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PROGRESS TOWARDS A BYZANTINE-MEDIEVAL HISTORIC BUILDINGS TREE-RING CHRONOLOGY FROM CYPRUS USING DENDROCHRONOLOGY AND RADIOCARBON

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ABSTRACT. The rich architectural heritage of Cyprus from the period of Byzantine and Latin rule includes 10 churches inscribed in the UNESCO World Heritage list. Most of these monuments preserve wooden elements: whether structural, decorative or furnishings. Many preserve wall paintings that are considered among the best examples of Byzantine and Medieval art in the Eastern Mediterranean. The dating of these paintings as well as the church buildings themselves, has been based mainly on style, with occasional dedicatory inscriptions and related historical interpretation. We report early results from a project investigating the wooden cultural heritage of Cyprus and in particular the combined use of dendrochronology with radiocarbon via tree-ring sequenced ^{14}C wiggle-matching to help place initial tree-ring sequences. This includes a floating 264-year *Pinus brutia* chronology from several monuments, which, with a ca. 5-year gap, suggests prospects for >700-years of *P. brutia* chronology for Cyprus, and, with one gap of several decades to fill, ca. 1100 years of *Pinus nigra* chronology for Cyprus. Several currently floating elements from the multi-phase UNESCO-listed Timios Stravros church at Pelendri, including a *terminus post quem* for the celebrated liturgical wooden cross, are approximately dated across the 11th to 16th centuries AD.

KEYWORDS: Byzantine cultural heritage, Cyprus, dendrochronology, wiggle-match dating, Medieval cultural heritage.

INTRODUCTION

The painted churches of Cyprus are monuments of global significance, and a key reference for Byzantine and Medieval art history that occupy prominent positions on the island's landscape (Stylianou and Stylianou 1997; Hein et al. 1998; Gkioles 2003; Given 2007; Papacostas 2013), with ten in the Troodos mountains of central Cyprus collectively inscribed in the UNESCO World Heritage List (http://whc.unesco.org/en/list/351). A number of other structures of equal artistic and historical value are located elsewhere across the island. Altogether, these structures comprise possibly the richest, well-preserved record of Byzantine heritage per-unit-area in the world. However, despite this recognition, we are in fact lacking details concerning crucial aspects of this important patrimony: most especially a refined, secure chronology for the buildings.

This is because our understanding of key inquiries in art history and broader themes related to cultural and religious identity, as reflected in the monuments of Cyprus, has been largely limited to the available sources and the related hypotheses drawn from established methods of stylistic and typological comparisons. Research on issues like the development of Middle Byzantine art and architecture, the transition to Latin rule and its implications for artistic patronage and cultural identity, as well as the influence of Crusader and Western European art

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and architecture, all remain largely defined by unspecified chronologies, a fact that can have serious implications in efforts to interpret and synthesize field observations and comparisons (Ćurćić 2000; Carr 2005; Eliadis 2009; Stewart 2010; Andronikou 2017).

The net result is that we currently lack a secure timeframe for much of this material, and thence the ability to establish an accurate historical context for most of these monuments is significantly limited. In particular, the wooden cultural heritage that especially characterizes these UNESCO churches stands as one of the key but most vulnerable materials. Time, biological activity, and anthropogenic activities, including pollution, fire, and, in the recent past, violence, all seriously threaten its survival. These buildings, which range from small rural chapels to larger churches, most originally being parts of monasteries, are decorated with elaborate wall-painting programs from the Byzantine, Medieval and Ottoman periods. They utilize substantial quantities of wood in their pitched roofs, and as integrated with masonry and other structural components, as well as employed in furnishings, icons, iconostasis screens and other liturgical objects such as crosses (Papageorghiou 1992; Stylianou and Stylianou 1997; Ćurćić 2000; Carr 2005). Overall, the ecclesiastical monuments of the Troodos region provide art and architectural historians with an invaluable resource for the study of Byzantine and more broadly Eastern Mediterranean art and architecture from the 10th century through the 16th and 17th centuries AD (dates given as AD and BC versus CE and BCE in this paper). This long period marks a time of cultural and political transitions for Cyprus as the island came under the control of a series of rulers: Byzantium (965–1191), the (Latin) Lusignan dynasty (1191–1489), Venice (1489–1571) and the Ottoman empire (1571–1878) (Hill 1940–1952; Metcalf 2009). During this period, Cyprus became a key junction of cultural and economic exchanges and interconnections. As a result, the art executed in these, seemingly isolated, chapels and monasteries in the mountains and the rural locales of Cyprus is representative of broader Mediterranean cultural and artistic developments and phenomena (Carr 1995; Carr and Nicolaïdès 2013; Bakirtzis 2013; Bakirtzis 2019). The role of traveling artists and workshops in the Medieval Mediterranean, the influence of Constantinopolitan art, the hybridity of religious art and architecture developed between the traditions of the Byzantine East and Western Europe, the role and identity of Crusader art, and the influence of Islamic culture, are all issues prevalent in the decorative programs and architecture of the painted churches of the Troodos and Cyprus (Carr 1998/1999; Carr 2009; Stewart 2010; Zarras 2012; Eliadis 2017a).

The foundation of many of these religious monuments on the forested slopes and ravines of the Troodos Massif during the 11th–16th centuries AD is connected to an influx of human habitation and settlement in the mountainous region, which had been sparsely inhabited during the Late Antique to Early Medieval Periods (4th–late 10th centuries AD) (Given and Knapp 2003; Given et al. 2013; Bakirtzis 2013; Papacostas 2013). By the 16th century, Venetian census records and archaeological survey data show many villages and heavily settled communities had developed in the Troodos, particularly in the fertile Solea and Marathasa valleys (Given 2007; Grivaud 1998; Papacostas 2013). Churches played a prominent role in the life of Troodos communities, some of which (like Galata and Kakopetria in the Solea Valley) had multiple religious buildings and monuments. These settlements helped transform the Troodos landscape by clearing the forested areas for viticulture and arboriculture, while increased grazing from pastoralist activities further modified the region's vegetation and landscape (Thirgood 1987; Papacostas 2013).

There is an enduring significance for these monuments of Byzantine and Medieval art and architecture. Most of these churches and monasteries are in effect "living sacred spaces", meaning that beyond being protected monuments and major tourist sites they also remain sites of religious activity, thus allowing one to observe and experience connections between the present and Byzantine-Medieval Orthodox traditions (Solomidou-Ieronymidou and Rickerby 2010; Irakleous and Bakirtzis 2020). The Orthodox-Christian majority population of Cyprus, along with a considerable number of Orthodox visitors from Greece, Ukraine, Russia, and other countries, traditionally use and visit these churches for religious purposes as they remain the focal points of well-respected cults. With their artistic and architectural importance acknowledged and appreciated, these sites retain their religious meaning and value. Relics of healing and miracle-making saints are still regularly worshipped, like in the case of Agios Ioannis Lambadistis at Kalopanayiotis village, while icons are celebrated daily for their miraculous powers, as is the case of the icons of the Virgin at the monasteries of Kykkos and Machairas (Carr 2006; Irakleous and Bakirtzis 2020). Local traditions and memory remain strong at the sites of village churches, and their icons, even in the cases of chapels that have long been abandoned (Given et al. 2013).

