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The Manor House King Street Fordwich Kent Oxygen Isotope Dendrochronology of Oak Timbers

Neil J Loader, Darren Davies, Danny McCarrol, Dan Miles, Cathy Tyers, and Giles H F Young

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FORDWICH
KENT

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SUMMARY
As part of an initiative to investigate the practical extent of the south-central England chronology for isotopic dating, two timbers that had been securely dated by ring-width dendrochronology from the Manor House, Fordwich were sampled for oxygen isotope analysis. Eighty-three measurements were obtained on latewood from single growth-rings of core KMF-A05 from the west brace to the north principal of truss 2 (rings 1–83 of the measured ring-width series which spans AD 1447–1529) and 127 measurements were obtained on latewood from single growth-rings of core KMF-A11 from the east brace to the north principal of truss 4 (rings 1–127 of the measured ring-width series spanning AD 1408–1534). Both samples were taken from the King Street range of the building.

The two isotopic series cross-match when offset by five years. This is consistent with the ring-width cross-matching. The 127-year isotopic mean cross-dates (t=8.39, 1/p>1 million, IF>1000) with the south-central England oxygen isotope master chronology, at a position that is compatible with that provided by ring-width dendrochronology. The two isotopic series date independently at positions consistent with the ring-width dendrochronology.

The location of the Manor House, Fordwich, to the south-east of the south-central England master chronology is located in an area that can be challenging for ring-width dendrochronology. This initial study suggests that, at present, secure dating is attainable from series of isotopic measurements on single or multiple timbers in this region. An oxygen isotope master chronology for Kent is likely to enhance further the potential for applying oxygen isotope dendrochronology in this region.

CONTRIBUTORS
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INTRODUCTION

In 2018, Historic England and Swansea University established a collaborative research initiative to explore the applicability of oxygen isotope dendrochronology in England, with a view to transferring this method into professional practice. This project investigates, firstly, the geographic limits and practical boundaries of the present reference chronology (Loader *et al* 2019) which relates closely to the region covered by the England and Wales precipitation record (Young *et al* 2015). A second objective was to explore whether shorter ring sequences that commonly remain undated by traditional dendrochronology can be dated by the isotopic approach.

Six buildings were selected for study, each located in areas well beyond the periphery of the south-central England chronology (Cumbria, Northumbria, the Vale of York, Cornwall, Kent, and East Anglia). These buildings were chosen specifically for this study because the site master chronologies obtained through ring-width cross-dating exhibited strong correlations with local ring-width reference chronologies rather than with ring-width reference chronologies across a broader region. To provide a degree of replication, bearing in mind the locations of the selected sites, two ring-width dated samples were selected from each building. This also provided the opportunity to explore the cross-matching of isotope series. The other five buildings included in this study are individually reported in the Historic England Research Report Series (Loader *et al* 2020, 2021a–d).

Selection of individual core samples from each building was guided by strong ring-width intra-site cross-matching combined with the aim of obtaining a mean isotope record of a minimum of *c* 80 rings. The selected core samples were typical of those routinely retrieved through dendrochronological sampling in the selected locations with some providing practical challenges in relation to the presence of potential contaminants (eg glue, ink, charring) and narrow growth rings with little or no latewood. All timbers were provided to the isotope laboratory “blind” without information on the site location or age of the samples.

The Manor House, Fordwich

The Manor House, which is Grade II listed (List Entry Number 1063742), is centrally located within Fordwich, Kent, at the junction of the High Street and King Street (Fig 1). It comprises two distinct but contemporary ranges built at right angles to each other (Fig 2). The upper floors of both ranges are timber-framed and jettied, whilst the ground-floor elevations are of brick. The King Street range is clearly domestic, although, the High Street range appears to have functioned as a workshop or store.

Ring-width dendrochronology, undertaken on core samples from 17 of the 20 sampled timbers representing both ranges, resulted in the construction of a single site sequence, KMFASQ01, and two individually dated timbers (Arnold and Litton 2003). Site sequence KMFASQ01 includes 12 samples and is 293-rings in length and spans AD 1264–1556 (Arnold and Litton 2003, table 2).

STABLE OXYGEN ISOTOPE DENDROCHRONOLOGY

Sample selection

Two core samples from KMFASQ01 were selected for inclusion in this study (KMF-A05 and KMF-A11; Table 1; Fig 3) because the individual ring-width series that are combined to form this chronology strongly cross-match by ring-width dendrochronology (see Arnold and Litton 2003), and the chronology itself has the highest level of similarity with other sites across south-eastern England (Table 2). These samples, therefore, have typical growth characteristics of timber used in historic buildings in this region. Both these samples had a sufficient number of rings for oxygen isotope dendrochronology, and their ring-widths were such that it was possible to obtain a latewood sample from each annual ring. KMF-A11 exhibited a clean break in the core which had previously been glued to facilitate ring-width dendrochronology (Fig 4).

