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ABSTRACT

In the Mediterranean region, stone and clay have long been the basic materials for buildings, crafts, and manufacturing. Wood plays a secondary, frequently hidden, role but is almost always present. Commonly considered a 'less important' building component, wood has been one of the first materials replaced and frequently discarded during restoration works. In this study, we apply dendrochronological techniques to timbers from Preveli Monastery on the island of Crete in the south Aegean (Greece). Samples were mainly collected from piles of building components discarded during renovations, as well as from standing features like ceiling beams and floorboards. A total of 74 samples from 59 different elements were collected and measured. Four different tree species were identified but by far the majority are fir (*Abies* sp.) and cypress (*Cupressus sempervirens*). Tree-ring correlations indicate that the fir timbers are *Abies alba* from the Alps. Cypress timbers were difficult to date because most samples had multiple false rings. Nevertheless, we were able to date about one-fifth of our cypress samples through comparison with a local cypress chronology. Our findings show that both local and imported timber were used for the Monastery's restorations during the 18th and 19th centuries AD.

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Abies alba; Crete; *Cupressus sempervirens*; dendrochronology; historical wood; timber

1. Introduction

In the Mediterranean region, stone and clay have long been the basic materials for buildings, crafts, and manufacturing. Wood played a secondary role — in roofs, door and window frames, wall supports, ceilings, and floors — but although frequently hidden from view, is almost always present. Because wooden building components have been frequently considered as 'disposable' by owners or architects and builders involved in restorations, they are one of the first materials replaced during renovation and restoration works. Some wooden components have been preserved by architects and archaeologists, especially if they are decorated, but most end their lives as firewood. This is an irreplaceable loss of a historic archive.

Although dendrochronology has been commonly used to date historic buildings (Génova et al. 2018; Sanjurjo-Sánchez 2016), the potential of dendrochronology was not recognized in Greece until 1961 (Schweingruber 1993). It was another ten years before P. I. Kuniholm and C. L. Striker began to collect and analyze tree-ring series from historic buildings, forests and archaeological sites in Greece and the surrounding Aegean region (Kuniholm and Striker 1983, 1987). Since then, publication of dendrochronological studies has been mainly limited to northern Greece and other parts of the Greek mainland (Kuniholm and Striker 1990). One reason for this bias is the scarcity of building timbers suitable for dendrochronological analysis in southern Greece (Kuniholm and Striker 1987; Schweingruber 1993). This is largely due to the use of tree species not suitable for dendrochronology (Haneca, Čufar, and Beeckman 2009) and/or the use of timbers from fast grown trees with an insufficient number of rings. Another contributing factor is the lack of appropriate master chronologies. Only one reliable, continuous tree-ring chronology for the East Mediterranean goes back to AD 1089 (Griggs et al. 2007) and it is based on forest oaks and dendrochronologically dated historical and archaeological material (Ważny et al. 2014a). Forthcoming dendroarchaeological studies should extend this chronology back another 1000 years or more (Kuniholm and Striker 1990; Pearson et al. 2012; Ważny et al. 2014a).

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Dendrochronology in Crete has been mainly done on living trees (Fazan et al. 2017, 2012; Ważny et al. 2014b), although significant efforts have also been made with Mediterranean dwarf shrubs (Zimowski et al. 2014). Recently, Mediterranean cypress (*Cupressus sempervirens*) was used to reconstruct hydrogeomorphic processes in two ungauged gorges on the south coast of Crete using dendrogeomorphic methods (Šilhán et al. 2018). Despite the potential of the Cretan landscape, which is full of medieval and later buildings, abandoned settlements and archaeological sites (Rackham and Moody 1996; Ważny et al. 2014b), this study is — to the best of our knowledge — the first comprehensive attempt to apply dendrochronology to historic buildings in Crete. The aim of the current study is (1) to identify the wood species used for the construction of Preveli Monastery, (2) to date absolutely wooden elements and timbers from different parts of the Monastery through dendrochronological analysis (3) to provide information on the provenance of the wood used for construction and finally (4) to highlight the value of dendrochronology in understanding the buildings and their history, even when specific information about the contexts of the wood samples is missing. Our study should help clarify the history of an important Cretan monastery and further our understanding of the Venetian and Ottoman periods on the island. It will also set an important precedent for using dendrochronology to date historic buildings in Crete and on other Greek islands (Kuniholm and Striker 1990).

Our study focuses on the historic Monastery of Preveli, which is located near the coast in the Municipality of Aghios Vasilios (Rethymno) on the Greek island of Crete (Figure 1). It consists of two building complexes separated by about 2 km: the grander Monastery of St. John the Theologian (Piso Moni Preveli) and the smaller Monastery of Timios Prodromos (Kato Moni Preveli). Preveli Monastery was a major religious, intellectual, artistic and economic center for the region during the 18th and 19th centuries AD. It was also an important center of resistance against the Ottomans, who ruled the island during the period 1669–1898. The Abbot of Preveli is listed among the clergy that declared their support for Cretan independence as early as AD 1819 (Andrianakis 1998, 2014; Detorakis 1994). Most of the buildings at both complexes are typical examples of local, traditional, monastic architecture and were likely constructed during the 18th and 19th centuries (Andrianakis and Giapitsoglou 2012).

1.1. Historical overview of Piso and Kato Moni Preveli

1.1.1. Piso Moni Preveli — the complex of St. John the Theologian

The Monastery of St. John the Theologian was probably established in the mid-17th century, near the end of the period of Venetian rule (1205–1669). It was associated with the Preveli family, relatives of the well-known and powerful

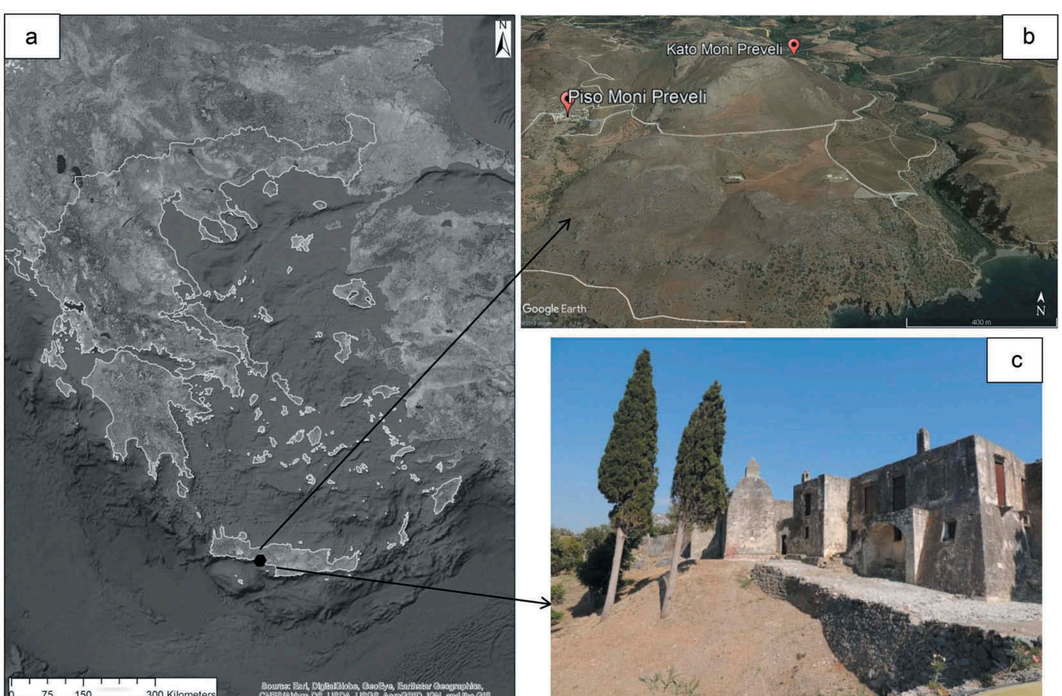

Figure 1. A. location of Preveli Monastery in Crete (Greece). (b) Detailed location of Piso and Kato Preveli (basemap Google Earth) (2018). (c) Kato Moni Preveli, 2013.