While the Troodos painted churches, their associated wooden objects, and accompanying village settlements are generally regarded as dating from the 11th through the 16th centuries AD, an exact timeline for their construction, building phases, and artistic histories, remains largely ambiguous. Stylistic criteria and (in some cases) inscriptions provide dating, but these chronologies are not always secure and present limitations as to the phases of building histories, or the actual date of painting programs and cycles. Many churches have subsequently endured multiple renovations, whose dates (and the building components affected) are, at best, known only as approximations (Stylianou and Stylianou 1997; Ćurćić 1999). The same is true for icons, since it was not customary for Byzantine artists to sign or date their work (Papageorghiou 1992). Dates are usually attributed on stylistic grounds with only rare exceptions where inscriptional evidence can be asserted (e.g., Eliades 2017b).

The overall aim of our project is to establish a secure chronology for a number of Byzantine-Medieval monuments of significant architectural and/or art historical relevance and of a range of portable art (e.g., icons). From there we hope to build on these chronologies and to elaborate on key problems and inquiries in the historical study of Byzantine, Medieval and early modern Cyprus and its connections to the wider East Mediterranean concerning the real timeline, agency (and individual identities), interconnections, and narratives of buildings, artworks and artists. Until now, much scholarship in this field has been self-referential and circular in reasoning, based on various assumptions which for the most part lacked solid evidential basis. A key reason for these limitations was the simple lack of data offering independent evidence for the timeline involved. Our project can thus help to reframe key humanities-driven inquiries around this extraordinary material by using the wood in these buildings or upon which art is directly applied in order to enable a step-change in the field and a permanent archived record of this wood and associated cultural heritage.

Our project thus seeks to bridge humanities research with technological and scientific methods and applications in order to address critical gaps in our knowledge of the painted churches of Cyprus—especially chronology—as well as to offer new digital and analytical documentation of these monuments. In particular, we are applying the techniques of dendrochronology allied with radiocarbon dating to begin to create chronologies and timelines for the wooden heritage of Cyprus. This paper presents some early results. The locations of the monuments mentioned in this paper are shown on the map in Figure 1a and the church of Timios Stavros at Pelendri (TIMT) is shown as an example in Figure 1b.

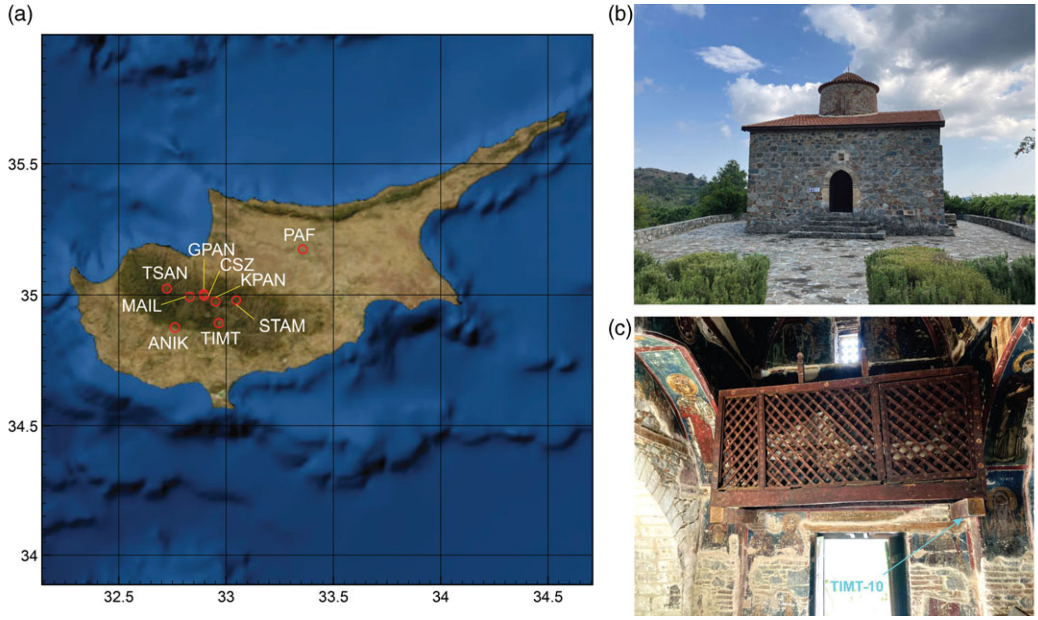

Figure 1 (a) Map of Cyprus indicating the locations of the sites/places mentioned in the text. ANIK: Agios Nikolaos, Agios Nikolaos village; CSZ: Agios Sozomenos, Galata; GPAN: Panagia Podithou, Galata; KPAN: Panagia Chrysokourdaliatissa, Kourdali; MAIL: Monastery of Agios Ioannis Lambadistis; PAF: Pafos Gate, Nicosia; STAM: Stavros tou Agiasmati; TIMT: Timios Stavros church, Pelendri; TSAN: Agios Nikolaos, Tsakistra. Map created in OxCal 4.4.4 using USGS imagery. (b) View of the Timios Stavros church at Pelendri, north wall/entrance. (c) Balcony on its E-W support beams into/through the west wall of the Timios Stavros church, with TIMT-10 indicated. Photos: Sturt Manning.

METHODS

We have investigated and recorded structural timbers and wooden materials (including furniture and decorative elements) from a number of buildings and cultural heritage collections and identified wood that is suitable for dendrochronology (i.e., samples with >50–100 visible annual rings and from species suitable for dendrochronology that produce regular visible annual tree-ring series). For this project this means the following genera are our focus: pines (*Pinus brutia* and *Pinus nigra*), deciduous oaks (*Quercus*), juniper (*Juniperus*), and cedar (*Cedrus*). In order to minimize destructive interventions and removal of material, we kept physical sampling to a minimum and as necessary to obtain fundamental data. Physical samples comprised cores (ca. 8mm diameter using a RinnTech drill, with drill holes subsequently filled with a wooden dowel) or sections cut off the ends of available timbers. Small ~1 cm^3 sections were collected from each sample for wood identification. Transverse, radial, and tangential sections of each was examined for wood species identification, using an Olympus Bx51 microscope and compared with reference collection materials, standard wood anatomical references (e.g., Akkemik and Yaman 2012; Crivellaro and Schweingruber 2013, and the InsideWood online database: Wheeler 2011). In as many cases as possible, we sanded and polished each timber's transverse surface (or part thereof) for digital scanning and used the resultant images for the tree-ring analysis to avoid damaging the wood via coring or cutting sections.