Method

Oxygen isotope dendrochronology relies upon the same fundamental principles, limitations and assumptions as conventional (ring-width-based) dendrochronology. However, rather than using ring-width measurements it uses the ratio of heavy to light oxygen (McCarroll and Loader 2004) in the latewood cellulose ($\delta^{18}O$). The isotopes can have a higher signal to noise ratio than ring-width measurements and strong signals do not require the trees to be growing under any environmental stress (Young *et al* 2015).

The method relies on a regional master chronology (Loader *et al* 2019) constructed using ring-width dendrochronologically-dated oak timbers sourced from across a *c* 45,200 km^2 (20,000 mile^2) region centred on Oxfordshire, in south-central England. The chronology was developed as part of a Leverhulme Trust funded project (RPG-2014-327) and currently covers a period from AD 1200–2000 with replication (sample depth) of 10 trees throughout the chronology.

Ring sampling

A thin slice (4mm) is removed from the base of the cores selected for isotopic analysis. This initial sub-sampling ensures that the original measured surface from which the reported ring-width measurements were derived is physically preserved and archived for future scientific analysis, as is the case for all samples obtained during Historic England funded investigations on historic buildings.

Several physiological studies of oak trees have shown that the earlywood is partially formed from carbohydrates fixed in previous years (Richardson *et al* 2013; McCarroll *et al* 2017). To avoid this chemical carry-over effect in oak, only the latewood of each tree-ring is prepared for chemical analysis and dating. Each annual latewood increment is carefully removed as thin slivers (*c* 40μm thick) using a scalpel and dissecting microscope. Where tree rings are indistinct, physically degraded, contaminated, or comprise only earlywood then these rings are not sampled for isotopic analysis. Consequently, the isotope sequence used for dating may not provide an isotope measurement for each ring that forms part of the measured ring-width series.

Laboratory methods

Latewood samples are converted to α-cellulose using an acidified sodium chlorite solution with removal of hemicelluloses by sodium hydroxide (after Loader *et al* 1997). Samples are homogenised using an ultrasonic probe and vacuum-dried at −50˚C for 48 hours. 0.30–0.35mg of dry α-cellulose is weighed into individual silver foil capsules for pyrolysis to carbon monoxide (CO) at 1400°C (Woodley *et al* 2012). The resulting carbon monoxide is analysed using a Delta V isotope-ratio mass spectrometer. Data are expressed as per mille (‰) deviations relative to the Vienna Standard Mean Ocean Water (VSMOW) international standard. Analytical precision is typically 0.30‰ (σ_{n-1}, n=10) (Loader *et al* 2015). The master chronology was prepared as two independent pools of five trees to ensure quality control and the resulting data combined to form the ten-tree master chronology. Individual samples for dating are prepared and analysed separately, using identical preparation protocols. The resulting stable isotopic data are presented as chronologies (time series).

Statistical analysis and dating

Tree-ring oxygen isotope data have statistical properties that are quite different from ring-widths, requiring different pre-treatment. The Baillie-Pilcher filter that works well for ring-width dating (Baillie and Pilcher 1973) is not appropriate for isotope data and would result in unrealistically high *t*-values (Loader *et al* 2019). Thus, the isotope data are filtered using a simple nine-year rectangular filter, with indices derived by subtraction. Degrees of freedom are corrected for autocorrelation and filtering resulting in *t*-values that conform to a Student's *t*-distribution and can be used to calculate one-tail probabilities of error. The probabilities are corrected for multiple testing by division by the number of possible matches against the master chronology (a 'Bonferroni' correction) (Dunn 1959; 1961). The ratio of probabilities for the first and second highest *t*-values provides an 'isolation factor'. All *t*-values pertaining to isotope data in this report are Student's *t*-values, not Baillie-Pilcher *t*-values.

Loader *et al* (2019) have suggested that potential stable isotope dates should only be considered for acceptance when the corrected probability of error (1/p) is less than one in a hundred and the probability for the best match is more than an order of magnitude less likely to be in error than the next best match (ie the isolation factor >10). The level for these thresholds necessary for isotopic dating to have equivalent confidence to traditional ring-width dendrochronology is currently uncertain. As the aim of this study is to explore the spatial extent of the south-central England chronology using dendrochronologically-dated samples of known age, dating results are reported irrespective of whether or not they pass these thresholds to enable an assessment of dating performance across the study region.

Cross-matching between individual isotope series is achieved using the same approach, with the number of possible matches determined by setting a minimum size of overlap. Student's *t*-values, corrected one-tail probabilities, and the isolation factor are reported as well as the highest correlation coefficient, offset in ring number from the most recent ring measured for oxygen isotope analysis, and the number of overlapping isotopic measurements. When cross-dating individual series, a Student's *t* value of 3.5 is currently used as a working indication of match position to inform chronology development, although it is again currently unclear what this threshold should be to be of equivalent confidence to the Baillie-Pilcher *t*-value threshold of 3.5 commonly used for cross-matching oak series in ring-width dendrochronology in England.

