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11 King’s Quay/11 St Austin’s Lane Harwich Essex

Tree-ring Analysis and Radiocarbon Wiggle-matching of Elm and Oak Timbers

Martin Bridge, Cathy Tyers, Alex Bayliss, Michael Dee, and Sanne Palstra

Discovery, Innovation and Science in the Historic Environment

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ESSEX

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SUMMARY
A number of elm timbers were initially assessed as being potentially useful for ring-width dendrochronology. These were in two main areas within the building, a stud wall in the basement of the building fronting onto King's Quay Street, which also included some oak elements, and a first-floor room to the south-west which includes the likely end gable of that building, now all included in one property. In addition, an elm mantel beam was photographed and a small number of associated oak timbers were all sampled. The timbers in the stud wall, possibly re-used, failed to cross-match each other and did not date. Four studs in the building parallel to St Austin's Lane matched each other and a 62-year ring-width elm site master chronology was formed. This gave a number of weak statistical matches in the first half of the sixteenth century against oak chronologies, but could not be considered dated by dendrochronology.

Radiocarbon dating was undertaken on six single-ring samples from one of the samples in the elm site master chronology. Wiggle-matching of these results suggests that the final ring of this site master chronology formed in *cal AD 1425–1436 (95% probability; HSTAelm felling)* or *cal AD 1428–1433 (68% probability)*, and that the gable-end wall was constructed then or very shortly thereafter. The weak statistical matching of this chronology suggested by the ring-width dendrochronology is not supported by the radiocarbon wiggle-matching.

CONTRIBUTORS
Martin Bridge, Cathy Tyers, Alex Bayliss, Michael Dee, and Sanne Palstra

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Historic Environment Specialist Team
Place Services
County Hall
Chelmsford
Essex CM1 1QH

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CONTACT DETAILS

Martin Bridge
UCL Institute of Archaeology
31-34 Gordon Square
London WC1H 0PY
martin.bridge@ucl.ac.uk

Cathy Tyers and Alex Bayliss
Historic England
Cannon Bridge House
25 Dowgate Hill
London EC4R 2Y
cathy.tyers@historicengland.org.uk
alex.bayliss@historicengland.org.uk

Michael Dee and Sanne Palstra
Centre for Isotope Research
University of Groningen
Nijenborgh 6
9747 AG Groningen
The Netherlands
m.w.dee@rug.nl
s.w.l.palstra@rug.nl

CONTENTS

INTRODUCTION

The investigation of the elm timbers from the building at 11 King's Quay Street/11 St Austin's Lane, Harwich, contributes to a research programme, Developing the dendrochronology of elm in historic buildings, funded by Historic England through its Heritage Protection Commissions programme and led by Martin Bridge from the Institute of Archaeology, University College London.

Developing the dendrochronology of elm in historic buildings
Ring-width dendrochronology of oak timbers from historic buildings in England is well established, with dating having been obtained on more than 3000 buildings (or parts thereof), with nearly one third of these having been funded by Historic England (and its predecessors). Dendrochronological evidence is a valuable component underpinning the discovery and identification of assets in the historic environment, aiding decisions relating to protection, management, and conservation, and enhancing appreciation and enjoyment of these buildings.

During this work on oak timbers, a significant amount of historic fabric constructed from timbers other than oak, most notably elm, has been identified, but this has previously been rejected as unsuitable for dendrochronological investigation. Elm in buildings has been identified in counties from Cornwall to Kent and up into the Midlands and beyond, but formal records of the presence of elm are scant as such buildings were generally dismissed for dating purposes and thus the presence of elm in the published record is rare. The inability to date historic buildings (or sections of buildings) constructed of elm by ring-width dendrochronology is seen as problematic in some areas of the country which have a comparatively high proportion of such buildings; buildings which nevertheless form a significant part of the historic environment but could not be afforded the same level of understanding in comparison to their oak counterparts.

Prior to the start of this project, only four instances of dating elm by ring-width dendrochronology have been successful (Groves and Hillam 1997; Haddon-Reece *et al* 1989, 1990; Bridge and Miles 2015). Each of these studies involved matching elm with oak from the same site, although the Ashdon, Essex example matched oak chronologies over a wide area (Bridge and Miles 2015). This project aimed to establish whether the use of standard ring-width dendrochronology could be extended to the dating of historic buildings in England where elm (*Ulmus* sp.) is the sole, or predominant species used rather than oak (*Quercus* sp.). A systematic approach was adopted, concentrating on elm in the geographical areas where it is most commonly found. Buildings were thus sought that contained a significant number of elm timbers with sufficient numbers of rings that might be matched against either oak timbers in the same building or oak chronologies from the surrounding area (Fig 1).

An article will summarise the overall outcomes of the project (Bridge forthcoming). However, each building sampled for dendrochronology has an associated building survey report or similar publication, whilst the primary archive of the dendrochronological analysis is reported in the Historic England Research Report Series.