Byzantine family — the Kallergi (Andrianakis 1998). The monastery was constructed on steep and rocky ground, which required adapting the traditional plan of an orthodox monastery, which is typically a square/rectangular enclosure with a church in its centre, to the rugged topography. This resulted in the unique arrangement of Piso Moni Preveli's wings and buildings, which are multi-leveled and form a large 'U' around a spacious courtyard that is supported by underground vaults and massive retaining walls (Figure 2a).

At the center of the courtyard stands the monastery's large two-aisled church, which was rebuilt *c.* AD 1837. According to inscriptions and architectural features, most of the monastery's buildings date to the 18th and 19th centuries (Figure 2b, c; Table 1). The *Igoumenion* (Abbot's Quarters), however, which forms the west wing, is a neoclassical construction built in the early-20th century.

Recent restoration work at Piso Moni Preveli was carried out by the Hellenic Archaeological Service from 2011 to 2015 with funding from the National Strategic Reference Framework (NSRF 2007–2014). Twenty-seven different parts of the monastery's northwest wing were targeted for restoration (Figure 3). This

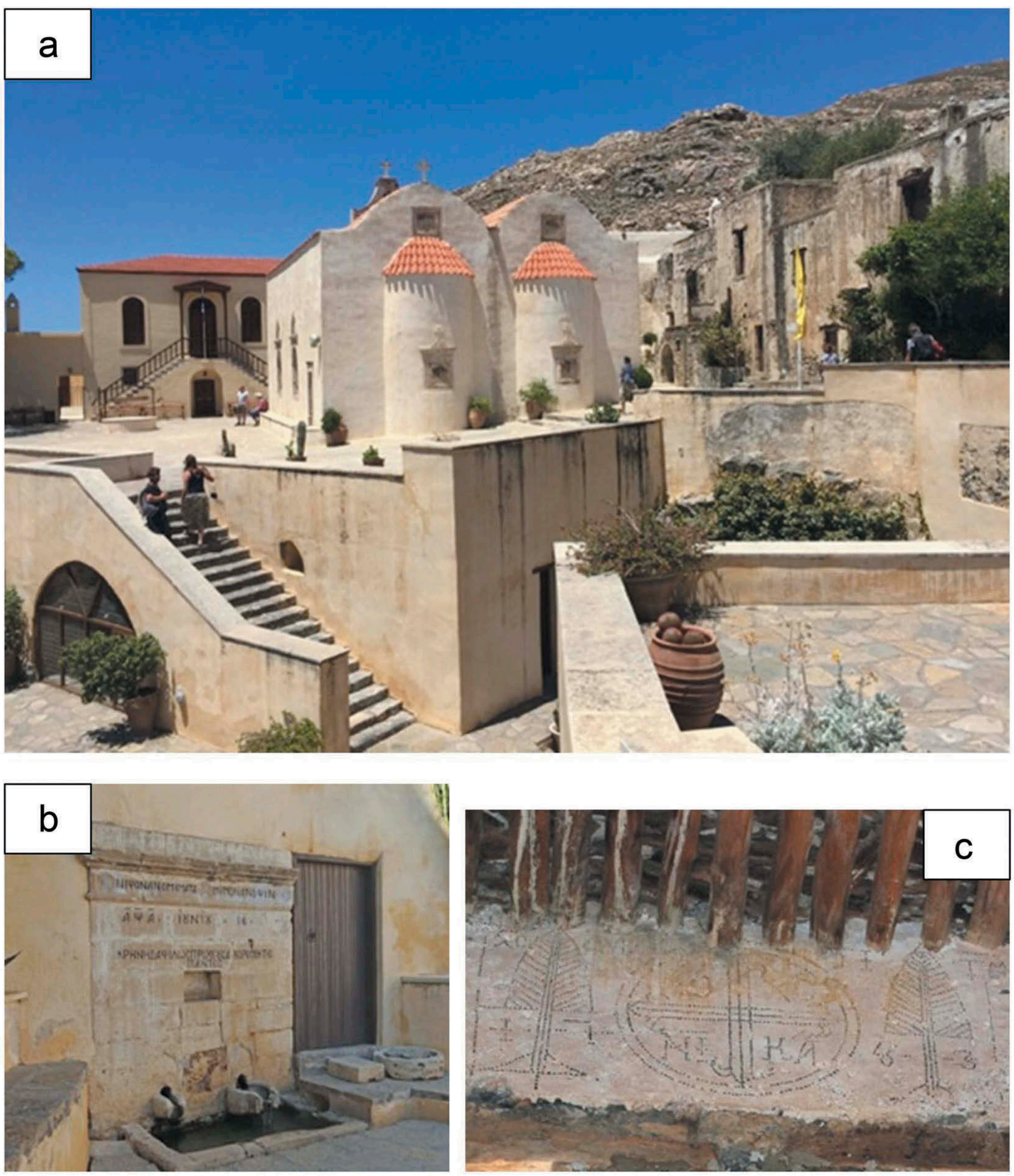

Figure 2. Piso Moni Preveli. (a) View of the courtyard and central church, 2017. Photo W Dossett. (b) Dated inscription above the fountain: 'Wash the trespasses not only the face — 1701 June 15th — From the fountain that pours generously the water, everyone can be satiated', Piso Preveli, 2013. Photo J Moody. (c) Dated inscription on the west wall of the upper floor of room 14 (see Figure 3): AD 1783. It was made by inserting small black pebbles into the plaster. Photo Archive EFARETH, ©EFARETH/YPPOA.

Table 1. Cutting dates for timbers at Piso and Kato Moni Preveli compared to inscription and construction dates at the monastic complexes, and to dates of important Cretan rebellions in west Crete during the 18th and 19th centuries. A question mark after a timber-cutting date indicates that bark may be present but was not securely identified.

Cutting dates	Piso Moni Preveli timber cut	Kato Moni Preveli timber cut	Inscription & known construction dates	Cretan rebellions & reprisals
1700s			1701 (Piso)	
1710s	1719? import fir			
1720–50s				
1760s	1761? local cypress			
1770–80s			1783 (Piso)	1770
1790s		1799? import fir	1795 (Kato)	
1800s			1804 (Kato & Piso)	
1810s		1819? import fir	1816 (Kato)	
1820s	1820 1820 1826 local cypress			1821
1830–40s			1835–1837 (Piso)*	1833 1841
1850s		1853? import fir	1855 (Piso)	1858
1860s	1866? local cypress	1862? 1866 import fir	1863 1866 (Piso) 1865 (Kato)	1866–69
late 19th C				1878 1888 1895 1897

*not an inscription but known from historic sources.

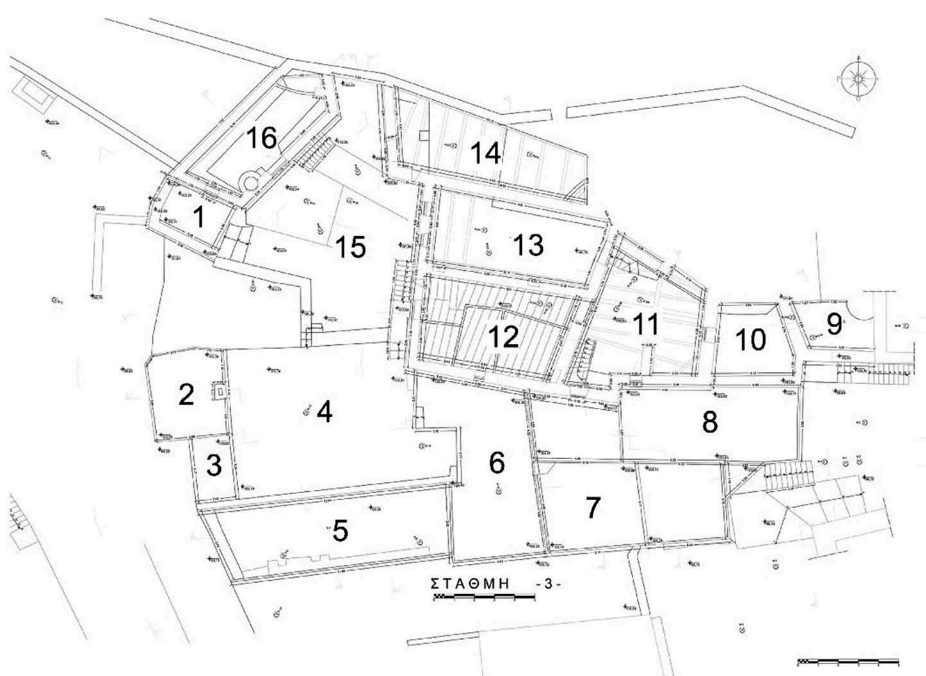

Figure 3. Plan of the upper level of the northwest wing of Piso Moni Preveli, showing the restored areas. 1: sheltered entrance, 2–4: oven complex, 5: internal courtyard, 6: the old kitchen, 7–8: hostels for visitors, 9: open space, 10: room, 11: distillery, 12–14: storerooms, 15: internal courtyard, 16: 'Candle-making building'. Plan courtesy the Archive EFARETH, ©EFARETH/YPPOA.

wing is built on three levels and includes storerooms, ovens, the Candle-making building, and hostels for visitors. It is believed to date to the late 18th and 19th centuries (Uranos and Fiolitaki 2003).