When sampling, we aimed to identify and examine timbers associated with primary construction and any other phases of activity in the structures. We sought to identify, where possible and available, timbers with preserved outer or outermost tree rings (that is: those preserving sapwood, waney edge, and/or bark), since these timbers can provide tree-ring data as close as possible to the cutting dates and (therefore) human use of the timbers (whether for structures or other material culture). In cases in which the outermost ring(s) are not preserved, only a *terminus post quem* (TPQ) for the timber's cutting is possible. In most cases in this region in pre-modern times it is likely timber for general construction purposes was employed either more or less immediately after felling or after a season of drying out ("seasoning"), and thus was used within a 0–1 year time range. Felling was typically late in the year (fall to winter, as recommended by Vitruvius: *De architectura* 2.9.1) after annual growth has finished and where the felled tree is then left to dry before use the following spring-summer (see: e.g., *De re aedificatoria* by Leon Battisa Alberti [Rykwert et al. 1988:40–41]; Salzman 1952). The alternative strategy involved "ringing" a tree trunk, with the tree dying and then drying out still standing, before subsequent cutting. The use of "green" (recently cut) timber as the norm in pre-modern times for general construction (versus fine craft objects, or, some argue, for key ship types, like triremes or elements where lightness and straightness were important [Borza 1987:38–39]) makes common sense as the wood is much easier to cut and work (Kuniholm and Striker 1987:387–388). For the wood samples reported/used in this paper, none had evident outermost rings preserved (no bark or bark edge); hence, they set TPQ dates.

Scanned images were examined using the CooRecorder and CDendro software (Larsson 2011); the physical samples were prepared (sanded/polished), examined, and their tree-ring widths measured under a Motic K-400P binocular microscope using a Velmex measurement platform. All samples and data (and information on specific samples and rings) were recorded via the Tellervo dendrochronological analysis package (Brewer et al. 2010). The tree-ring measurement series obtained were then investigated and, where possible, same species sets were crossdated and combined into site, and then wider regional chronologies, following standard dendrochronological methods (Baillie 1982; Schweingruber 1988; Speer 2010). Samples are measured in relative years (RY) starting at RY1001 (the expectation is that crossdated and subsequent realignments of RY dates between samples and then between sites will remain positive integers, e.g., RY943-RY1206 for the eventual interim Byzantine Cyprus Pine (*Pinus brutia*) Master (BCPM) chronology reported in this paper). Crossdating and chronology verification employed the Corina (Harris 2007) and COFECHA (Holmes 1983) software packages. Where samples formed series or chronologies, but these do not yet offer crossdates with chronologies from forest or other buildings with secure known calendar ages, we then employed ^{14}C-wiggle-match dating (e.g. Bronk Ramsey et al. 2001; Galimberti et al. 2004) using the IntCal20 ^{14}C calibration curve (Reimer et al. 2020, with curve resolution set at 1 calendar year) in order to achieve approximate near-absolute placements (listed as *Cal AD* in the text below). The wiggle-matching is both to aid (i.e., constrain) subsequent dendrochronological efforts to securely crossdate the various series, and to inform on-going historical-archaeological analyses. In this paper we focus on several cases where tree-ring sequenced ^{14}C wiggle-matching are key to the on-going research. The ^{14}C dates employed are listed in Table 1. The OxCal runfiles are listed in the Online Supplementary Material.

Radiocarbon dates employed here were made on specific tree-rings from samples dating and comprising of the developed dendrochronological series, whose tree-rings were dissected with a steel blade under a binocular microscope. Where ^{14}C dates were obtained on identical (crossdated) tree-ring relative years (RY) in the dendrochronological time-series, these were combined into a weighted average and used if the dates were consistent with this assumption following the method of Ward and Wilson (1978) (see Table 1). The AMS radiocarbon dates

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Table 1 Samples and the radiocarbon dates employed in this study. The quoted GrM (Groningen) $\delta^{13}C$ values were determined independently via IRMS; the quoted VERA (Vienna) $\delta^{13}C$ values were as determined with the AMS system. Dates on crossdated samples placed as belonging to the identical relative years (RY) were combined into a weighted average (and tested whether consistent with this assumption) following Ward and Wilson (1978) using the R_Combine function in OxCal. Each tree-ring sample was originally measured in terms of relative years (RY) starting from RY1001. Subsequent crossdating can then lead to revised RY placement versus other samples.

Laboratory ID	Wood ID	Sample	$\delta^{13}C$‰	^{14}C age (BP)	SD
GrM-16750	*P. brutia*	PAF-6 RY1004-1008	–23.10±0.20	620	20
GrM-16752	*P. brutia*	KPAN-3 RY1004-1008	–22.18±0.20	588	19
Weighted average χ^2 test df=1 T=1.3 < 5% critical value of 3.8				**603**	**14**
GrM-16751	*P. brutia*	PAF-6 RY1076-1080	–22.14±0.20	515	19
GrM-16828	*P. brutia*	KPAN-3 RY1076-1080	–21.75±0.05	535	20
Weighted average χ^2 test df=1 T=0.5 < 5% critical value of 3.8				**525**	**14**
GrM-19053	*P. brutia*	KPAN-3 RY1096-1100	–21.60±0.15	448	19
GrM-19054	*P. brutia*	KPAN-3 RY1146-1150	–21.52±0.15	367	19
GrM-26294	*P. nigra*	GPAN-13 RY1388-1392	–21.41±0.15	618	19
GrM-26299	*P. nigra*	GPAN-9 RY1388-1392	–21.73±0.15	605	20
Weighted average χ^2 test df=1 T=0.2 < 5% critical value of 3.8				**612**	**14**
GrM-26300	*P. nigra*	GPAN-9 RY1445-1450	–21.60±0.15	441	18
GrM-26362	*P. nigra*	GPAN-13 RY1271-1274	–21.85±0.15	750	20
GrM-27164	*P. nigra*	TIMT-10A RY1015-1017	–19.96±0.15	1188	24
GrM–27165	*P. nigra*	TIMT-10A RY1041-1043	–20.41±0.15	1135	18

Table 1 (*Continued*)