11 King's Quay Street/11 St Austin's Lane, Harwich

This grade II listed building (LEN 1204773) actually appears to be two buildings, now under single ownership. The property is thought to have early-sixteenth century origins but diagnostic characteristics are sparse and thus stylistic dating is difficult. The 'front' property has a ground-floor shopfront onto King's Quay Street and contains an elm stud wall in the basement, possibly made from re-used timbers, and also containing some oak. The other building, to the left of the entry from St Austin's Lane, has a first-floor room containing several elm timbers, many of which make up what looks like an original end-gable wall. The building lies on a north-east to south-west axis, but the St Austin's lane elevation is taken as site south for the purposes of this report. The location of the building is illustrated in Figure 2. An annotated photograph of the southern elevation of the property indicates the position of the areas of the building sampled for dendrochronology (Fig 3).

RING-WIDTH DENDROCHRONOLOGY

Sampling

Fieldwork for the present study was carried out in March 2018, following an initial assessment of the potential for elm dendrochronology some weeks beforehand. In the initial assessment, based on the general criteria used for oak timbers, accessible elm timbers with more than 50 rings and where possible traces of sapwood were sought, although slightly shorter sequences may be sampled if little other material is available. Those timbers judged to be potentially useful were cored using a 16mm auger attached to an electric drill. The cores were labelled, and stored for subsequent analysis. Additional oak timbers with complete sapwood were also sampled to provide same-site comparative material to increase the chances of producing dating evidence for the elm samples. In addition, a digital photographic record was made of a ground-floor mantel beam, and a ring-width sequence was derived from the photographs using CooRecorder 9.1 (Cybis Elektronik and Data AB, Sweden).

Methodology

The cores were polished on a belt sander using 80 to 400 grit abrasive paper to allow the ring boundaries to be clearly distinguished. The samples had their tree-ring sequences measured to an accuracy of 0.01mm, using a specially constructed system utilising a binocular microscope with the sample mounted on a travelling stage with a linear transducer linked to a PC, which recorded the ring widths into a dataset. The software used in measuring and subsequent analysis was written by Ian Tyers (2004). Cross-matching was attempted by a combination of visual matching and a process of qualified statistical comparison by computer. The ring-width series were compared for statistical cross-matching, using a variant of the Belfast CROS program (Baillie and Pilcher 1973). Ring sequences were plotted on the computer monitor to allow visual comparisons to be made between sequences.

This method provides a measure of quality control in identifying any potential errors in the measurements when the samples cross-match.

In comparing one oak sample or site master against other samples or chronologies, *t*-values over 3.5 are considered significant, although in reality it is common to find demonstrably spurious *t*-values of 4 and 5 because more than one matching position is indicated. For this reason, dendrochronologists prefer to see some *t*-value ranges of 5, 6, and higher, and for these to be well replicated from different, independent chronologies with both local and regional chronologies well represented, except where imported timbers are identified. Where two individual oak samples match together with a *t*-value of 10 or above, and visually exhibit exceptionally similar ring patterns, they may have originated from the same parent tree. Same-tree matches can also be identified through the external characteristics of the timber itself, such as knots and shake patterns. Lower *t*-values however do not preclude same tree derivation. Threshold values for elm samples are as yet unknown, but are likely to be of similar value.

Once a tree-ring sequence has been firmly dated in time, a felling date, or date range, is ascribed where possible. With samples which have sapwood complete to the underside of, or including bark, this process is relatively straightforward. Depending on the completeness of the final ring, ie if it has only the spring vessels or early wood formed, or the latewood or summer growth, a precise felling date and season can be given. If the sapwood is partially missing, or if only a heartwood/sapwood transition boundary survives, then an estimated felling date range can be given for each sample. In oak, the number of sapwood rings can be estimated by using an empirically derived sapwood estimate with a given confidence limit. If no sapwood or heartwood/sapwood boundary survives then the minimum number of sapwood rings from the appropriate sapwood estimate is added to the last measured ring to give a *terminus post quem* (*tpq*) or felled-after date.

A review of the geographical distribution of dated sapwood data from historic oak timbers has shown that a sapwood estimate relevant to the region of origin should be used in interpretation, which in this area is 9–41 rings (Miles 1997). The equivalent values for elm are as yet unknown, but the results of this project suggest that the range of the number of sapwood rings in elm timbers is likely to be much lower. One problem that has been encountered in considering elm is that it has often proved very difficult to determine the position of the heartwood/sapwood boundary, even when it is known that the complete sapwood is present on a timber. It must be emphasised that dendrochronology can only date when a tree has been felled, not when the timber was used to construct the structure or object under study.

Results

Basic information about the samples taken is given in Table 1, with the locations of most of the timbers sampled shown in Figures 4–6 (the locations of samples hsta02, hsta06, and hsta12 could not be photographed).

The ground-floor elm mantel beam had a large number of apotropaic inscribed marks (Fig 4), and has been referred to Timothy Easton for further study. Its end grain was exposed and a ring sequence of 56 rings was derived from the photographs. The stud wall in the basement (Fig 5) is also in the north-east end of the building to the right of the present entry. It appears to be constructed from re-used timbers, and contains a mix of oak and elm. All the samples taken had very short ring sequences, and only one was measured which contained 40 rings. Neither this, nor the mantel beam series, could be cross-matched with the other measured series from this site and both remain undated. The ring-width measurements are given in the Appendix.