In isotope dendrochronology, it is not always necessary or possible to measure isotopically each tree-ring, in which case the last ring measured isotopically must be placed within the context of the entire sequence of tree-rings present in the sample. This may require the addition of years present in the sample, but not measured isotopically. Once a date for the last ring has been calculated, a felling date, or felling date range based on an appropriate sapwood estimate, may be assigned using identical methods to those in ring-width dendrochronology (English Heritage 1998).

Results

Sample KMF-A05 comprises 83 ring-width and 83 isotope measurements (rings 1–83 of the ring-width series; Table 1) and KMF-A11 comprises 127 ring-width and 127 isotope measurements (rings 1–127 of the ring-width series; Table 1). In both instances it was possible to sample every ring in the series as there was sufficient latewood available for analysis. The oxygen isotope data from both cores are provided in the Appendix.

The isotopic series from KMF-A05 cross-matches with a relative offset of –5 years against the last (most recent) isotopic measurement from KMF-A11 (Table 3; Fig 5), which is consistent with the relative position of these samples produced by the ring-width dendrochronology (Arnold and Litton 2003, fig 9). The Student's *t*-value (9.05) between the isotopic series compares favourably with the Baillie-Pilcher *t*-value (8.95) between the ring-width series for these samples.

A 127-year mean isotope series was compiled at the offset of –5 years between KMF-A05 and KMF-A11 which, when compared against the south-central England oxygen isotope master chronology, produced the strongest cross-matching where the last ring of the mean isotopic series dates to AD 1534 (Table 4; Fig 6). This suggests that the last ring on which isotopic measurements were obtained from KMF-A11 (ring 127) dates to AD 1534, and that the last ring on which isotopic measurements were obtained from KMF-A05 (ring 83) dates to AD 1529. This is compatible with the cross-dating for these timbers indicated by ring-width dendrochronology (Table 2; Arnold and Litton 2003) which indicates dates of AD 1447–1529 for the 83-year ring-width series from KMF-A05 and AD 1408–1534 127-year ring-width series from KMF-A11.

The cross-dating of the mean isotopic series from Manor House, Fordwich passes the thresholds for consideration as dated suggested by Loader *et al* (2019), (Student's t=8.39, df=108, 1/p > 1 million, IF > 1000). In this test case, there is independent ring-width dendrochronology available which supports the date obtained through oxygen isotope dendrochronology. Individually, both the timbers produce cross-dating statistics that pass the thresholds for consideration; KMF-A05, Student's *t*=6.15, df=71, 1/p = 69,516, IF > 1000, and KMF-A11, Student's *t*=8.30, df=107, 1/p => 1 million, IF > 1000.

The dates obtained by oxygen isotope dendrochronology are in agreement with those attained using ring-width dendrochronology, with the strength of the dating statistics indicating that the oxygen isotope signals recorded in these trees from the south-east corner of England share much in common with the south-central England signal as contemporaneous trees growing within the region from which the reference chronology originates (Loader *et al* 2019). This would suggest that isotopic dendrochronology using the south-central England chronology may be considered for dating timbers from this region, although the development of an isotopic reference chronology developed from trees growing within Kent may provide a more locally-representative dating signal.

CONCLUSIONS

The two oxygen isotope series obtained from Manor House cross-match with each other (Student's *t*-value of 9.05) with an offset consistent with the ring-width analyses performed previously (Arnold and Litton 2003, table 1 and figure 9). Combination of these two series into a 127-year mean record dates strongly (Student's *t*-value of 8.39) against the south-central England oxygen isotope master chronology (Loader *et al* 2019) returning a date of AD 1534 for the last (most recent) ring of the measured isotope series (Table 4).

This date is consistent with that obtained for the same rings using conventional ring-width dendrochronology. Manor House, Fordwich is located to the south-east of the south-central England region where the master chronology was constructed. The dominant control on the latewood oxygen isotope composition of tree-rings across the UK is summer precipitation, it is therefore likely that the isotopic composition of precipitation in Kent shares much with the precipitation regime recorded in the south-central England master chronology. This study suggests that, dates are likely to be obtained from series of isotopic measurements on single or multiple timbers in this region, although further investigation of other timbers securely dated by ring-width dendrochronology in this region is clearly appropriate. The development of a more area-specific chronology may provide further potential for stronger, more localised dating, particularly with respect to short ring series that prove problematic for conventional ring-width dendrochronology.

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TABLES

Table 1: Sample description: timber type and position, material analysed, number of complete tree rings (N), number (Ni) and range of rings for which δ¹⁸O measurements were undertaken, and laboratory code.