1.1.2. Kato Moni Preveli — the complex of Timios Prodromos

The building complex of Timios Prodromos (Figures 1 and 4) was built as a dependency (*metochion*) of Piso Moni Preveli. The agricultural and workshop activities carried out at Kato Moni Preveli were mainly for the benefit of the main monastery.

Kato Moni Preveli consists of an irregular set of buildings (monk's cell, stables, storerooms, kitchen, etc.) constructed on uneven ground and arranged around a rectangular courtyard with the monastery's main church at its center (Figure 4**, space 1**). The oldest part of the monastery is the double-vaulted building that housed the stable and oil press, located at the northeast end of the complex (Figure 4**, spaces 4, 5**). Although this structure follows the architectural traditions of the late Venetian period, an inscription built into the stable entry indicates it was constructed in AD 1795, during the Ottoman Occupation. The rest of the monastic buildings seem to date to the 19th century.

To the west of the central church is the now ruined, two-story *Igoumenion* (Abbott's Quarters, Figure 4**, space 2**), which included storerooms and monk's cells on the ground floor, and the Abbott's main rooms on the first floor. The building's present form probably dates to the late-19th century.

2. Materials and methods

2.1. Sample collection, tree species identification and laboratory analysis

Visual inspection and sampling took place at Piso and Kato Moni Preveli in two stages. Sampling in Piso Moni Preveli started in 2013, when 52 samples were collected from a huge pile of building components that had been discarded during recent reconstructions (Figure 5a, b). This pile could include (among others) partly burnt elements from the monastery's 'Oven Complex', which was renovated by the Hellenic Archaeological Service between 2011 and 2015. The 'Oven Complex' (Figure 3**, spaces 2–4**) is located in the south part of the northwest wing and has a flat roof. It consists of three rooms connected by two large arches. At the east end of this space is a wooden loft and at the west end is the monastery's large built oven. The rooms are believed to date to the 19th century. In 2017, eight more samples were collected from the discard pile and one wood sample (PREV051) was collected from the 'Candle-making

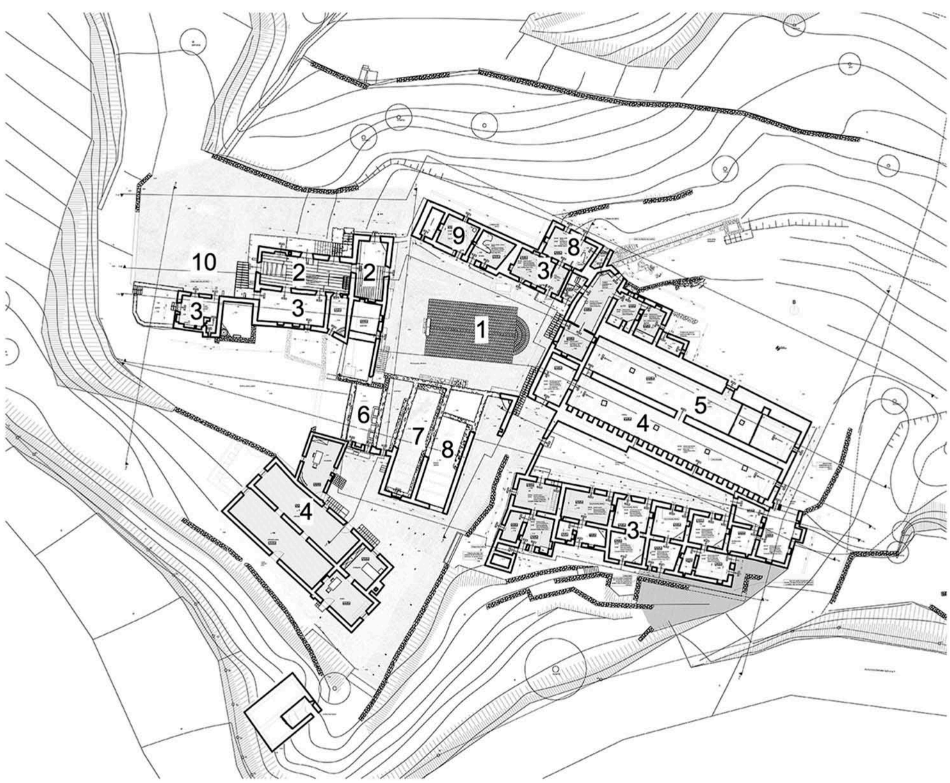

Figure 4. Detail of a plan of Kato Moni Preveli. 1: church, 2: Igoumenion (Abbott's Quarters), 3: cells, 4: stables, 5: oil press, 6: workshops, 7: refectory, 8: storerooms, 9: kitchen, 10: fountain. The plan is courtesy Valti Manolezakis (architect) and Konstandinos Manolezakis (civil engineer).

Building' (Figure 3, **space 16;** Figure 5d), a ground-floor structure in the northernmost part of the monastery. This building has a flat roof supported by three great wooden beams sitting on carved stone beads. Inside, the room includes a built-in, low bench around its west and north walls, a trough on the south wall (possibly involved in the candle-making process), and a stone fireplace at its east end. Architectural features indicate this building dates to the 19th century (Panagopoulos and Fiolitaki 2012).

Sampling in Kato Moni Preveli took place in 2017. Thirteen wood samples were collected from the floorboards of the Abbott's main rooms. The deteriorated condition of the floorboards made them a safety hazard and therefore likely to be replaced soon.

A total of 74 samples from 59 different elements were collected from the two monastic complexes (Figure 5c, d). Most samples were parts of doors, shutters, and floorboards (44. 6%), or from different types of beams (40.5%).

Samples from the discard pile at Piso Moni Preveli were collected by cutting cross-sections with a chainsaw or handsaw; samples from standing elements were collected as cores and taken with a modified electric drill.

In dendrochronology it is important to know the architectural context of a sample (Génova et al. 2018), i.e. where each sample came from in the structure, as this may help in understanding the building's construction history. This information was not available for most of the samples collected from the discard pile and was expected to limit the analysis of our data. We were, nevertheless, interested in learning what these less-than-ideal samples could contribute to our understanding of the monastic complexes.

Figure 5. Sample collection. (a) Searching for suitable dendrochronological samples in the pile of discarded timbers, Piso Preveli, 2013; (b) Cutting a sample with a chainsaw, Piso Preveli, 2013; (c) Hand sawing a floor plank at Piso Preveli, 2017; (d) Coring a beam from the 'candle-making building' at Piso Preveli with a modified electric drill, 2017.

Our sample preparation, measurements and further analyses followed traditional dendrochronological methods (Baillie 1982; Schweingruber 1988). Pre-measurement preparation consisted of sanding and polishing samples with progressively finer-grade abrasive paper until tree-rings and cells were clearly visible under magnification. Micro-slices showing transverse, radial, and tangential sections were then prepared for wood identification and studied under a transmitted-light microscope at magnifications of 40x to 400x. Identifications were based on comparisons with reference material from known tree-types (Akkemik and Yaman 2012; Schoch et al. 2004).

Tree-ring widths were then measured to an accuracy of 1/100 mm using the Time Series Analysis and Presentation (TSAP) software package (Rinn 2011) and LINTAB measuring table (Rinntech, Heidelberg, Germany). Two or more radii were measured on larger samples, especially if they had irregular cross-sections (Génova et al. 2018).