The wall timbers sampled at first-floor level in the part of the property to the left of the present entry appears to be a gable-end wall, now enclosed (Fig 6). A further stud was visible beyond the internal wall shown in Fig 6. Many of the timbers showed clusters of burn marks. One of these samples had fewer than 30 rings but the four measured (see Appendix) elm series cross-matched each other (Table 2; Fig 7) and their ring series were combined into a 62-year site master chronology, HSTAelm. This elm sequence was compared with the available oak data, and a weak statistical match was found in the early sixteenth century, although this was not considered strong enough to provide secure dating for the chronology, particularly as other weaker but consistent matches were also identified.

Oak was sampled in three locations (Table 1) where it was thought it may assist in dating the elm samples. No cross-matching was indentified between the two measured oak series, however, nor with any of the elm series.

RADIOCARBON DATING

Following the failure of the ring-width dendrochronology to provide secure calendar dating for elm site master chronology, sample hsta10 was selected for radiocarbon dating and wiggle-matching as this had the most growth-rings of the four samples in the master chronology (Table 1; Figs 7 and 8).

Radiocarbon dating is based on the radioactive decay of ^{14}C, which trees absorb from the atmosphere during photosynthesis and store in their growth-rings. The radiocarbon from each year is stored in a separate annual ring. Once a ring has formed, no more ^{14}C is added to it, and so the proportion of ^{14}C versus other carbon isotopes reduces in the ring through time as the radiocarbon decays. Radiocarbon ages, like those in Table 3, measure the proportion of ^{14}C in a sample and are expressed in radiocarbon years BP (before present, ‘present’ being a constant, conventional date of AD 1950).

Six radiocarbon measurements have been obtained from single annual tree-rings from timber hsta10 (Table 3). Dissection was undertaken by Alison Arnold and

Robert Howard at the Nottingham Tree-Ring Dating Laboratory. Prior to sub-sampling, the core was checked against the tree-ring width data. Then each annual growth ring was split from the rest of the tree-ring sample using a chisel or scalpel blade. Each radiocarbon sample consisted of a complete annual growth ring, including both earlywood and latewood. Each annual ring was then weighed and placed in a labelled bag. Rings not selected for radiocarbon dating as part of this study have been archived by Historic England.

Radiocarbon dating was undertaken by the Centre for Isotope Research, University of Groningen, the Netherlands in 2019. Each ring was converted to α-cellulose using an intensified aqueous pretreatment (Dee *et al* 2020) and combusted in an elemental analyser (IsotopeCube NCS), coupled to an Isotope Ratio Mass Spectrometer (Isoprime 100). The resultant CO_2 was graphitised by hydrogen reduction in the presence of an iron catalyst (Wijma *et al* 1996; Aerts-Bijma *et al* 1997). The graphite was then pressed into aluminium cathodes and dated by AMS (Synal *et al* 2007; Salehpour *et al* 2016). Data reduction was undertaken as described by Wacker *et al* (2010). The facility maintains a continual programme of quality assurance procedures (Aerts-Bijma *et al* forthcoming), in addition to participation in international inter-comparison exercises (Scott *et al* 2017; Wacker *et al* 2020). These tests demonstrate the reproducibility and accuracy of these measurements.

The results are conventional radiocarbon ages, corrected for fractionation using $\delta^{13}C$ values measured by Accelerator Mass Spectrometry (Stuiver and Polach 1977; Table 3). The quoted $\delta^{13}C$ values were measured by Isotope Ratio Mass Spectrometry, and more accurately reflect the natural isotopic composition of the sampled wood.

WIGGLE-MATCHING

Radiocarbon ages are not the same as calendar dates because the concentration of ^{14}C in the atmosphere has fluctuated over time. A radiocarbon measurement has thus to be calibrated against an independent scale to arrive at the corresponding calendar date. That independent scale is the IntCal20 calibration curve (Reimer *et al* 2020). For the period covered by this study, this is constructed from radiocarbon measurements on tree-ring samples dated absolutely by dendrochronology. The probability distributions of the calibrated radiocarbon dates, derived from the probability method (Stuiver and Reimer 1993), are shown in outline in Figure 9.

Wiggle-matching is the process of matching a series of calibrated radiocarbon dates which are separated by a known number of years to the shape of the radiocarbon calibration curve. At its simplest, this can be done visually, although statistical methods are usually employed. Floating tree-ring sequences are particularly suited to this approach as the calendar age separation of tree-rings submitted for dating is known precisely by counting the rings in the timber. A review of the method is presented by Galimberti *et al* (2004).