Laboratory ID	Wood ID	Sample	$\delta^{13}C$‰	^{14}C age (BP)	SD
GrM-27166	*P. nigra*	TIMT-10A RY1128-1130	–21.17±0.15	1087	18
VERA-6354	*Cupressus sempervirens*	TIMT-1 RY1001-1005	–20.9±0.9	1166	35
VERA-6354	*Cupressus sempervirens*	TIMT-1 RY1052-1056	–20.6±1.0	1156	36
VERA-6355	*Cupressus sempervirens*	TIMT-1 RY1145-1149	–20.5±0.9	1095	38
VERA-6356	*P. brutia*	TIMT-2 RY1006-1010	–20.8±0.9	817	35
VERA-6357	*P. brutia*	TIMT-2 RY1041-1045	–20.6±0.8	799	38
VERA-6358	*P. brutia*	TIMT-2 RY1064-1068	–20.7±0.8	739	34
VERA-6359	*P. brutia*	TIMT-5 RY1001-1005	–20.9±0.7	549	35
VERA-6360	*P. brutia*	TIMT-5 RY1051-1055	–19.4±0.8	394	34
VERA-6361	*P. brutia*	TIMT-5 RY1100-1104	–18.8±0.8	321	38

were run either at the Vienna Environmental Research Accelerator (VERA) or the Centre for Isotope Research, Groningen (GrM). For sample preparation and analysis methods, see respectively Wild et al. (2008) and Dee et al. (2020). We used small groups (typically three or five consecutive years) of specific tree-rings for dating from our chronologies, versus single tree-rings, for two reasons: (i) the tree-ring samples involved typically have narrow rings and thus groups of tree-rings ensure accurate ring dissection and sufficient mass, especially when using small core samples, and (ii) we believe that an average ^{14}C value from a few consecutive tree-rings (thus damping inter-annual variations) in fact offers equal or better "wiggle-matching" for sequenced time-series against IntCal20 which, although using underlying annual data in this time period, is in fact itself a similar smoothed time-series. The wiggle-matched date is treated as the mid-point of the group of dated tree-rings/years (e.g., ring/year 3 of a group of rings/years 1–5).

RESULTS

(a) Towards a Byzantine Cyprus Pine (*Pinus brutia*) Master (BCPM) chronology

The ubiquitous pine of Cyprus found at lower to mid-elevations and used as the principle local wood resource for the majority of traditional building activities on the island is *Pinus brutia* (Calabrian pine) (Mauri et al. 2016). Previous work, along with on-going work by the Cornell Tree Ring Laboratory, has established a number of *P. brutia* chronologies from forest trees for several areas of Cyprus (e.g., Kienast et al. 1987; Touchan et al. 2014a; 2014b; Griggs et al. 2014; Coulthard et al. 2017). These known-age resources at present reach back to the mid-16th century AD. Work to be reported in more detail elsewhere by this project has constructed (so far) a tentative earlier 264-year *P. brutia* chronology comprising 26 timbers from six different churches and monuments 1. Agios Sozomenos, Galata (CSZ), 2. Stavros tou Agiasmati (STAM), 3. Pafos Gate, Nicosia (PAF), 4. Panagia Chrysokourdaliotissa, Kourdali (KPAN), 5. Agios Nikolas, Tsakistra (TSAN), and 6. Agios Nikolaos, Agios Nikolaos village (ANIK). This chronology does not offer any crossdate with the available known-age *P. brutia* forest-historic chronologies (which as noted only run back to the mid-16th century AD), and so, on the basis of the structures involved and their estimated dates (e.g., Stylianou and Stylianou 1997; Papacostas 2013), we assume this chronology is likely to be earlier. Therefore, as a first step towards towards chronological resolution, we employed a tree-ring sequenced ^{14}C-wiggle-match, using samples from the BCPM from Pafos Gate (PAF) and Panagia Chrysokourdaliotissa, Kourdali (KPAN), to place this 264-year chronology in initial near-absolute terms ca. 1285–1548 *Cal AD* -4/+5 years at 68.3% highest posterior density, hpd, probability: Figure 2.

(b) Church of the Holy Cross (Timios Stavros), Pelendri

This important UNESCO-listed church complex (Stylianou and Stylianou 1997: 223-232, 507-510; Zarras 2010; Konstantinidi and Zarras 2015; Zarras 2022; Christoforaki 1996) (Figure 1b) was originally built in the 12th century as a single chapel which was later rebuilt and expanded in the 13th, the 14th and 16th centuries AD, with the result being the present three-aisle topped with a dome church complex. A preserved inscription underneath the 14th-century fresco from the church's apse dates the earliest painting program back to the 1170s AD. In addition, the present church provides ample wooden architectural elements and furnishings from different parts of the building complex, thus offering promising possibilities for dendrochronological study. For example, one of the wooden planks from the floor of the narrow balcony set against the west wall of the church's central aisle is *P. brutia* (sample TIMT-2). Some of the outer rings are definitely missing and the ring sequence is relatively short at 70 preserved rings only. This

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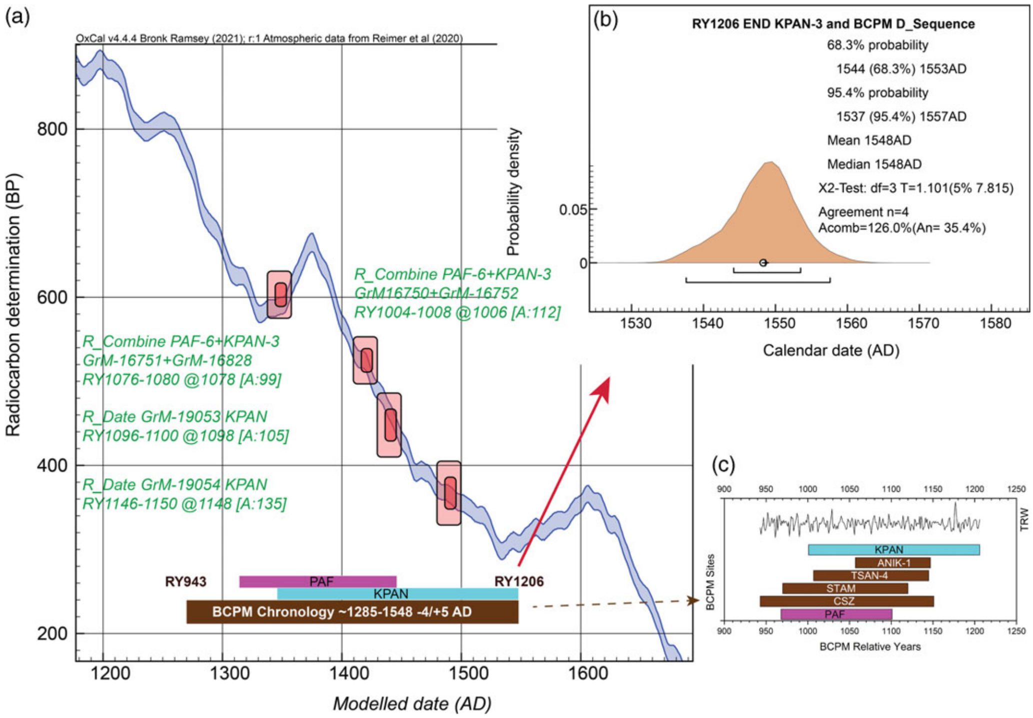

Figure 2 Tree-ring sequenced ^{14}C wiggle-match of the *P. brutia* Byzantine Cyprus Pine Master (BCPM). (a) Radiocarbon date ranges (68.3% highest posterior density, hpd, and 95.4% hpd) from the sets of 5 tree-rings from the crossdated Pafos Gate (PAF) and Panagia Chrysokourdaliotissa, Kourdali (KPAN) series, both parts of the crossdated BCPM chronology running from Relative Year (RY) 943–1206, wiggle-match fitted against the IntCal20 ^{14}C calibration curve (data plotted at midpoint of each 5-ring/year block). (Note: an alternative presentation of this wiggle-match is shown in the Online Supplementary Material.) (b) The calculated calendar date probability, 68.3% and 95.4% hpd ranges, and median and mean values for the last extant tree-ring, RY1206, of the current BCPM chronology. (c) The constituent elements of the BCPM chronology shown as bars representing the years included as part of each site or element with the combined tree-ring width (TRW) chronology for the BCPM chronology shown above (relative, indexed, scale).