2.2. Statistical analysis

TSAP software (Rinn 2011) was used for cross-dating and other statistical analyses. Samples from the same species were cross-dated against each other and synchronized to build composite 'floating' chronologies. These 'floating' chronologies were then cross-correlated and synchronized with regional and supraregional reference chronologies (Muigg et al. 2018) of the same species or with species that have similar growth responses to environmental conditions. The selection of the right reference chronology is of paramount importance for the dating procedure to be successful (Bernabei and Bontadi 2012; Génova et al. 2018). Cross-dating results were evaluated based on three parameters. The first, Gleichlaeufigkeit (Glk), measures how well the growth of two trees parallel each other in an overlapping set of years. Glk values close to 100 indicate that two time series are identical in terms of the direction of their annual trends (Eckstein and Bauch 1969). The second are the special modified t-values commonly used in dendrochronology: t-value Ballie-Pilcher (TVH) and t-value Hollstein (TVH). T-values have to reach a minimum of 4.0 and data must show a minimum overlap of 30 years for reliable dating (Weigl 2006). T-values increase with increasing similarity between two time series (Baillie and Pilcher 1973) and are sensitive to extreme values, such as marker years (Rinn 2011). The third parameter is the Cross-Dating Index (CDI), which calculates the potential series matches by combining the overall accordance of two series, represented by Glk and t-values (Rinn 2011). The highest value that CDI can reach is 100. The common interval expressed by the number of overlapping years (OVL) was also taken into account. The longer the overlapping period, the more accurate the results of statistical cross-dating. Apart from statistical cross-dating, we also use visual methods to verify the cross-matches and to make final decisions. In addition to TSAP, we used DENDRO for Windows (Tyers 2004) systems and the 'dplR' package in the R statistical software package (R Core Team 2017) to visualize our results.

3. Results

3.1. Tree species identification

Our samples from Piso Moni Preveli came from four different tree species. Fir (*Abies* sp.) and cypress (*Cupressus sempervirens*) comprise the majority (92%) of the collected samples. Three samples were spruce (*Picea abies*) and two were pine (*Pinus* sp.).

The pine samples could be either Scots pine (*Pinus sylvestris*) or Black pine (*P. nigra*), since the two species cannot be distinguished by their wood anatomy (Schoch et al. 2004). Given its geographical distribution (Isajev et al. 2004), which comprises part of Southern Greece; Black pine seems the likelier of the two.

Although fir was used only for doors, shutters and floorboards, cypress timber was used for different types of beams. All the wood used for tie beams (Figure 6a) came from low-altitude cypress trees, recognizable by the presence of many false rings (Figure 6b). A second group of cypresses consisted of higher altitude trees with fewer false rings. They were used mostly for smaller longitudinal beams with a more rectangular shape. A high proportion of these samples were complete sections, starting at the pith and going to the bark, which is very important because it shows the entire history of these trees (Figures 6c and 9a).

All our samples from Kato Moni Preveli were fir that had been used as floor boards.

3.2. Dendrochronological dating and analysis

Thirty-seven (50%) of our 74 samples were dated dendrochronologically.

3.2.1. Fir (*Abies* sp.)

We were able to date 31 (91%) of our fir samples; 20 from Piso and 11 from Kato Moni Preveli. All fir samples from both buildings were aggregated together and cross-dated with each other to create a 275-year

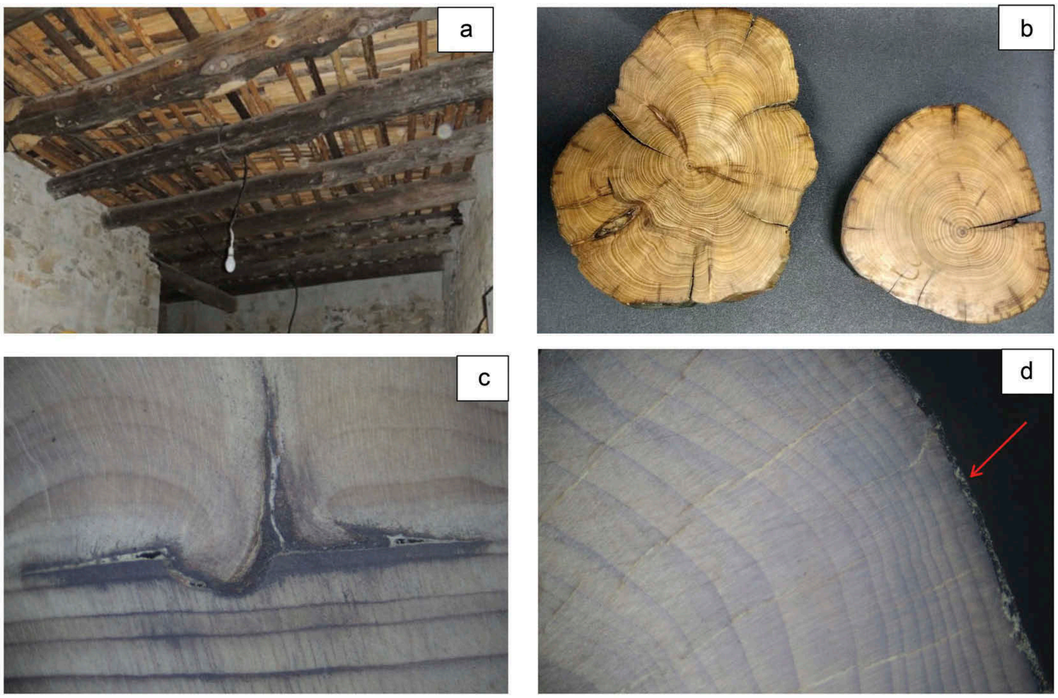

Figure 6. (a) Cypress tie-beams, Piso Preveli, 2013. (b) Sections of low-altitude, fast grown cypress with many false rings (PREV007A and PREV007B). (c) Cypress cross-section showing a possible fire scar (10x) (PREV009A). (d) Cross-section of a higher altitude cypress tree with well-defined rings and bark (red arrow) (10x) (PREV030A).

Table 2. Mean chronologies per species for Piso and Kato Moni Preveli.

Species	Number of series	Average no. of rings per series	Total no. of years	Years AD
Fir	31	95.3	275	1613–1887
Cypress	7	55.6	157	1710–1866

floating chronology (Table 2). This fir chronology (PREV00AS) was also cross-dated with several fir chronologies from different parts of Europe and more than ten of these reference chronologies gave the identical last year for PREV00AS chronology: AD 1887. The three best cross-dating results are presented in Table 3. In Figure 7 the PREV00AS chronology is visually cross-matched with 0526002M, an *Abies alba* chronology from South Germany (Becker and Giertz-Siebenlist 1970), which correlates the best with our developed chronology. Cross-dating results indicate that the fir timbers used at Piso and Kato Moni Preveli are European Silver Fir, probably imported from the Alps. Fir has never grown on Crete. At the end of the PREV00AS chronology there is an abrupt reduction in 'tree-ring' width (Figure 7), which is attributed to the low replication at the most recent part of the chronology (Figure 8).

Most of our fir samples date to the late-19th century (Figure 9a and b). Nevertheless, at both monastic complexes there is a second group of *Abies* samples dating from the beginning to the end of the 18th century that probably represents earlier building phases (Piso; Figure 9a and Kato; Figure 9b). Knowing that only if the bark or a waney edge (the smooth wood surface after removal of bark and phloem) is present, the year in which a tree was cut for construction can be accurately determined

Table 3. Cross-dating results of the fir chronology (PREV00AS) for the year 1887 with three reference chronologies. TVBP/TVH are t-values sensitive to extreme values, such as marker years; CDI = Cross-Dating Index; Glk = Gleichlaeufigkeit, a measure of how well the growth of two trees parallel each other in an overlapping set of years.