The approach to wiggle-matching adopted here employs Bayesian chronological modelling to combine the relative dating information provided by the tree-ring analysis with the calibrated radiocarbon dates (Christen and Litton 1995). It has been implemented using the program OxCal v4.3 (http://c14.arch.ox.ac.uk/oxcal.html; Bronk Ramsey *et al* 2001; Bronk Ramsey 2009). The modelled dates are shown in black in Figure 9 and quoted in italics in the text. The Acomb statistic shows how closely the assemblage of calibrated radiocarbon dates as a whole agree with the relative dating provided by the tree-ring analysis that has been incorporated in the model; an acceptable threshold is reached when it is equal to or greater than An (a value based on the number of dates in the model). The A statistic shows how closely an individual calibrated radiocarbon date agrees its position in the sequence (most values in a model should be equal to or greater than 60).

Figure 9 illustrates the chronological model for HSTAelm. This model incorporates the gaps between each dated annual ring known from tree-ring counting (eg that the carbon in ring 2 of the measured tree-ring series (GrM-19787) was laid down 10 years before the carbon in ring 12 of the series (GrM-19788; Fig 8), along with the radiocarbon measurements (Table 3) calibrated using the internationally agreed radiocarbon calibration data for the northern hemisphere, IntCal20 (Reimer *et al* 2020).

The model has good overall agreement (Acomb: 39.9, An: 28.9, n: 6), although two of the individual dates have poor individual agreement (A: > 60.0). *GrM-19791* appears to be a late outlier, but is not outside the range of statistical expectation. The model suggests that the final ring of HSTAelm formed in *cal AD 1425–1436 (95% probability; GrM-19792*; Fig 9), probably in *cal AD 1428–1433 (68% probability)*.

DISCUSSION

The final complete growth ring of all four elm samples included in the ring-width site master chronology, HSTAelm, were formed in the same year, although hsta08 contained some growth from the following season. Evidence suggests that, with the exception of reused timbers, in most historical periods construction took place within a very few years of felling (Miles 2006). The results of the radiocarbon wiggle-matching can therefore be interpreted as an estimate for the date of construction of the gable-end wall in 11 St Austin's Lane, which occurred in *cal AD 1425–1436 (95% probability; GrM-19792*; Fig 9), probably in *cal AD 1428–1433 (68% probability)* or possibly a few years later. As indicated above there are few diagnostic characteristics of the framing of the first-floor room on the west side to give a stylistic dating, so this radiocarbon dating produces useful information in establishing a fifteenth-century origin of the building, and feeds into the wider appreciation and understanding of the growth of Harwich.

The lack of cross-matching and cross-dating of the other ring-series obtained from this property is unsurprising given the limited number of growth-rings in both the elm and oak timbers.

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TABLES

Table 1. Details of the samples taken from 11 King's Quay Street/11 St Austin's Lane, Harwich

Sample number	Timber and position	No of rings	Mean ring width	Sapwood rings	Mean sensitivity
Elm samples – King's Quay Street end of building					
hsta01	Ground floor mantel beam	56	2.66	-	0.22
hsta02	North end stud of stud wall	<30	NM	h/s	-
hsta03	2nd stud from north	<30	NM	h/s	-
hsta05	4th stud, possibly a re-used joist	40	2.49	-	0.21
Elm samples – gable-end wall of St Austin's Lane end					
hsta08	5th stud from east end	59	1.66	9¼C	0.20
hsta09	4th stud from east end	61	1.55	C	0.16
hsta10	6th stud from east end	62	2.12	?C	0.20
hsta11	7th Stud from east end	<30	NM	C	-
hsta12	8th stud from east end	57	1.87	C	0.22
Oak samples					
hsta04	Sill beam to stud wall – King's Quay Street end	<30	NM	-	-
hsta06	Large central stud in first floor (probably inserted)	48	3.45	10?C	0.20
hsta07	North gable wall, mid-rail – St Austin's Lane end	33	3.99	9¼C	0.17

Key: NM = not measured; h/s = heartwood/sapwood boundary; C = complete sapwood, winter felled; ¼C = complete sapwood, felled the following spring; ?C = thought to be complete sapwood, but not certain

Table 2. Cross-matching between the elm samples from the north gable wall of the St Austin's Lane end of the building

t-value (years overlap)			
Sample	hsta09	hsta10	hsta12
hsta08	6.8 (59)	7.5 (59)	7.3 (57)
hsta09		6.9 (61)	7.9 (57)
hsta10			6.4 (57)

Table 3. Radiocarbon measurements and associated δ13C values from hsta10

Laboratory Number	Sample	Radiocarbon Age (BP)	$\delta^{13}C_{IRMS}$ (‰)
GrM-19787	hsta, ring 2 (*Ulmus* spp.)	661±19	−23.92±0.15
GrM-19788	hsta, ring 12 (*Ulmus* spp.)	677±19	−24.37±0.15
GrM-19789	hsta, ring 22 (*Ulmus* spp.)	615±19	−24.96±0.15
GrM-19790	hsta, ring 32 (*Ulmus* spp.)	572±18	−24.74±0.15
GrM-19791	hsta, ring 42 (*Ulmus* spp.)	489±19	−23.43±0.15
GrM-19792	hsta, ring 62 (*Ulmus* spp.)	518±18	−24.76±0.15