plank crossdates with three other planks from the same balcony (TIMT-3, 17 and 70) to form an overall 138-year *P. brutia* chronology running from Relative Years (RY) 976-1113. This chronology does not offer a convincing crossdate against other available *P. brutia* chronologies. Hence, we carried out a small-scale tree-ring sequenced ^{14}C wiggle-match on TIMT-2 to gain an appropriate approximate date range for both this element and the chronology from the set of four balcony planks (Figure 3a, b). This places the TPQ for use of the TIMT-2+3+17+70 timbers most likely ca. 1317–1335 *Cal AD* (68.3% hpd), pointing to an earlier to mid-14th century AD use/construction for the balcony fittings like its floor (see below on the earlier likely date of the primary balcony structure itself).

A small piece of wood (TIMT-5) which was added as a horizontal element to the back of the iconostasis is also *P. brutia*, but the ring sequence does not offer a convincing crossdate with the *P. brutia* chronologies available. Therefore, we undertook a tree-ring sequenced wiggle-match that places the last extant tree-ring (thus a TPQ for use of TIMT-5) most likely ca. 1531–1551 *Cal AD* (68.3% hpd range): Figure 3c, d. This would suggest that it was part of the likely 16th century AD building phase (south aisle) and renovation works at the church complex.

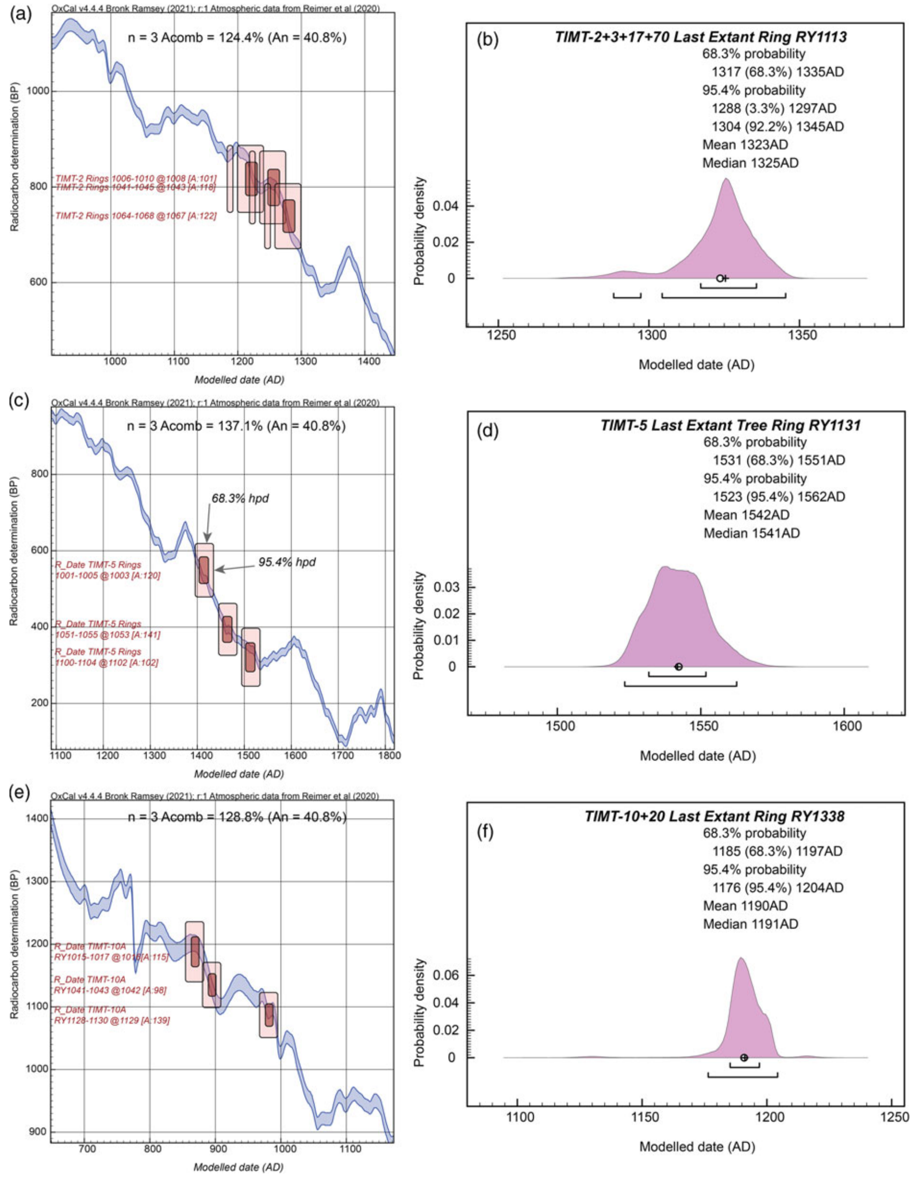

Figure 3 ^{14}C wiggle-matches on elements of the Timios Stavros church, Pelendri (TIMT). (a) Dendro-sequenced ^{14}C wiggle-match placement of the series of three ^{14}C dates on TIMT-2 showing the modeled 68.3% hpd calendar age ranges (smaller, solid, darker histograms) and the 95.4% hpd calendar age ranges (larger, light-shaded, histograms) for the three ^{14}C ages (Y axis ranges) given the tree-ring sequence constraints versus the IntCal20 ^{14}C calibration curve. (b) The modeled calendar probability for the last extant tree-ring, RY1113, from the chronology comprising TIMT-2+3+17+70. Since no bark or outermost tree-ring is present, this date is a TPQ for the use date. (c) Dendro-sequenced ^{14}C wiggle-match placement of the series of three ^{14}C dates on TIMT-5. (d) The modeled calendar probability for the last extant tree-ring, RY1131, from TIMT-5. Since no bark or outermost tree-ring is present, this date is a TPQ for the use date. (e) Dendro-sequenced ^{14}C wiggle-match placement of the series of three ^{14}C dates on TIMT-10. (f) The modeled calendar probability for the last extant tree-ring, RY1338, from TIMT-10. Since no bark or outermost tree-ring is present, this date is a TPQ for the use date—although, as a mature sample, and with most of part of the transverse section used, it appears likely the last extant tree-ring is not too far from the original exterior. (Note: alternative presentations of the wiggle-matches for 3a, 3c and 3e are shown in the Online Supplementary Material.)