Reference Chronology Code	Region	Years AD (no. of years)	TVBP/TVH	CDI	Glk	No. of overlap-ping years
0526002M (Becker and Giertz-Siebenlist 1970)	South Germany	1101–1950 (850)	10.6/9.0	68	70***	275
DUBR00AS (Kuniholm, unpubl.)	Palaca Tudizic, Dubrovnik (Croatia)	1550–1780 (231)	7.2/7.6	49	74***	168
CzAbAl1m (Becker, noaa-tree-2695)	Beskid Mountains, Carpathians	1701–1943 (243)	8.0/6.4	47	72***	187

***: statistical significance of Glk at 99.9%.

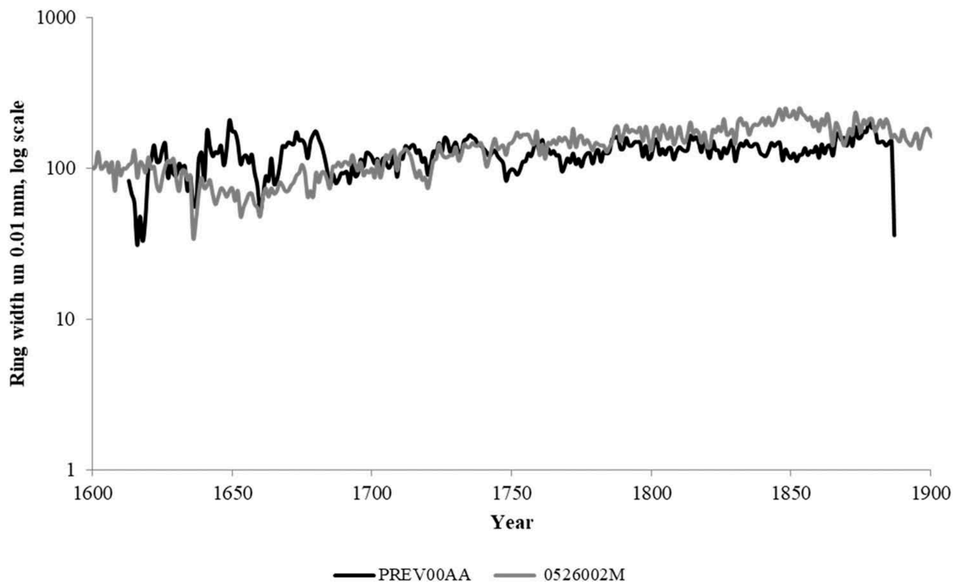

Figure 7. Visual cross-matching of the Preveli fir chronology (PREV00AC, in black) with the Abies alba chronology from South Germany (0526002M, in grey). Only the overlapping period of the two chronologies is presented.

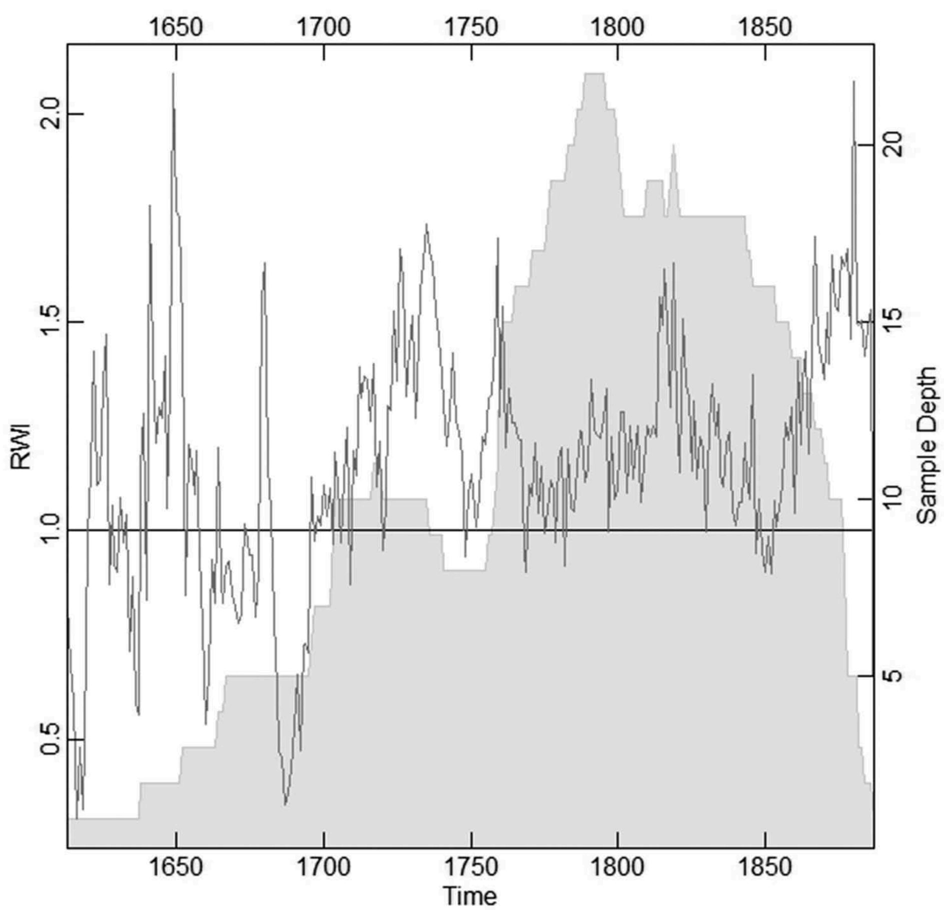

Figure 8. Fir chronology (PREV00AC), showing the sample depth (shaded grey). RWI represents mean ring-width index.

(Druckenbrod et al. 2017), we gave more emphasis to the samples that preserved the bark. One sample from Kato Moni Preveli (PREV308A), which was cut from a floorboard, clearly preserves bark, allowing us to calculate securely the year it was cut: AD 1866 (Figure 9a). Three floorboards (PREV301A, PREV312A and PREV314A)

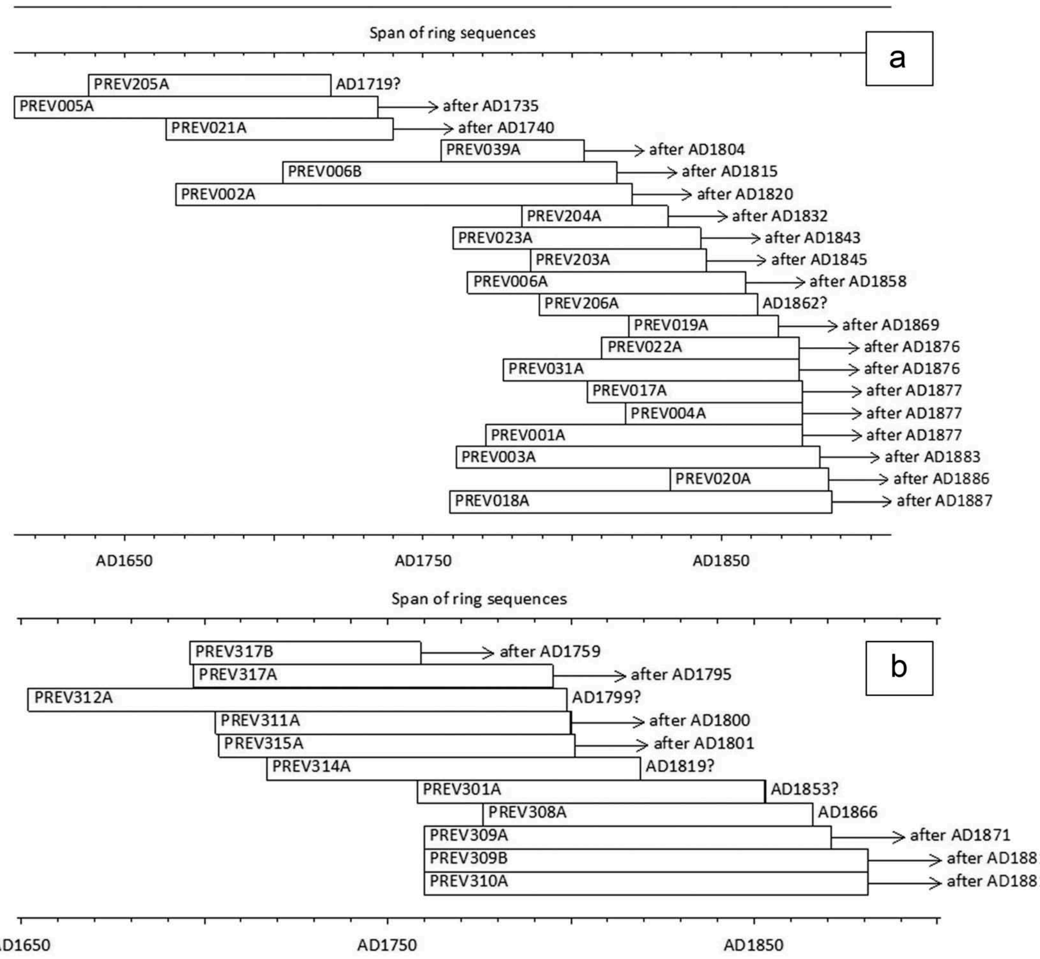

Figure 9. (a) chronological span of dated fir (Abies alba) timbers from Piso Moni Preveli, (b) Chronological span of dated fir (Abies alba) timbers from Kato Moni Preveli.

from the same building might preserve bark but it could not be securely identified; they are indicated by a question mark after their timber-cutting date in Figure 9. The presence of bark was also possible, but again not certain, in two floor or shutter boards (PREV205A and PREV206A) collected from the discard pile at Piso Moni Preveli. Thus, 1866 is the only certain date given by fir samples. This date is probably connected to the Cretan rebellions and reprisals that took place from 1866 to 1869 (Table 1). The oldest possible date given by a sample collected from the discard pile at Piso Moni Preveli is 1719.