Sample	Timber and position	Material	N	N_i	$\delta^{18}O$ (Measured rings)	Laboratory code
KMF-A05	West brace to the north principal, truss 2	Latewood α-cellulose *Quercus* spp	83	83	1–83	SWAN-33a
KMF-A11	East brace to the north principal, truss 4 (h/s)	Latewood α-cellulose *Quercus* spp	127	127	1–127	SWAN-33b

Key: h/s=heartwood/sapwood boundary

Table 2: Results of the cross-dating of the 293-year ring-width site chronology KMFASQ01, which includes KMF-A05 and KMF-A11, against a selection of independent ring-width reference chronologies when the first-ring date is AD 1264 and the last-ring date is AD 1556 against the enhanced network of oak site reference chronologies now available

Reference chronology	Span of chronology	t-value	Reference
Stonepitts Manor, Seal, Kent	AD 1445–1542	8.8	Arnold *et al* 2003
Shurland Hall gatehouse, Eastchurch, Kent	AD 1405–1526	8.5	Arnold and Howard 2008
Mary Rose (refit) wreck, Hampshire	AD 1372–1535	8.1	Bridge 1996
Martin Tower, Tower of London, London	AD 1379–1534	7.7	Bridge 1986
Hays Wharf, Southwark, London	AD 1248–1647	7.3	Tyers 1996a; Tyers 1996b
Trig Lane, London	AD 1130–1407	7.1	Tyers 1992
Westenhanger Castle barn, Stanford, Kent	AD 1323–1489	6.9	Arnold and Howard 2009
Chilton Manor, Sittingbourne, Kent	AD 1368–1520	6.7	Howard *et al* 1988
Walmer Castle, Kent	AD 1396–1523	6.5	Arnold and Howard 2015
Longport Farmhouse, Kent	AD 1334–1599	6.5	Tyers 1996c

Table 3: Cross-dating matrix for samples KMF-05 and KMF-11 identifying number of rings [Ni] for which $\delta^{18}O$ measurements have been undertaken. Upper right: significant Student's t-value and position (offset; the KMF-05 isotopic series ends 5 years before that of KMF-11). Lower left (shaded cell): Pearson's correlation coefficient and degrees of freedom for position of best match (series compared column versus row)

	KMF-A05 [83]	KMF-A11 [127]
KMF-A05 [83]	-	9.05 –5
KMF-A11 [127]	0.732 71	-

Table 4: Stable oxygen isotope dating of the composite and individual samples from the Manor House, Fordwich against the south-central England master chronology (Loader et al *2019) over the period AD 1200–AD 2000. Number of whole rings present in core sample (N), number of rings on which $\delta^{18}O$ measurements were undertaken (Ni), Pearson's correlation coefficient (r), degrees of freedom (adjusted for autocorrelation and multiple sampling), Student's* t-*value, probability (1/p), isolation factor (IF), and date.*

Sample	Description	N	N_i	r	df	*t*	1/p	IF	Date
KMF-x	Mean of KMF-05 & KMF-11	127	127	0.624	108	8.39	>1 million	>1000	AD 1534
KMF-A05	W brace to N principal, T2	83	83	0.590	71	6.15	69,516	>1000	AD 1529
KMF-A11	E brace to N principal, T4	127	127	0.622	107	8.30	>1 million	>1000	AD 1534