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Several other of the wooden elements (both architectural and iconostasis elements) investigated at the Timios Stavros church are not *P. brutia*, but are instead *Pinus nigra* (Austrian pine), which grows on Cyprus at higher elevations in the Troodos mountains. This includes the two iconostasis doors (TIMT-75 and 76). TIMT-76 (the north door) yields a 173-year chronology with a plausible crossdate against the Troodos *P. nigra* chronology developed by Touchan et al. (2014a, b) from ca. 1282–1454 AD which, since the last extant tree-ring is only a TPQ for the making and carving of these doors, suggests that they date to the later 15th century AD or even earlier/mid-16th century AD (since mature *P. nigra* tree-rings are often narrow and an even relatively modest loss of outer wood portions could easily mean 50+ to even 100 years are absent). Therefore, these doors may probably be associated with the estimated 16th century AD works at the church.

A most interesting feature of the Timios Stavros church is the low balcony projecting from the western wall of the central aisle of the complex (Figure 1c). The primary support beams for this balcony project through the western wall. Samples TIMT-10 and 20 represent one of these *P. nigra* timbers and crossdate with the other supporting timber (samples TIMT-11 and 13); altogether they comprise a 338-year chronology with the last extant tree-ring (no bark) setting a TPQ for use of these timbers. The chronology offers no likely association with the known-age Troodos forest *P. nigra* chronology. This suggests that perhaps this structure dates before the mid-14th century AD (and the earliest part of the current known-age *P. nigra* forest chronology from Cyprus). Thus, we again undertook a ^{14}C-wiggle-match on TIMT-10 to secure an approximate absolute placement of what we anticipated to be earlier balcony timber elements. This wiggle-match places the last extant tree-ring, RY1338, ca. 1185–1197 *Cal AD* at 68.3% hpd (Figure 3e, f), which we might approximate as 1191±6 *Cal AD*, and so the overall 338-year *P. nigra* chronology lies ca. 854–1191±6 *Cal AD*. Hence a precise absolute (calendar) date for this chronology should be possible in future through identification of the 993 AD Miyake event (as for example carried out in Kuitems et al. 2022). The construction of the balcony, which appears to be integral to the central aisle of the church and its western wall, was after the ca. 1191±6 *Cal AD* TPQ date range, and hence a date in the late/end 12th through the middle or later 13th century AD appears plausible. This is a valuable chronology which will help us to date the remodeling of the church following its original building phase. An inscription discovered in the sanctuary indicates that the early wall-paintings of Timios Stavros likely date to the ca. 1170s AD (Christoforaki 1996: 215 and n.1; Stylianou and Stylianou 1997:507; Zarras 2010:15–17). The date depends on the reading of 6686 years and assuming the standard Byzantine dating of either 21 March 5508 BC or later 1 September 5509 BC for the creation/Adam as the reference point (see Ware 1992—while the standard convention, there were different calculations and source problems, e.g. Greenaway 1999: 131; for a review of bibliography on all aspects of Medieval time-keeping to 2010, see Porter 2010). This inscription hence points to a later 12th century AD origin for the church. This would place the extant western wall and balcony of the church sometime from (earliest) within a few decades after this point in time to (latest) perhaps several decades later and should help date the second building phase of the long history of the complex.

One further wooden liturgical element at the church is of particular note: the devotional/sacred Holy Cross associated with the name and origin of the church (Hadjichristodoulou 2005). The base of the Holy Cross was cleaned and examined: it is made from *Cupressus sempervirens* (cypress); three very small tree-ring samples were taken for a tree-ring sequenced ^{14}C-wiggle-match to establish an approximate absolute (calendar) age for this object: Figure 4a–b. The last extant tree-ring (RY1163) places its minimum age (a *terminus post quem*, TPQ, since no outer/

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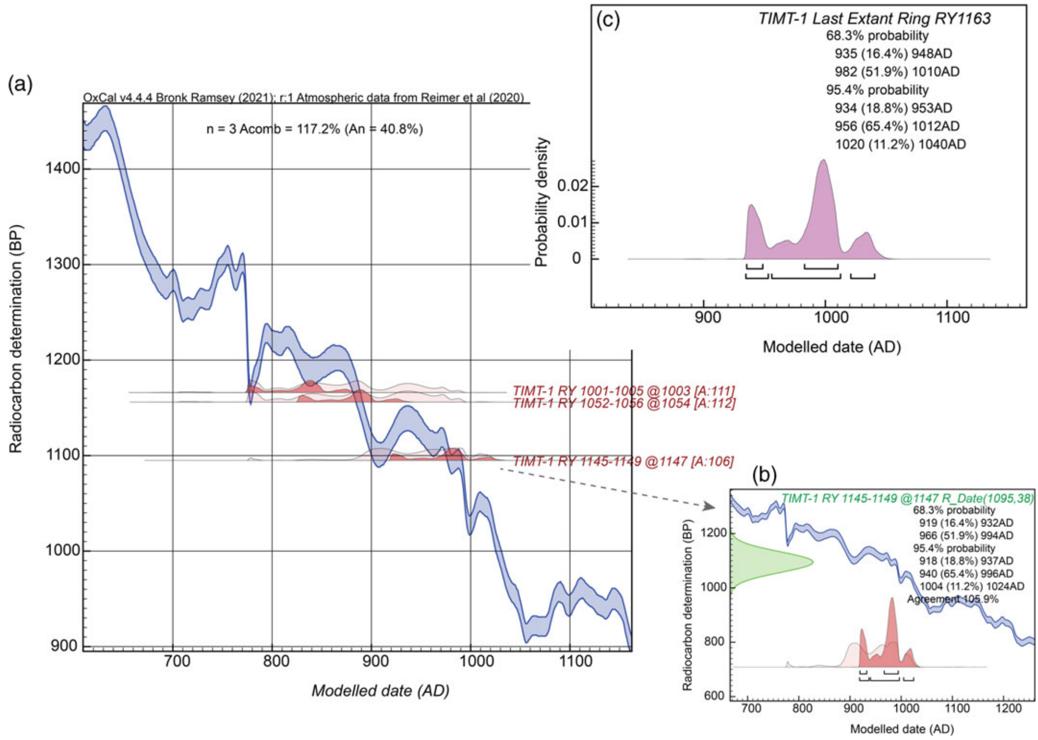

Figure 4 Dendro-sequenced ^{14}C wiggle-match placement of the series of three ^{14}C dates on TIMT-1, the Holy Cross, from Timios Stavros church, Pelendri. (a) The modeled (solid, darker histograms) and non-modeled (light-shaded histograms) overall probability for the three ^{14}C dates given the tree-ring sequencing versus the IntCal20 ^{14}C calibration curve. Note there are multiple plausible possible ranges. (Note: an alternative presentation of this wiggle-match is shown in the Online Supplementary Material.) (b) Detail of the fit probabilities for the RY1145-1149 sample in (a) showing the two possible ranges at 68.3% hpd and three possible ranges at 95.4% hpd. The central range (of the three possible ranges at 95.4% hpd) is clearly the most likely. (c) The modeled calendar probability for the last extant tree-ring preserved in the cross, RY1163, as derived from the wiggle-match. The most likely sub-ranges are 982–1010 *Cal AD* (51.5% probability from the 68.3% hpd range) or 956–1012 *Cal AD* (65.4% probability from the 95.4% hpd range).

outermost rings are present) most likely (51.9% of the 68.3% hpd range) ca. 982–1010 *Cal AD*: Figure 4c. These outer extant tree-rings may even include the 993 AD Miyake event which could potentially allow an absolute date.