FIGURES

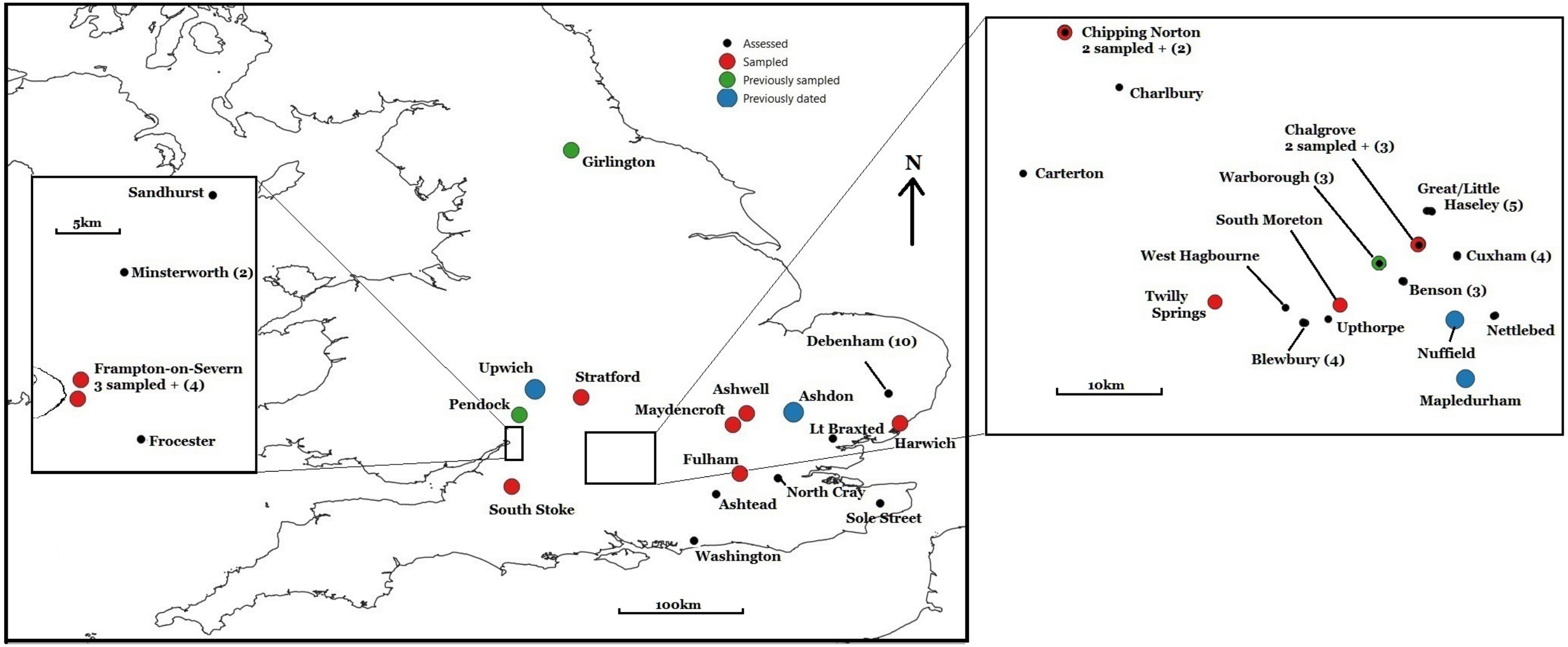


Figure 1: Map showing the distribution of sites sampled, some of which were dated, prior to the start of this project, and sites assessed and sampled properties for this project. Numbers in brackets after a place name represent the number of properties assessed in that location

