64–71. <https://doi.org/10.1016/j.quageo.2018.07.015>.
- Schweingruber, F.H., 1990. Mikroskopische Holzanatomie. Formenspektren mitteleuropäischer Stamm- und Zweighölzer zur Bestimmung von rezentem und subfossillem Material. Anatomie microscopique du bois. Microscopic wood anatomy.
- Sohar, K., Vitas, A., Läänelaid, A., 2012. Dendrochronologie Sapwood estimates of pedunculate oak (Quercus robur L.) in eastern Baltic. Dendrochronologia 30, 49–56. <https://doi.org/10.1016/j.dendro.2011.08.001>.
- Szidat, S., Salazar, G.A., Vogel, E., Battaglia, M., Wacker, L., Synal, H.-A., Türlér, A., 2014. 14C Analysis and Sample Preparation at the New Bern Laboratory for the Analysis of Radiocarbon with AMS (LARA). Radiocarbon 56, 561–566. <https://doi.org/10.2458/56.17457>.
- Touchais, G., 2008. Sovjan et l'Âge du bronze en Albanie. In: Guilaine, J. (Ed.), Villes, villages, campagnes de l'Âge du Bronze. Séminaire du Collège de France, Editions Errance, Paris, pp. 108–123.
- Touchais, G., Lera, P., Oberweiler, C., 2005. L'habitat préhistorique lacustre de Sovjan (Albanie). Dix ans de recherches franco-albanaises (1993–2003). In: Della Casa, P., Trachsel, M. (Eds.), WES' 04. Wetlands Economies and Societies. Proceedings of the International Conference, Zurich, 10–13 march 2004. Collectio Archaeologica 3, Chronos Verlag, Zürich, pp. 255–258.
- Ważny, T., Lorentzen, B., Köse, N., Akkemik, Ü., Boltryk, Y., Güner, T., Kyncl, J., Kyncl, T., Nechita, C., Sagaydak, S., Vasileva, J.K., 2014. Bridging the Gaps in Tree-Ring Records: Creating a High-Resolution Dendrochronological Network for Southeastern Europe. Radiocarbon 56, S39–S50. https://doi.org/10.2458/azu_rc.56.18335.
- Westphal, T., Tegel, W., Heussner, K.U., Lera, P., Rittershofer, K.-F., 2010. Erste dendrochronologische Datierungen historischer Hölzer in Albanien. Archäologischer Anzeiger 75–95 <https://doi.org/urn:nbn:de:0048-journals.aa-2010-2-p75-95-v4764.5>.
- Wiersma, C., 2014. Building the Bronze Age. Architectural and Social Change on the Greek Mainland During Early Helladic III, Middle Helladic and Late Helladic I. Archaeopress, Oxford.
- Wigley, T.M.L., Briffa, K.R., Jones, P.D., 1984. On the average value of correlated time series, with applications in Dendroclimatology and hydrometeorology. J. Clim. Appl. Meteorol. 23, 201–213.