(c) Tentative link of BCPM (*P. brutia*) and *P. nigra* chronology from Panagia Podithou, Galata

As a principle, crossdating in tree-ring studies is investigated by examining and comparing trees/wood of the same species from the same/similar regions whether by visual or computer-statistical methods (e.g., Stokes and Smiley 1968; Baillie and Pilcher 1973; Holmes 1983; Schweingruber 1988). However, in some cases crossdating tree-ring series of similar species (like comparable pines) from the same or quite analogous growth zones is possible, since the trees experience and similarly represent comparable climate-environmental circumstances. This appears to be the case when comparing the early *P. nigra* chronology from the Panagia Podithou church near Galata (GPAN) with the BCPM (Figure 5a). This circumstance likely

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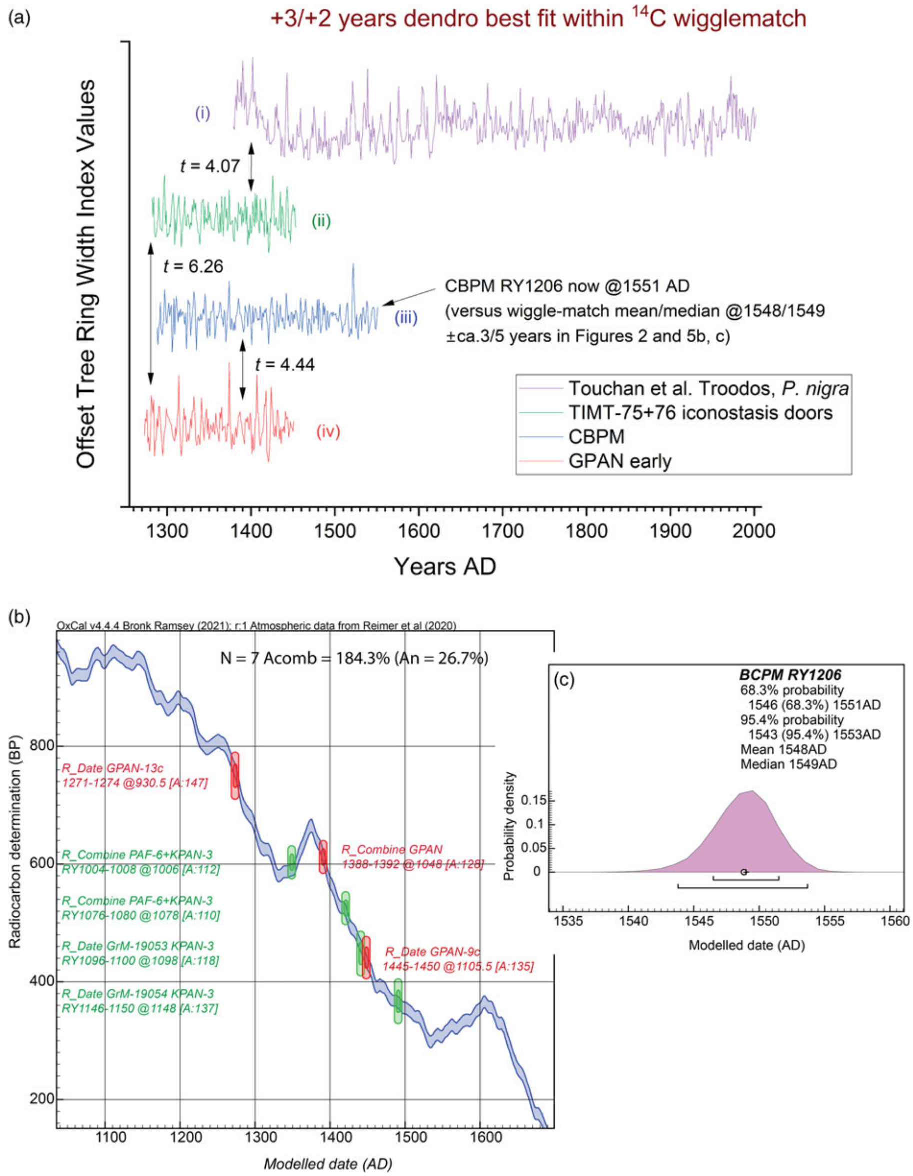

Figure 5 (a) Tree-ring width patterns, shown as offset indexed values, comparing the (i) known-age *P. nigra* Troodos (Chionistra) chronology of Touchan et al. (2014a,b) versus (ii) the TIMT-75+76 iconostasis doors *P. nigra* chronology placed at the tentative best crossdate versus (i), and then with (iv) the GPAN early *P. nigra* chronology placed at the tentative best crossdate against (ii) and then with (iii) the 264-year CBPM *P. brutia* chronology placed at the best crossdate versus (iv)—this crossdate is also (well) within the 68.3% hpd best fit range for the chronology from the ^{14}C wiggle-matches in Figures 2 and 5b, c (and is also consistent with a preliminary tentative crossdate versus a Cyprus *Cedrus brevifolia* chronology to be reported on in future work). The *t* (Baillie and Pilcher 1973) values cited are those from the Corina software (Harris 2007). (b) Tree-ring sequenced ^{14}C wiggle-match of ^{14}C dates on the BCPM chronology (PAF-6 and KPAN-3 samples) as in Figure 2 combined, via the tentative dendrochronological crossdate in (a), with the set of ^{14}C dates on samples from the GPAN early *P. nigra* chronology (the latter now placed in terms of the BCPM relative years, RY). (Note: an alternative presentation of this wiggle-match is shown in the Online Supplementary Material.) (c) Calendar placement of the end of the BCPM chronology (RY1206) according to the tree-ring sequenced ^{14}C wiggle-match shown in (b).