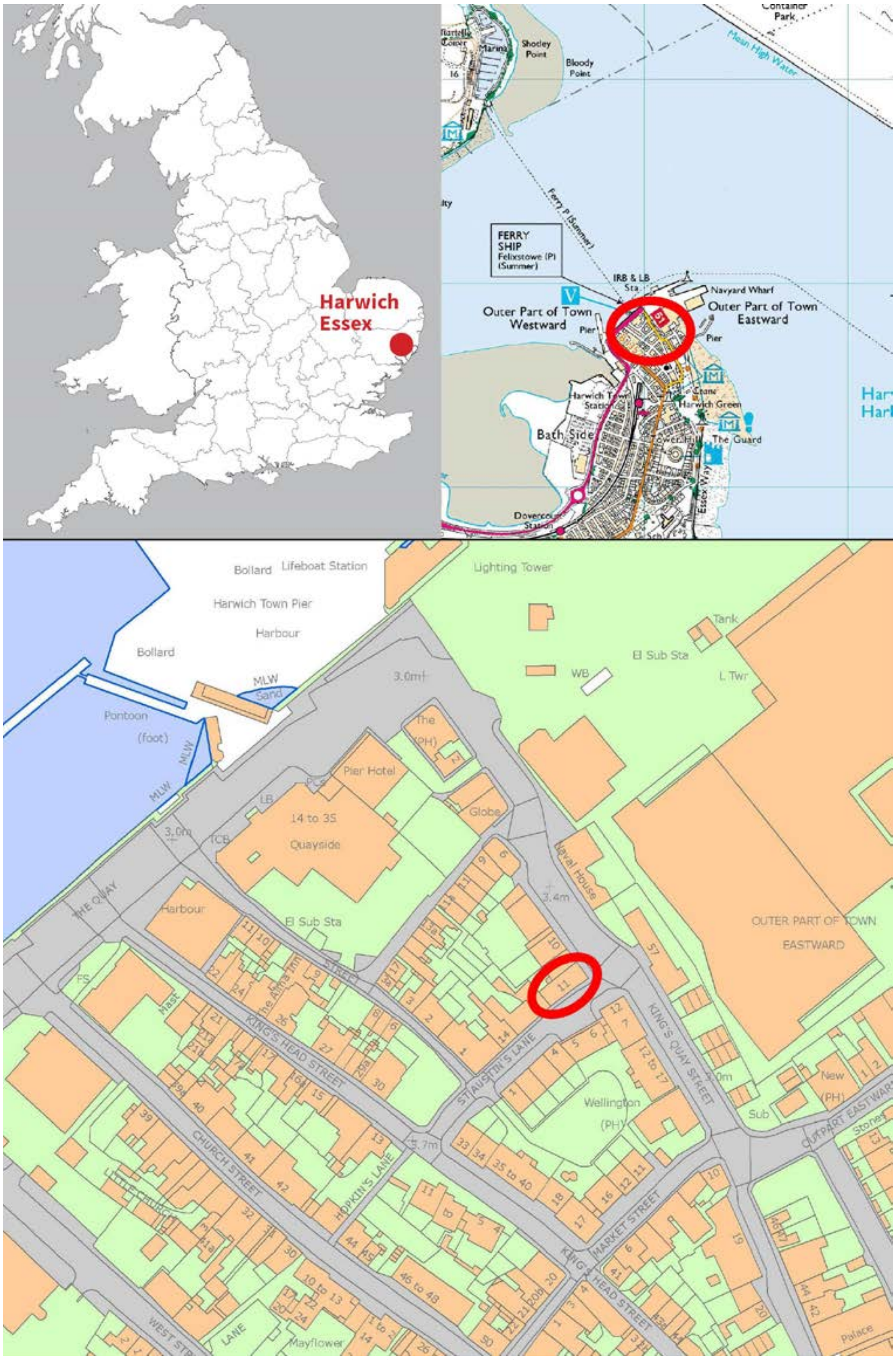


Figure 2: Maps marked to show the location of Harwich, Essex and 11 King's Quay Street/11 St Austin's Lane. Scale: top right 1:25000; bottom 1:500. © Crown Copyright and database right 2020. All rights reserved. Ordnance Survey Licence number 100024900. © British Crown and SeaZone Solutions Ltd 2020. All rights reserved. Licence number 102006.006. © Historic England.

Figure 3: View of the south-east side of the property (site south) showing the approximate position of the north-south partition in the cellar shown in Figure 5 (1) and the line of the east-end gable wall shown in Figure 6 (2) (photograph: Martin Bridge)

Figure 4:Mantel beam in ground-floor north room (fronting onto King's Quay Street) with an abundance of apotropaic marks, the exposed end of this beam was photographed to derive sequence hsta01 (photograph: Martin Bridge)

Figure 5: Part of the basement stud wall showing some of the timbers sampled (photograph Martin Bridge)