3.2.2. Cypress (*Cupressus sempervirens*)

Most of our cypress samples come from low-altitude, fast-grown trees. Only 17% of them could be dated due to the presence of multiple false rings from the pith to their outermost ring (Figure 6b).False rings are common in low-altitude *Cupressus sempervirens* (Schweingruber 1993), and are usually the result of intra-annual density fluctuations, which are formed by anomalous conditions during the growing season (De Micco et al. 2016; Šilhán et al. 2018). Therefore, the balance of evidence suggests that the cypress timbers were sourced from low-altitude sites.

We also observed anatomical features indicative of disturbance. Two samples, one from a low-altitude cypress (PREV028A) and one from a high-altitude tree (PREV037A), had unknown injuries that resulted in internal resin pockets. At least five samples, collected from four different elements (Figure 6c), had internal fire scars, showing that these cypress trees were burnt when they were still alive, but survived and continued to grow. None of these samples could be calendar dated, thus the dates of these disturbance events remain unknown.

Three cypress samples (PREV012A, PREV012B, PREV040A), showed signs of burning on their exterior surface, indicating that they were burnt after being cut and placed in the monastery. All came from the discard pile at Piso Moni Preveli and probably originated from the ‘Oven Complex’ (Figure 3, space 2–4), which had been recently renovated, according to the local

Ephorate of Antiquities. Unfortunately, none of these samples could be dated.

Six samples from different cypress beams were used to create a 115-year cypress chronology (Table 2). All of these samples came from the discard pile at Piso Moni Preveli. Although the replication of the chronology is rather poor (Figure 10b), it correlates strongly with a local cypress chronology developed from living trees in the Lefka Ori of West Crete (LEOR00CS) (Wazny et al. in prep.) (Table 4, Figure 11). The final date of the Preveli cypress chronology (PREV00CS) based on this cross-matching is 1826 (Figures 10a and 11). Interestingly, the same date is given by cross-dating PREV00CS with chronologies for *Juniperus excelsa* (NESELI and SILJ) from Turkey (Touchan et al. 2005), even though the t-values are low (Table 4) because the cross-matching is between two different species. .

The presence, or possible presence, of bark in four of the dated cypress samples (Figure 10a), shows that the trees were probably cut in two separate periods: the 1760s and the 1820s. The three samples with possible dates within the 1760s, were probably from longitudinal beams, and could relate to the construction date of 1783, which is known from inscriptions. This construction phase is possibly related to the Cretan rebellion and reprisal of 1770 (Table 1). The 1820 and 1826 cutting dates most probably represent reconstructions that took place after the famous rebellion of 1821.

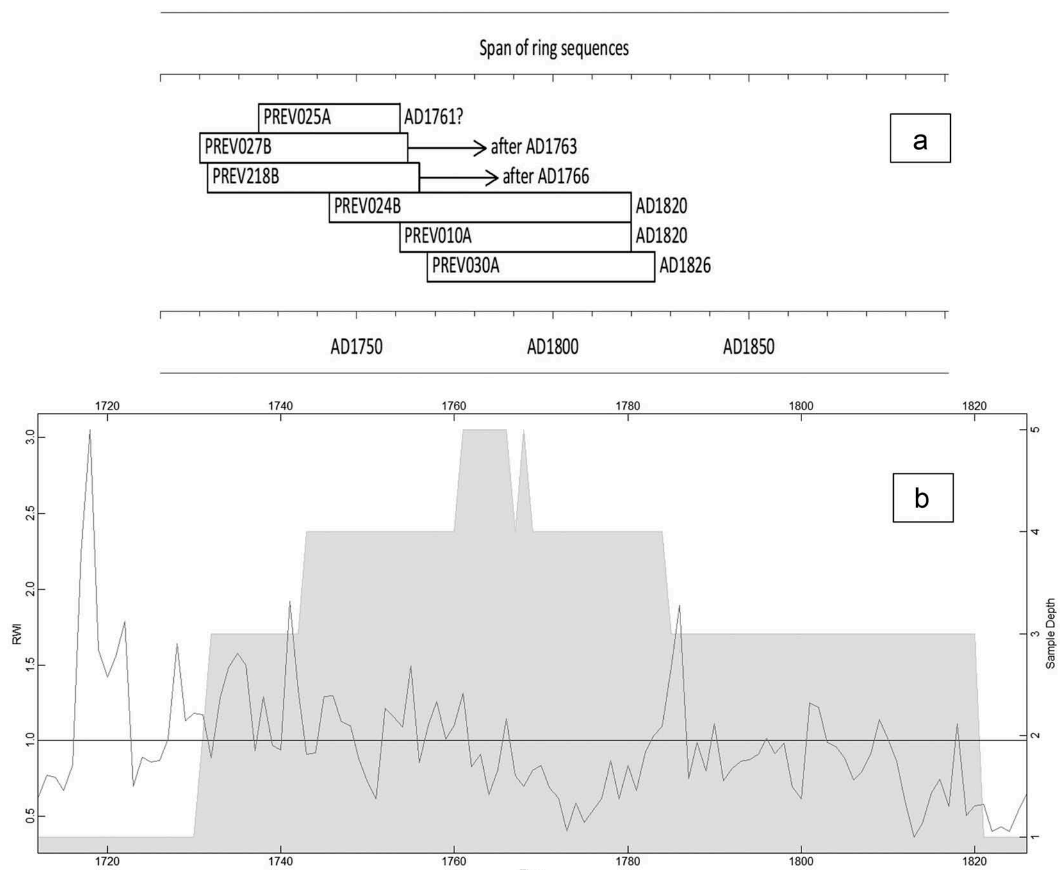

Figure 10. (a) chronological span of dated cypress (Cupressus semprevirens) timbers from Piso Preveli; (b) Cypress chronology (PREV00CS), showing the sample depth (shaded grey). RWI represents mean ring-width index.

Table 4. Cross-dating results of the cypress chronology (PREV00CS) for the year 1866 with three reference chronologies. TVBP/TVH are t-values sensitive to extreme values, such as marker years; CDI = Cross-Dating Index; Glk = Gleichlaeufigkeit, a measure of how well the growth of two trees parallel each other in an overlapping set of years.

Reference Chronology Code	Region	Years AD (no. of years)	TVBP/TVH	CDI	Glk	No. of overlap-ping years
LEOR00CS	Lefka Ori, West Crete (Greece)	1110–2012 (903)	9.7/8.7	66	71***	157
NESELI	Neşeli, Turkey	1235–2001 (767)	4.5/3.9	26	62**	157
SILJ	Silpişli, Turkey	1350–2001 (652)	4.4/4.4	29	65***	157

*: statistical significance of Glk (*** = 99.9%, ** = 99.0%)

Figure 11. Visual cross-matching of the Preveli cypress chronology (PREV00CS, in black) with the Cupressus semprevirens chronology from Lefka Ori in West Crete (LEOR00CS, in grey). Only the overlapping period of the two chronologies is presented.

3.2.3. Spruce (*Picea abies*) and pine (*Pinus* sp.)

All spruce and pine samples were collected from the discard pile at Piso Moni Preveli. Two spruce samples came from a single, shaped beam; the third is from an unknown element. The two pine samples came from a single unknown element. None of these samples could be dated because of the short length of the samples — 46 rings was the longest sequence developed — and also because there were too few samples per species.