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reflects the fact that the BCPM *P. brutia* trees probably derive from mid to higher elevation (versus lower elevation) *P. brutia* forest areas on Cyprus whereas GPAN is a relatively lower elevation site for the Troodos churches at around 560m. It is perhaps likely (assuming builders were minimizing the distance the wood was transported) that the *P. nigra* employed came from the lower limits of its range where it mixes into higher elevation *P. brutia*; hence reasonably similar tree-ring growth patterns are plausible. We sought to test the credibility of this tentative crossdate by including the tentatively crossdated GPAN early elements in a wiggle-match with the BCPM series (Figure 2 above): Figure 5b, c. This offers a consonant result and suggests that the tentative set of crossdates shown in Figure 5a are plausible. In which case, a crossdate between the GPAN early *P. nigra* chronology and the *P. nigra* TIMT iconostasis series ($t = 6.26$) (Baillie and Pilcher 1973), and a tentative and as yet only quite short crossdate ($t = 4.07$) between the latter and the known-age Troodos *P. nigra* chronology of Touchan et al. (2014a, b) (Figure 5a) would indicate an absolute placement for the CBPM chronology either ca. 3 or 2 years more recent than the ^{14}C wiggle-matches shown in Figures 2 and 5b, c: i.e., RY1206 at 1551 AD versus the mean/median placements of ca. 1548/1549 *Cal AD* in Figures 2 and 5b, c. Not shown here, and to be reported on in a future publication, this approximate calendrical position is further supported by a reasonably good ($t = 6.94$) cross date between the BCPM chronology and a known-age *Cedrus brevifolia* chronology under construction that links forest samples and samples from cultural heritage materials from western Cyprus. Interestingly, a neutral Delta_R test (Bronk Ramsey 2009) of 0 ± 10 ^{14}C years on the wiggle-match in Figure 5b, c reports a very small but positive offset of 2.6 ± 7.8 ^{14}C years and places RY1206 at mean/median 1549 *Cal AD* –3/+4 within the 68.3% hpd range, again very compatible with the now tentative absolute date of 1551 AD. This confirms that these particular trees show no substantive offset versus IntCal20, consistent with the growing seasons of mid to higher elevation *P. brutia* on Cyprus, spring-summer, which offer a timing that is largely in parallel with the trees used to construct IntCal across the last millennium (and in contrast with the more offset growing seasons, and hence small ^{14}C offsets recorded, in some other Mediterranean-Near Eastern trees: Manning et al. 2018, 2020).

DISCUSSION

The near-absolute placement of the 264-year *P. brutia* Byzantine Cyprus Pine Master (BCPM) opens up several areas for further work and already indicates almost absolute dates for those elements from the six main sites that helped build this chronology. Both the ^{14}C wiggle-match and the tentative dendrochronological placement using cross-species linkages to *P. nigra* and *Cedrus brevifolia* independently suggest that only a very short gap of no more than 10 years at most, and most likely around 5 years, remains to be bridged between the recent end of the BCPM and the earliest known-age *P. brutia* chronologies from forest and securely associated cultural heritage sites. Hopefully this can be achieved in future work, an exciting development which would then create >700 years of continuous chronology from the present backwards. Since *P. brutia* is by far the most common tree on Cyprus and is employed in much historic construction and wooden cultural heritage on the island, creation of a long *P. brutia* master chronology for Cyprus is important not only for climatic/environmental studies but especially for dating and provenance analyses for a range of cultural heritage applications. The *P. nigra* tree-ring series from Panagia Podithou, Galata, and Timios Stavros, Pelendri, also indicate promise with further work to extend the current forest-based *P. nigra* chronologies further back in time.

Dendrochronological investigations allied with ^{14}C at the Timios Stavros church in Pelendri provide TPQ dates that contribute to the dating of building and restoration phases from the late/end 12th to earlier 13th centuries, in the 14th century, through to the mid-16th centuries AD. These findings largely correspond with, but also elaborate, previous historical and art-historical assessments (e.g., Christoforaki 1996; 2000; Stylianou and Stylianou 1997:223–232, 507–510). The most intriguing wooden object at Pelendri is the devotional/sacred *Cupressus sempervirens* Holy Cross (probably not an accidental species choice as tradition linked cypress as one of the supposedly three wood species used for the True Cross: Kazan and Higham 2020). The minimum (TPQ) date for the cross is estimated ca. 956–1012 *Cal AD* (65.4% most likely range within the 95.4% hpd range) and especially ca. 982–1010 *Cal AD* (51.9% most likely range within the 68.3% hpd range) (Figure 4c). It is possible that a considerable number of original exterior tree-rings are missing; otherwise, the chronology offered by the preserved rings is earlier than the estimated foundation of the church which has framed to this day any efforts to date it. As a result, the proposed chronological window between the 12th and the 14th century for the dating of the cross remains quite broad (Hadjichristodoulou 2005). Considering the long tradition of the cult of the Holy Cross in Cyprus, the 12th and the 13th centuries are reasonable possibilities for the donation of the liturgical cross to the church. A later date in the 14th century is also probable, due to the popularity of the Legend of the True Cross under the Latin rulers of Cyprus. Such a date would also fit the dates for the contemporaneous extensive remodeling and decoration of the church (Keene 2018). But this would suggest that at least ca. 300+ tree-rings were removed—which, while possible since *Cupressus sempervirens* can be a very long-lived tree, seems inherently less than likely. Yet, given the dating provided by the extant ring sequence, we must also consider that the cross is substantially older. This potentially raises interesting questions: was it part of the original church foundation project, or was it donated and brought to Pelendri and the Timios Stavros church at a later date, for example in the 14th century AD?

The growth record of the tree used to make the Holy Cross indicates this must be high-elevation *Cupressus sempervirens*—since the ring record indicates consistent (mainly narrow) annual rings, whereas lower elevation *Cupressus sempervirens* examples tend often to exhibit frequent false rings/intra-annual density fluctuations, reflecting the great cambial plasticity of the cypress species and its growth response to varying climatic-environmental conditions (availability of moisture especially) during the overall growing season (e.g. Schweingruber 1993; Šilhán et al. 2018; Christopoulou et al. 2021). This points also to this sample deriving from wild *Cupressus sempervirens* variety *horizontalis*. Although the species is found widely across the eastern to central Mediterranean (Brofas et al. 2006), higher elevation examples with consistent annual rings are less common. A Cypriot origin is possible and higher elevation *Cupressus sempervirens* is found today not far from Pelendri (for example, two of the three loci on the island recorded in Farjon 2022; personal observations, SWM and BL), but the wood for TIMT-1 could also derive from mountainous areas in the surrounding region with natural populations of this species occurring in Crete, Greece, Lebanon, Syria and Turkey.

Based on the dendrochronological evidence available to us, we cannot rule out the possibility that this is an imported artefact, a cult object that was brought to Cyprus and deposited at Pelendri during its 14th century remodeling phase. In general, the practices around the creation, curation and attribution of Christian devotional/sacred objects and relics have a long history from early in the Christian period with much activity focused around collecting and creation both in the early and later Medieval periods (Bynum 2011; Kazan and Higham 2020; Smith 2020). If we consider a source outside Cyprus, the close connections between Cyprus and

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both the Levant and the Armenian Kingdom of Cilicia (e.g., Christoforaki 2000:81) offer a probable route. The alternative is local manufacture, either around the time the Timios Stavros was originally built, or an earlier date (from the 10th to the 12th century) which would necessitate the suggestion for the existence of an earlier church or cult site associated with the worship of the Holy Cross and which hosted the wooden relic before its subsequent installation at the Timios Stavros church.

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COMPETING INTERESTS

The authors declare none.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2023.84

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