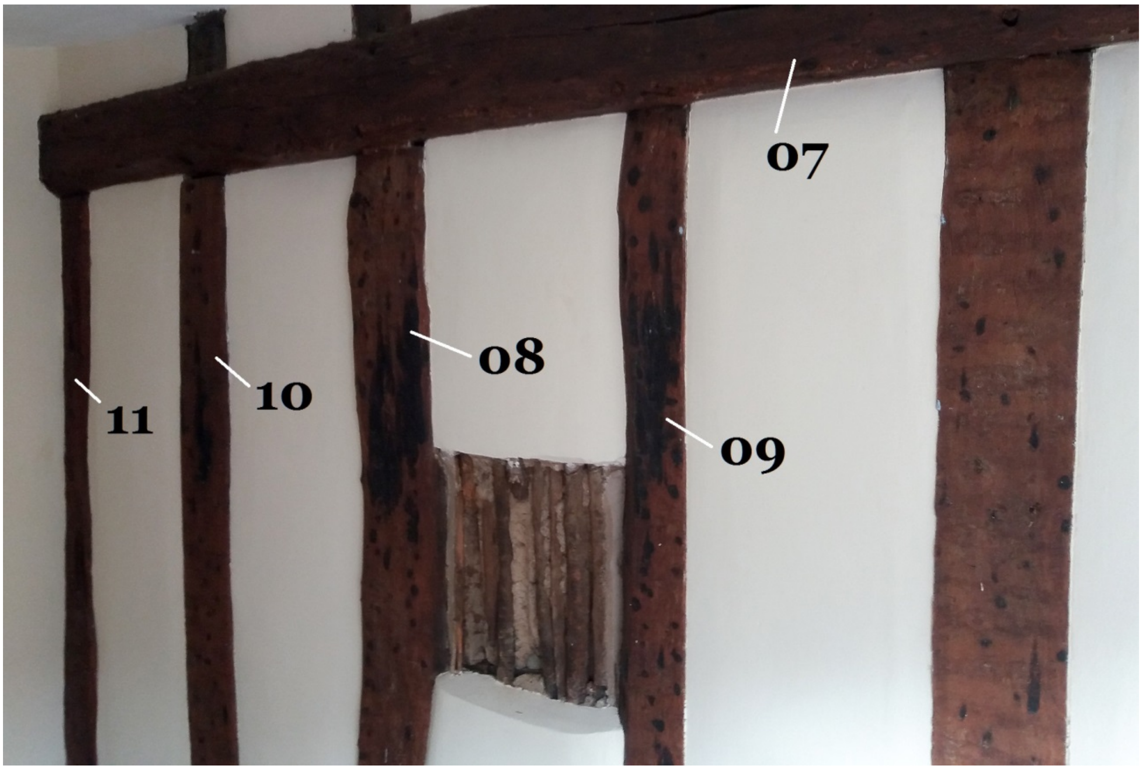


Figure 6: Gable wall of the St Austin's Lane building showing an abundance of burn marks and the locations of some of the timbers sampled (photograph Martin Bridge)

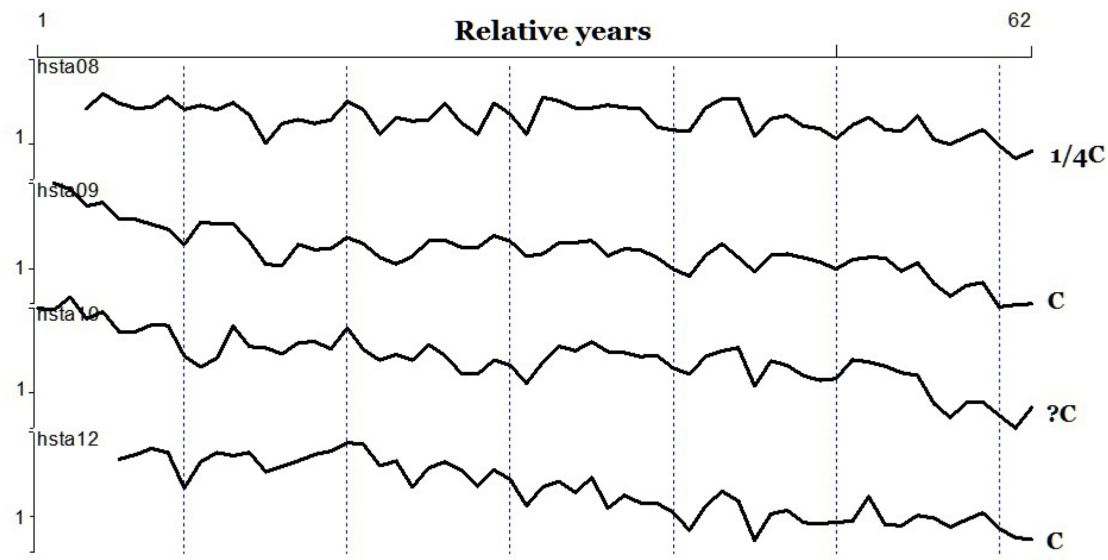


Figure 7: Plots of the four cross-matched elm series showing the similarity in growth. The y-axis is ring width (mm) on a logarithmic scale. (C = complete sapwood, winter felled; ¼C = complete sapwood, felled the following spring; ?C = thought to be complete sapwood, but not certain)

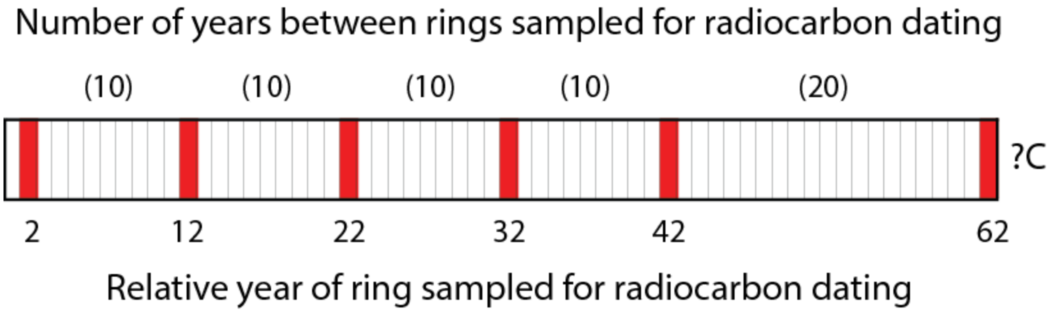


Figure 8: Schematic illustration of hsta10 to locate the single-ring sub-samples submitted for radiocarbon dating (?C = thought to be complete sapwood, but not certain; red = rings sampled for radiocarbon dating)