FIGURES

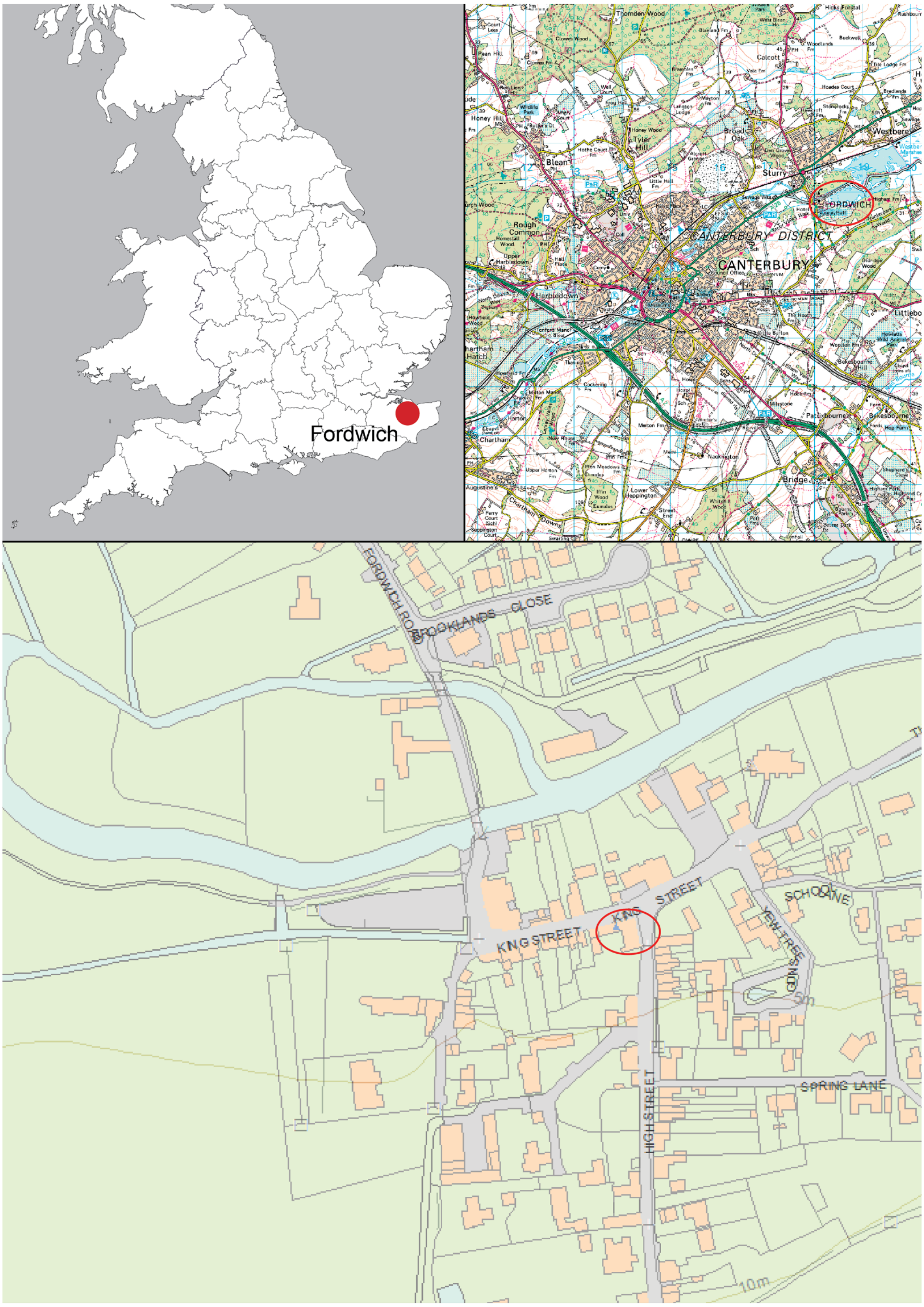

Figure 1: Maps to show the location of Manor House, Fordwich, circled. © Crown Copyright and database right 2022. All rights reserved. Ordnance Survey Licence number 100024900.

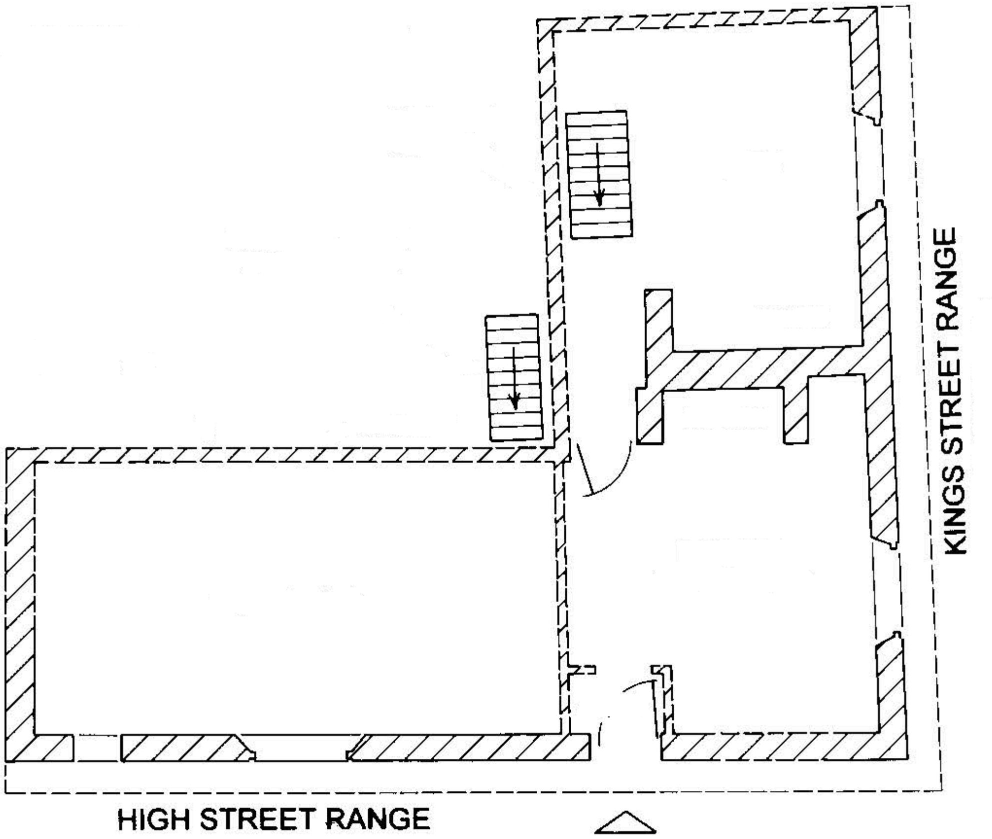

Figure 2: The Manor House, Fordwich, ground floor layout (based on a drawing by Rupert Austin 1997 unpubl)