4. Discussion

Wood identification and dendrochronology have identified the use of four genera at Piso Moni Preveli (cypress, fir, spruce and pine) and one genera at Kato Moni Preveli (fir). Three of the tree species used at Piso Moni Preveli — fir, Black pine and spruce — have never grown in Crete and were therefore imported, demonstrating that both local and imported timbers were used for construction and repairs at Preveli Monastery. Although all four species are theoretically suitable for dendrochronology, in the current study only cypress and fir samples could be used to calendar date the wood from the monastic complexes.

Bark was unquestionably preserved in four of our samples and possibly in another six, giving a range of timber-cutting dates from the early-18th to the late-19th centuries (Table 1). The earlier cutting dates correspond broadly to inscription dates built into the walls of the monastic complexes (Figure 2b, c; Table 1), while the later cutting dates compare well to dates of important Cretan rebellions against the Ottomans. We know from documentary sources that Preveli was an active center of resistance during the 19th century (Andrianakis 1998; Detorakis 1994). Perhaps the timbers cut between the 1820s and 1860s were used for restorations at the monasteries because of damages suffered in reprisals by the Ottomans. Interestingly, both local and imported timber from the Alps were used, even in times of strife.

The local timber, *C. sempervirens*, was used for a variety of beams and in some cases these beams were nearly whole trees, implying that local timber was not intensively processed before being used. Cypress timbers came from trees growing wild in the Cretan mountains and probably from trees growing in local timber plantations. The latter material was hard to date because it contained numerous false rings and intra-annual density fluctuations, which in many cases were impossible to differentiate from annual tree-rings (Schweingruber 1993; Šilhán et al. 2018). Since antiquity cypress wood has been appreciated for its rot resistance and used for a variety of constructions (Caudullo and de Rigo 2016). Our study confirms its use for building construction in Ottoman Crete.

The presence of internal fire scars in several of our cypress samples demonstrates the fire-tolerance of this tree, which together with its ability to slow fire progression, could be important for forest and land management in the Mediterranean. For example, planting fire-breaks with cypress could help prevent the rapid spread of wildfires (Della Roca et al. 2015).

In contrast to the predominant use of cypress for beams, imported fir was almost exclusively used for doors, shutters and floorboards, implying a more intensive and complicated wood-working process. Cross-dating of our fir chronology with *A. alba* reference chronologies suggests that the fir timber used at Preveli probably came from the Alps, where Silver fir has been a commercially important timber tree from Ancient (Million et al. 2018) to Historic times (Senn and Suter 2003; Shindo and Claude 2019). Silver fir wood is non-resinous, light-coloured, fine-grained and easy to work, making it a good material for carpentry and furniture (Mauri, de Rigo, and Caudullo 2016).

Silver fir timber was especially popular during the 17th, 18th and 19th centuries AD (Senn and Suter 2003; Shindo and Claude 2019), and our results clearly show that it was traded between Europe and Ottoman Crete during the 18th and 19th centuries. We estimate that importing fir from Europe to Crete along trade routes would take just a few weeks longer than importing Greek fir from the mainland of Greece, depending on the wind. Fir planks produced from trees cut in winter could be delivered in summer of the same year to Crete. Unlike the Greek mainland, which won its independence in 1821, Crete remained under Ottoman control until 1898 (Detorakis 1994; Kallivretakis 2012). Many rebellions broke out on the island during the 19th century, especially in the west where Preveli Monastery is located (Table 1). So it was somewhat unexpected that our analyses would demonstrate a thriving timber trade between Europe and Ottoman Crete during this turbulent century.

Our results show that even wood samples that have partly lost their context can be used to reconstruct a building's history.

5. Conclusions

Dendrochronology, the science of tree-rings, has tremendous potential for the study and preservation of East-Mediterranean heritage, but sources of historic timbers and tree-rings are rapidly disappearing. Our study demonstrates that every piece of wood, even discarded elements, can be useful and important in dating historical buildings.

Our work provides independent evidence and confirmation of several construction phases at Kato and Piso Moni Preveli during the 18th and 19th centuries. We have also shown that imported and local timbers were used for these constructions at both monastic complexes. Forty-six percent of the examined timber was Silver fir. Although the presence of imported timbers in historic buildings has been previously documented for Crete (Ważny et al. 2014b), what is surprising is that the timber trade continued to thrive throughout the troubled 19th century, when the island was torn by rebellions and reprisals.

The main local timber used for construction at Preveli was cypress (*Cupressus sempervirens*), probably both wild and plantation grown. Furthermore, our study shows that cypress can be used to study historic buildings dendrochronologically, even though the presence of false rings, and especially density fluctuations, makes measuring and cross-dating difficult.

Most importantly, our analyses of wood samples collected from Preveli Monastery demonstrate that dendrochronological methods can be successfully applied to historic buildings in Crete, and contribute important insights into local and regional history. We have found that the dendrochronological dating of Cretan timbers requires the use of both local tree-ring chronologies and chronologies from much of Europe, and that historical insights require the interdisciplinary collaboration of archaeologists, historians, architects, ecologists and dendrochronologists.

There are hundreds of historic buildings with wooden elements in Crete and Greece awaiting renovation, which might result in the loss of their original timbers, or that are silently disintegrating into dust. These historic wooden archives can only reveal their secrets through dendrochronology. It is time to make dendrochronology a standard part of any architectural study or restoration in Greece. The clock is ticking.

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Disclosure statement

The authors declare no conflicts of interest.

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References

Akkemik, Ü., and B. Yaman. 2012. Wood Anatomy of Eastern Mediterranean Species. Germany: Verlag Kessel Publishing House, pp. 310.

Andrianakis, M. 1998. *Holy stavropegiac and patriarchal Preveli Monastery*. Rethymnon (in Greek).

Andrianakis, M. 2014. The christian monuments of the Aghios Vasilios District. Proceedings of the International Conference "Agios Vasilios District, from Antiquity to Today", Volume B, Rethymnon (in Greek), 13–50.

Andrianakis, M. G., and K. D. Giapitsoglou. 2012. Holy Preveli Monastery. In *Christian monuments of Crete*, 324–25. Synod Committee for Religious Tourism of the Church of Crete - NGO Philoxenia. Heraklion (in Greek).

Baillie, M. G. L. 1982. *Tree-ring dating and archaeology*, 274. London and Canberra: Croom Helm.

Baillie, M. G. L., and J. R. Pilcher. 1973. A simple cross-dating program for tree-ring research. *Tree- Ring Bulletin* 33:7–14.

Becker, B., and V. Giertz-Siebenlist. 1970. Eine über 1100-jährige mitteleuropäische Tannenchronologie. *Flora* 159:310–46. doi:10.1016/S0367-2530(17)31035-6.

Bernabei, M., and J. Bontadi. 2012. Dendrochronological analysis of the timber structure of the church of the nativity in Bethlehem. *Journal of Cultural Heritage* 13 (4 Suppl): e54–e60. doi:10.1016/j.culher.2012.10.002.

Caudullo, G., and D. de Rigo. 2016. *Cupressus sempervirens* in Europe: Distribution, habitat, usage and threats. In *European Atlas of forest tree species*, ed. J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, and A. Mauri, e01afb4+. Luxembourg: Publ. Off. EU.

De Micco, V., F. Campelo, M. De Luis, A. Bräuning, M. Grabner, G. Battipaglia, and P. Cherubini. 2016. Intra-annual density fluctuations in tree rings: How, when, where, and why? *IAWA Journal* 37 (2):232–59. doi:10.1163/22941932-20160132.

Della Roca, G., C. Hernando, J. Madrigal, R. Danti, J. Moya, M. Guijarro, A. Pecchioli, and B. Moya. 2015. Possible land management uses of common cypress to reduce wildfire initiation risk: A laboratory study. *Journal of Environmental Management* 159:68–77. doi:10.1016/j.jenvman.2015.05.020.

Detorakis, T. E. 1994. *The history of Crete*, 292. Crete, Heraklieon.

Druckenbrod, D. L., L. A. Stachowiak, E. A. Schneider, D. M. Graves, and H. D. Grissino-Mayer. 2017. Dendrochronological dating of the graves mill grist mill, Madison County, Virginia, USA. *Dendrochronologia* 43:27–32. doi:10.1016/j.dendro.2016.12.002.