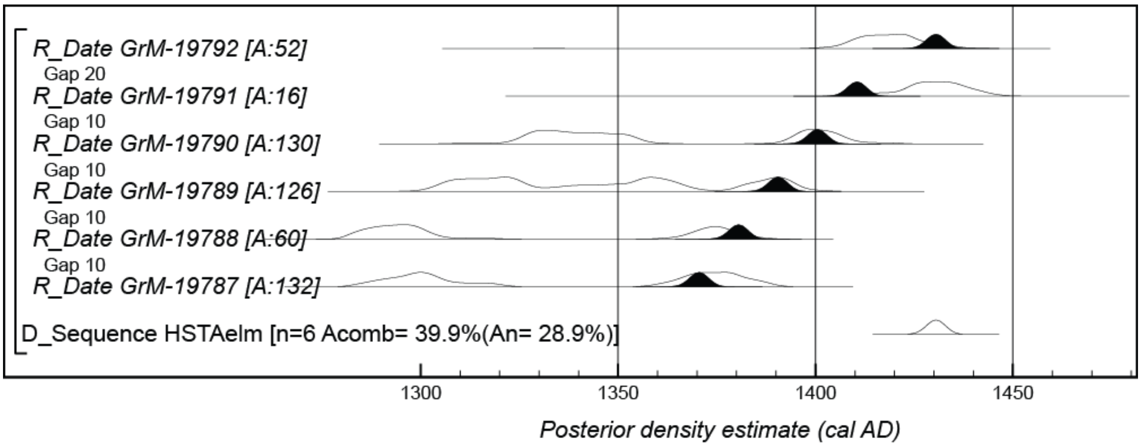


Figure 9: Probability distributions of dates from site master sequence HSTAelm. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. As GrM-19792 dates the last complete ring of the sequence, this is the estimated date for when the trees which produced the timbers in HSTAelm were felled. The large square brackets down the left-hand side along with the OxCal keywords and the description of the sapwood estimates in the text defines the overall model exactly.

APPENDIX

Ring width values (0.01mm) for the sequences measured

Elm

hsta01

138	211	331	358	406	318	329	280	372	432
234	237	242	184	227	180	271	194	295	290
275	392	275	234	281	266	192	275	307	307
240	251	281	383	328	345	364	366	251	243
164	193	201	125	108	123	259	322	215	224
301	247	328	250	183	275				

hsta05

477	398	484	541	458	267	165	247	229	129
149	227	314	235	257	392	369	340	365	311
220	257	211	229	151	179	197	169	123	152
145	108	96	111	150	211	188	196	237	261

hsta08

194	255	214	196	198	242	191	206	190	216
172	102	147	158	147	158	221	190	121	164
154	157	213	149	121	215	175	121	239	223
196	196	207	198	193	138	130	128	198	231
232	116	161	171	140	134	111	143	165	132
127	169	109	100	115	131	98	77	88	

hsta09

486	435	319	340	250	249	227	207	156	236
229	229	165	108	106	156	142	145	178	158
123	109	125	168	169	148	147	184	166	126
131	162	162	168	127	144	141	123	99	87
128	158	123	94	128	131	122	113	99	118
123	122	95	111	76	60	73	77	49	51
52									

hsta10

479	464	589	394	448	310	310	353	348	198
161	190	344	235	230	205	253	258	225	332
222	183	203	183	243	199	143	141	183	167
119	176	236	218	257	214	210	195	200	158
141	196	217	230	113	180	166	137	126	130
184	177	164	145	138	82	63	83	84	66
52	76								

hsta12

292	317	356	330	171	278	330	311	331	231
255	283	318	339	396	384	258	282	174	249
277	237	176	239	201	123	175	193	158	207
118	149	130	129	109	78	123	161	134	65
106	113	90	88	91	92	146	87	85	103
98	83	95	108	81	68	66			

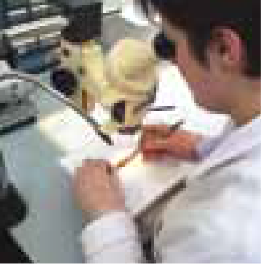
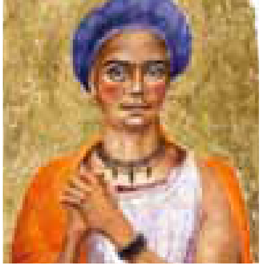
Oak

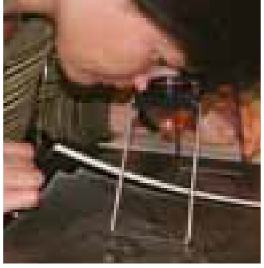
hsta06

407	297	199	278	373	380	317	237	506	413
539	424	360	357	387	443	378	454	363	276
306	256	363	334	270	354	247	261	276	359
304	400	353	316	339	292	377	381	416	367
383	370	360	452	298	203	318	225		

hsta07

372	299	279	330	299	336	300	393	274	414
468	460	500	336	412	285	284	304	285	325
319	443	476	469	513	586	576	671	369	407
575	375	445							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