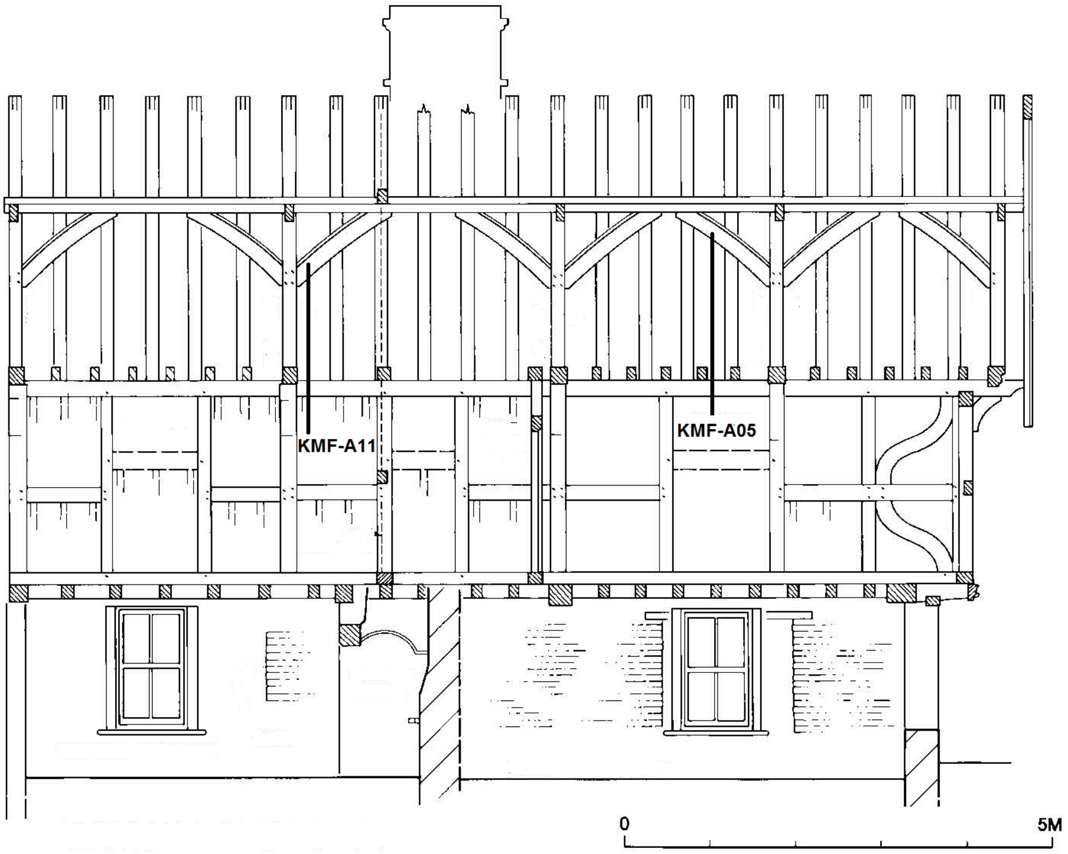

Figure 3: The Manor House, Fordwich, section to north showing the location of samples KMF-A05 and KMF-A11 (based on a drawing by Rupert Austin 1997 unpubl)

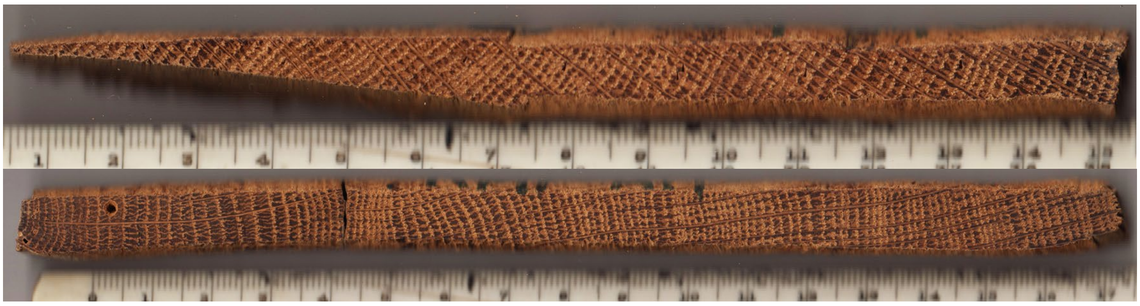

Figure 4: Samples KMF-A05 (top) and KMF-A11 (bottom) showing the ring-widths for both of these cores (note crack in KMF-A11)