Eckstein, D., and J. Bauch. 1969. Beitrag zur Rationalisierung eines dendrochronologischen Verfahrens und zur Analyse seiner Aussagesicherheit. *Forstwissenschaftliches Centralblatt* 88:230–50. doi:10.1007/BF02741777.

Fazan, L., S. Guillet, C. Corona, G. Kozlowski, and M. Stoffel. 2017. Imprisoned in the cretan mountains: How relict *Zelkova abelicea* (Ulmaceae) trees cope with Mediterranean climate. *Science of the Total Environment* 599–600:797–805. doi:10.1016/j.scitotenv.2017.04.047.

Fazan, L., M. Stoffel, D. J. Frey, S. Pirintsos, and G. Kozlowski. 2012. Small does not mean young: Age estimation of severely browsed trees in anthropogenic Mediterranean landscapes. *Biological Conservation* 153:97–100. doi:10.1016/j.biocon.2012.04.026.

Génova, M., A. Díez-Herrero, M. A. Moreno-Asenjo, and M. A. Rodríguez-Pascua. 2018. Natural disasters written in historical woods: Floods, a thunderbolt fire and an earthquake. *Journal of Cultural Heritage* 32:98–107. doi:10.1016/j.culher.2017.12.011.

Google earth 7.3.2.5491. (July 23, 2018). Accessed February 06, 2019. http://www.earth.google.com.

Griggs, C. B., A. T. DeGaetano, P. I. Kuniholm, and N. W. Newton. 2007. A regional reconstruction of May-June precipitation in the north Aegean from oak tree-rings, AD 1089-1989. *International Journal of Climatology* 27 (8):1075–89. doi:10.1002/joc.1459.

Haneca, K., K. Čufar, and H. Beeckman. 2009. Oaks, tree-rings and wooden cultural heritage: A review of the main characteristics and applications of oak dendrochronology in Europe. *Journal of Archaeological Science* 36 (1):1–11. doi:10.1016/j.jas.2008.07.005.

Isajev, V., B. Fady, H. Semerci, and V. Andonovski. 2004. EUFORGEN technical guidelines for genetic conservation and use for European black pine (*Pinus nigra*). International Plant Genetic Resources Institute, Rome, Italy, 6.

Kallivretakis, L. 2012. A century of revolutions: The Cretan question between European and Near Eastern politics. In *Eleftherios Venizelos: The trials of statesmanship*, P. Kitromilides. ed., Edinburgh: University Press. pp. 11-36. doi:10.3366/edinburgh/9780748624782.001.0001.

Kuniholm, P. I., and C. L. Striker. 1983. Dendrochronological investigations in the Aegean and neighboring regions, 1977–1982. *Journal of Field Archaeology* 10:411–20.

Kuniholm, P. I., and C. L. Striker. 1987. Dendrochronological investigations in the Aegean and neighboring regions, 1983–1986. *Journal of Field Archaeology* 14 (4):385–98.

Kuniholm, P. I., and C. L. Striker. 1990. Dendrochronology and the architectural history of the church of the Holy Apostles in Thessaloniki. *Architectura* 2:1–26.

Mauri, A., D. de Rigo, and G. Caudullo. 2016. *Abies alba* in Europe: Distribution, habitat, usage and threats. In *European Atlas of forest tree species*, ed. J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, and A. Mauri, e01493b+. Luxembourg: Publ. Off. EU.

Million, S., A. Eisenhauer, A. Billamboz, M. Rösch, D. Krausse, and O. Nelle. 2018. Iron age utilization of silver fir (*Abies alba*) wood around the Heuneburg – Local origin or timber import? *Quaternary International* 463 (363–375). doi: 10.1016/j.quaint.2017.05.035.

Muigg, B., W. Tegel, P. Rohmer, U. E. Schmidt, and U. Büntgen. 2018. Dendroarchaeological evidence of early medieval water mill technology. *Journal of Archaeological Science* 93:17–25. doi:10.1016/j.jas.2018.02.009.

Panagopoulos, S., and A. Fiolitaki. 2012. Rehabilitation study of the catholic of the monastery of timios prodromos (lower monastery), Archive EFARETH (in Greek).

Pearson, C. L., C. B. Griggs, P. I. Kuniholm, P. W. Brewer, T. Ważny, and L. Canady. 2012. Dendroarchaeology of the mid-first millennium AD in Constantinople. *Journal of Archaeological Science* 39 (11):3402–14. doi:10.1016/j.jas.2012.05.024.

R Core Team. 2017. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/.

Rackham, O., and J. Moody. 1996. *The making of the cretan landscape*. Manchester: University Press.

Rinn, F. 2011. TSAP - Time series analysis and presentation for dendrochronology and related applications. Version 4.64 for Microsoft Windows - User Reference. Heidelberg, Germany.

Sanjurjo-Sánchez, J. 2016. Dating historical buildings: An update on the possibilities of absolute dating methods. *International Journal of Architectural Heritage* 10 (5):620–35. doi:10.1080/15583058.2015.1055384.

Schoch, W., L. Heller, F. H. Schweingruber, and F. Kienast. 2004. Wood anatomy of central European Species. Online version. www.woodanatomy.ch.

Schweingruber, F. H. 1988. *Tree rings: Basics and application of dendrochronology*. Dordrecht, The Netherlands: D. Reidel Publishing.

Schweingruber, F. H. 1993. *Trees and wood in dendrochronology: Morphological, anatomical, and tree-ring analytical characteristics of trees frequently used in dendrochronology*. Berlin: Springer-Verlag.

Senn, J., and W. Suter. 2003. Ungulate browsing on silver fir (*Abies alba*) in the Swiss Alps: Beliefs in search of supporting data. *Forest Ecology and Management* 181 (1–2):151–-64. doi:10.1016/S0378-1127(03)00129-4.

Shindo, L., and S. Claude. 2019. Buildings and wood trade in aix-en-provence (South of France) during the modern period. *Dendrochronologia* 54:29–36. doi:10.1016/j.dendro.2019.02.003.

Šilhán, K., R. Tichavský, T. Galia, and V. Škarpich. 2018. Hydrogeomorphic activity in ungauged Mediterranean gorges: Specifics of tree ring data-based study. *Catena* 167:90–99. doi:10.1016/j.catena.2018.04.033.

Touchan, R., E. Xoplaki, G. Funkhouser, J. Luterbacher, M. K. Hughes, N. Ü. Akkemik, and J. Stephan. 2005. Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large scale atmospheric circulation. *Climate Dynamics* 25 (1):75–98. doi:10.1007/s00382-005-0016-5.

Tyers, I. 2004. Dendro for windows program guide. 3rd edition, 500b. *ARCUS Rep* 340.

Uranos, K., and A. Fiolitaki. 2003. Restoration study of NW Wing Ag. Ioannis theologos, Archive EFARETH (in Greek).

Ważny, T., B. E. Lorentzen, N. Köse, Ü. Akkemik, Y. Boltryk, T. Güner, J. Kyncl, T. Kyncl, C. Nechita, S. Sagaydak, et al. 2014a. Bridging the gaps in tree-ring records - creating a high-resolution dendrochronological network for Southeastern Europe. *Radiocarbon* 56 (4):39–50. doi:10.2458/azu_rc.56.18335.

Ważny, T., O. Rackham, J. Moody, and B. E. Lorentzen. 2014b. The cretan tree-ring project: Investigating the dendrochronological and dendroclimatological potential of the Mediterranean cypress (*Cupressus sempervirens* L.). In *Eurodendro - Book of abstract*, ed. I. García-González, and M. Souto- Herrero, 28. Lugo, Spain.

Weigl, M. 2006. Annual and intra-annual variations of ring-widths and stable isotopes in sessile oak (*Quercus petraea* (Matt.) Liebl.). PhD diss., Universität für Bodenkultur Wien.

Zimowski, M., H. H. Leuschner, H. Gärtner, and E. Bergmeier. 2014. Age and diversity of Mediterranean dwarf shrublands: A dendrochronological approach along an altitudinal gradient on Crete. *Journal of Vegetation Science* 25 (1):122–34. doi:10.1111/jvs.12067.