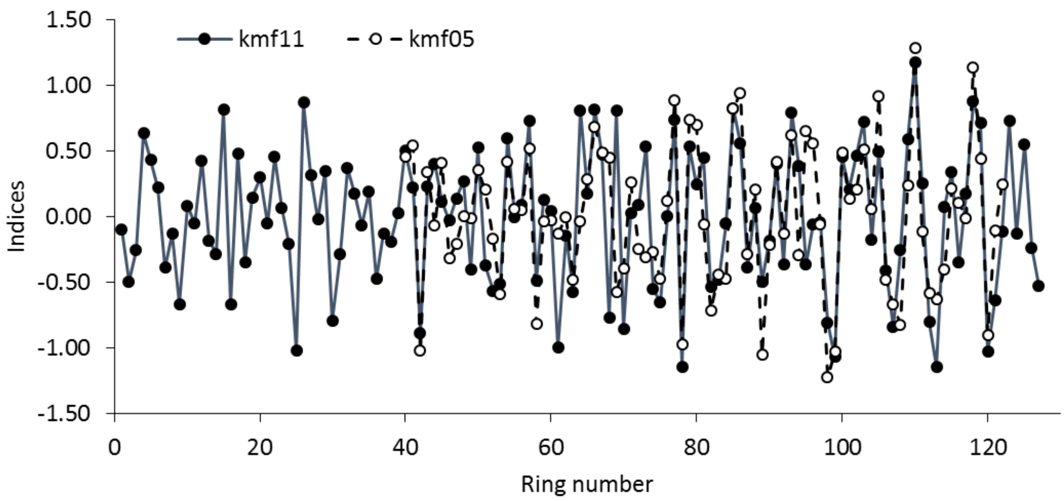

Figure 5: Time series of the filtered and indexed $\delta^{18}O$ values from the two samples plotted at the position of strongest match (Student's t*-value of 9.05).*

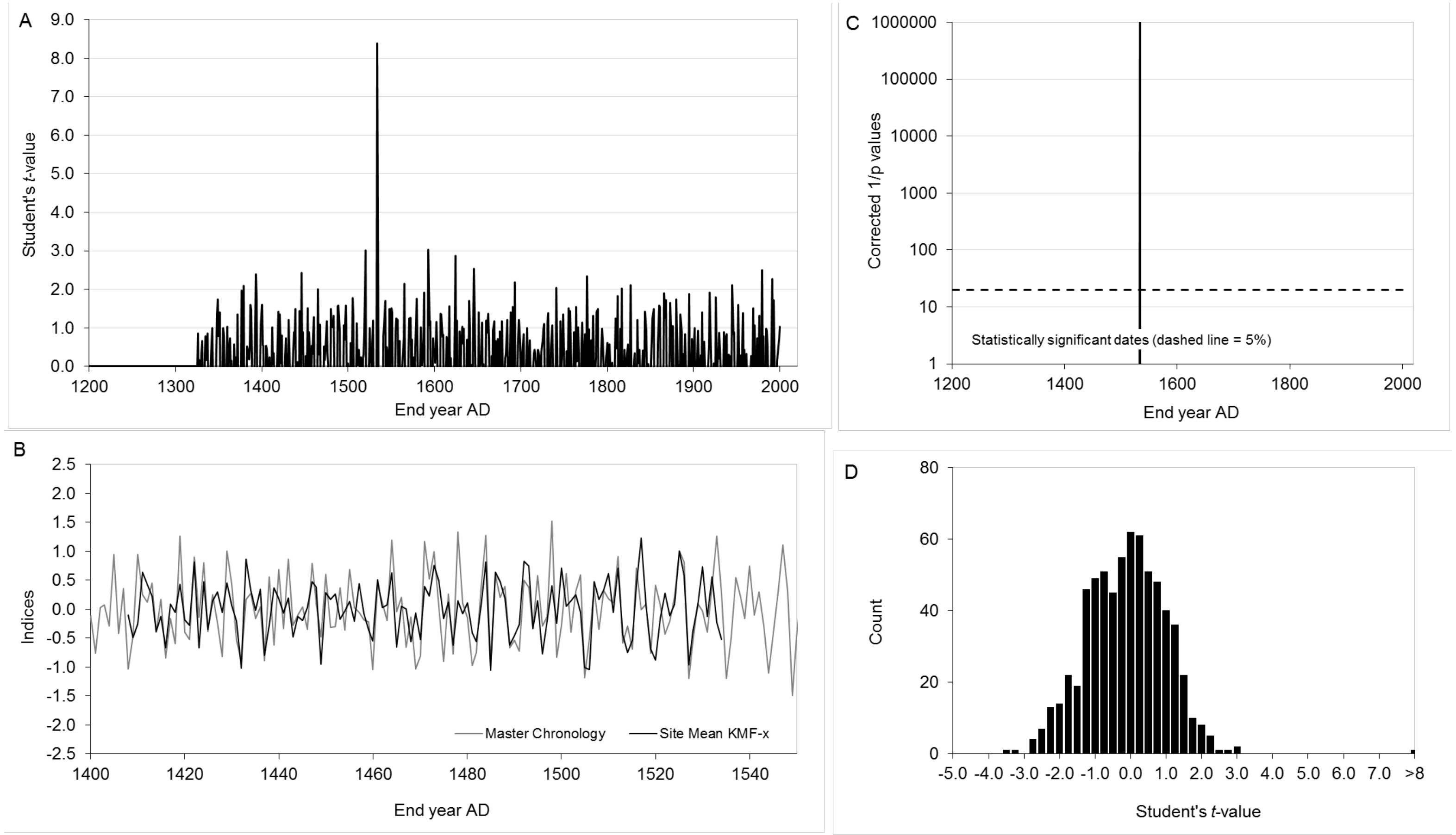

Figure 6: Dating results for the 127-year mean isotope chronology (KMF-A05 and KMF-A11). A: Student's t*-values for all possible end dates with full overlap against the master chronology. B: Time series of the site isotopic mean plotted against the master chronology (Student's* t*-value of 8.39). C: End dates with corrected probabilities (1/p) of more than one. Those below the dashed line (1/p = 20) are not statistically significant. D: Distribution of Student's* t*-values for all possible matches*

APPENDIX

Oxygen isotope ratios ($\delta^{18}O$) for the measured tree ring series

Data are reported as per mille (‰) deviations relative to the VSMOW standard (Coplen 1995).

Sample KMF-A05

Ring	$\delta^{18}O$	Ring	$\delta^{18}O$	Ring	$\delta^{18}O$
1	29.10	36	27.64	71	29.57
2	29.23	37	28.33	72	28.26
3	27.57	38	29.18	73	27.90
4	29.02	39	27.34	74	27.98
5	28.52	40	29.12	75	28.38
6	28.92	41	29.14	76	29.00
7	28.14	42	28.50	77	28.87
8	28.36	43	27.89	78	28.88
9	28.48	44	28.28	79	30.20
10	28.38	45	28.24	80	29.57
11	28.72	46	29.38	81	28.13
12	28.58	47	29.51	82	29.00
13	28.18	48	28.43	83	29.50
14	27.77	49	28.97		
15	28.66	50	27.84		
16	28.22	51	28.58		
17	28.15	52	29.18		
18	28.59	53	28.73		
19	27.31	54	29.43		
20	28.00	55	28.46		
21	28.02	56	29.29		
22	27.98	57	29.19		
23	28.16	58	28.57		
24	27.86	59	27.33		
25	28.39	60	27.60		
26	28.68	61	29.05		
27	29.06	62	28.73		
28	28.87	63	28.77		
29	28.82	64	29.14		
30	27.72	65	28.69		
31	27.79	66	29.51		
32	28.29	67	28.20		
33	27.72	68	27.96		
34	27.70	69	27.67		
35	27.70	70	28.65		

Sample KMF-A11

Ring	δ18O	Ring	δ18O	Ring	δ18O	Ring	δ18O
1	27.58	36	27.99	71	28.51	106	28.65
2	27.17	37	28.34	72	28.47	107	28.20
3	27.31	38	28.18	73	29.04	108	28.61
4	28.25	39	28.47	74	27.68	109	29.33
5	28.05	40	29.01	75	27.71	110	29.85
6	27.89	41	28.81	76	28.40	111	28.99
7	27.37	42	27.73	77	29.20	112	27.95
8	27.77	43	28.92	78	27.23	113	27.64
9	27.21	44	29.12	79	28.99	114	28.90
10	27.98	45	28.72	80	28.82	115	29.14
11	28.00	46	28.58	81	29.15	116	28.33
12	28.55	47	28.78	82	28.19	117	28.89
13	28.10	48	28.78	83	28.37	118	29.73
14	28.14	49	27.97	84	28.79	119	29.64
15	29.36	50	28.92	85	29.62	120	27.84
16	28.01	51	27.99	86	29.30	121	28.36
17	29.18	52	27.76	87	28.45	122	28.86
18	28.50	53	27.83	88	28.90	123	29.57
19	29.09	54	28.93	89	28.41	124	28.61
20	29.17	55	28.27	90	28.64	125	29.47
21	28.80	56	28.42	91	29.08	126	28.71
22	29.35	57	29.03	92	28.30	127	28.50
23	29.02	58	27.87	93	29.41		
24	28.69	59	28.40	94	28.91		
25	27.86	60	28.45	95	28.03		
26	29.64	61	27.47	96	28.33		
27	28.97	62	28.40	97	28.41		
28	28.60	63	28.13	98	27.63		
29	28.96	64	29.48	99	27.43		
30	27.86	65	28.98	100	29.03		
31	28.25	66	29.67	101	28.91		
32	28.79	67	29.33	102	29.20		
33	28.57	68	28.13	103	29.52		
34	28.24	69	29.66	104	28.75		
35	28.57	70	27.85	105	29.46		

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