Tree-Ring Analysis of Timbers from Waxham Great Barn, Sea Palling, Norfolk

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Summary

Dendrochronological analysis was undertaken on eighteen oak timbers from Waxham Great Barn. The barn, 55m (180ft) in length, is the longest historic barn in Norfolk, and doorways excepted, the trusses alternate between queen-strut and hammer beam. Sixteen samples were successfully cross-matched to produce a single site chronology WAXHAMBN of 147 rings, spanning the period AD 1437 - AD 1583. The analysis indicates that construction of Waxham Great Barn occurred shortly after felling in the winter of AD 1583/4.

Keywords
Dendrochronology,
Standing Building

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INTRODUCTION

Waxham Great Barn (NGR: TG 4395 2620) is located on the north Norfolk coast, 27.1km (16.8 miles) northeast of Norwich and 2.3km (1.4 miles) southeast of Sea Palling (Fig 1). A grade I listed building, it is thought from stylistic evidence to date from the late sixteenth century, *c* AD 1570. Seven trusses located at the eastern end of the building were blown down in AD 1987 by the October gale. During the repairs that followed it was possible to re-erect the original trusses with only a few lengths of new timber needed. The building is now owned by Norfolk County Council. Tree-ring analysis was commissioned by Peter Marshall, English Heritage assistant Scientific Dating Co-ordinator, with the aim of obtaining a precise date of construction for the barn, to help inform future management, and presentation to the public. The following history and description are summarised from Heywood and Ayton (1994).

Figure 1: Area location map

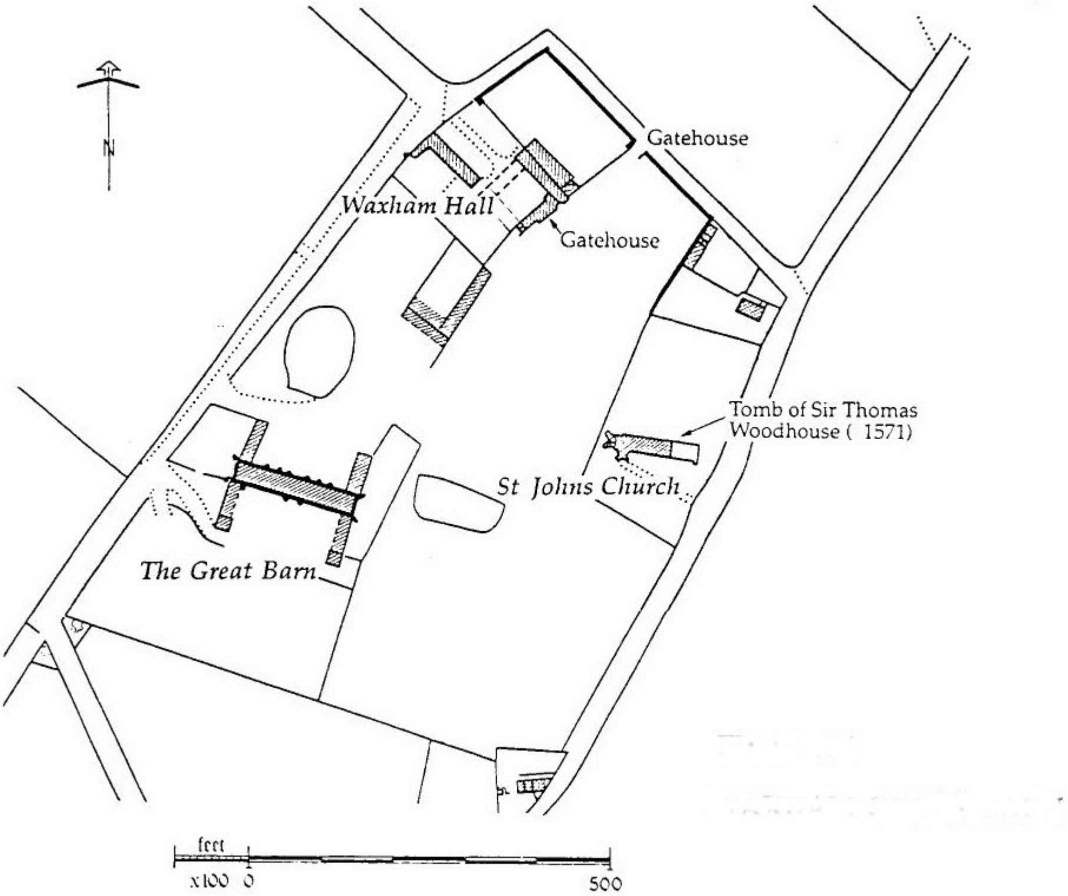
History

Waxham Great Barn is just one major element of the important Elizabethan manor of Waxham (Fig 2). The earliest mention of the Woodhouse family of Waxham is in AD 1504, and it was probably in the time of Sir Thomas Woodhouse, who died in AD 1571, and his brother William, who succeeded him, that the barn and hall were built. Sir Thomas Woodhouse was the High Sheriff in AD 1553, and his brother William was knighted for gallantry in AD 1544. Both Sir William and his son Sir Henry were Vice Admirals of the Fleet.

During the AD 1580s the threat of the Spanish Armada caused the creation of coastal defences. Sir Henry Woodhouse played a role as captian of footmen responsible for the defence of Great Yarmouth during certain specified weeks in the summer months (Cozens-Hardy 1938). A map made to accompany the defence arrangements in AD

1588, now held at Hatfield House, draws the hall as a fortified manor house, clearly representing a coastal stronghold.

Figure 2: Site map of the Manor of Waxham (from Heywood and Ayton, 1994)



Description of Waxham Great Barn
The barn is 55m (180ft) long and the longest barn in the county. The barn is constructed of carefully coursed flint with brick and limestone dressing. All the limestone is re-used, having been taken from three local priories bought by the Woodhouses after the Dissolution of the Monasteries in the AD 1530's. The diagonal buttresses at the corners of the building were literally dismantled, transported by boat, and re-erected as they were. The gable-ends and the side of the barn facing the hall are decorated with a diamond pattern of brick (Fig 3).

The interior of the barn is dominated by the massive roof structure consisting of 20 principal trusses (Fig 4). Except at the doorways, the trusses alternate between queen-strut and hammer beam. Both hammer beams and tiebeams have arched braces dropping to the wall posts, which are mostly missing or replacements (Fig 5). Queen struts rise to the principle rafters and support three tiers of butt purlins. Each truss is clearly and consecutively numbered with carpenters' marks. There are curved windbraces below the top tier of purlins. The collars are carried on arch braces. Presumably at a later date, the interior has been partitioned at truss T15 by a brick wall up to tiebeam level.

Figure 3: Waxham Great Barn, west aspect (Andy Moir 2003)

Figure 4: Roof trusses, looking west (Andy Moir 2003)

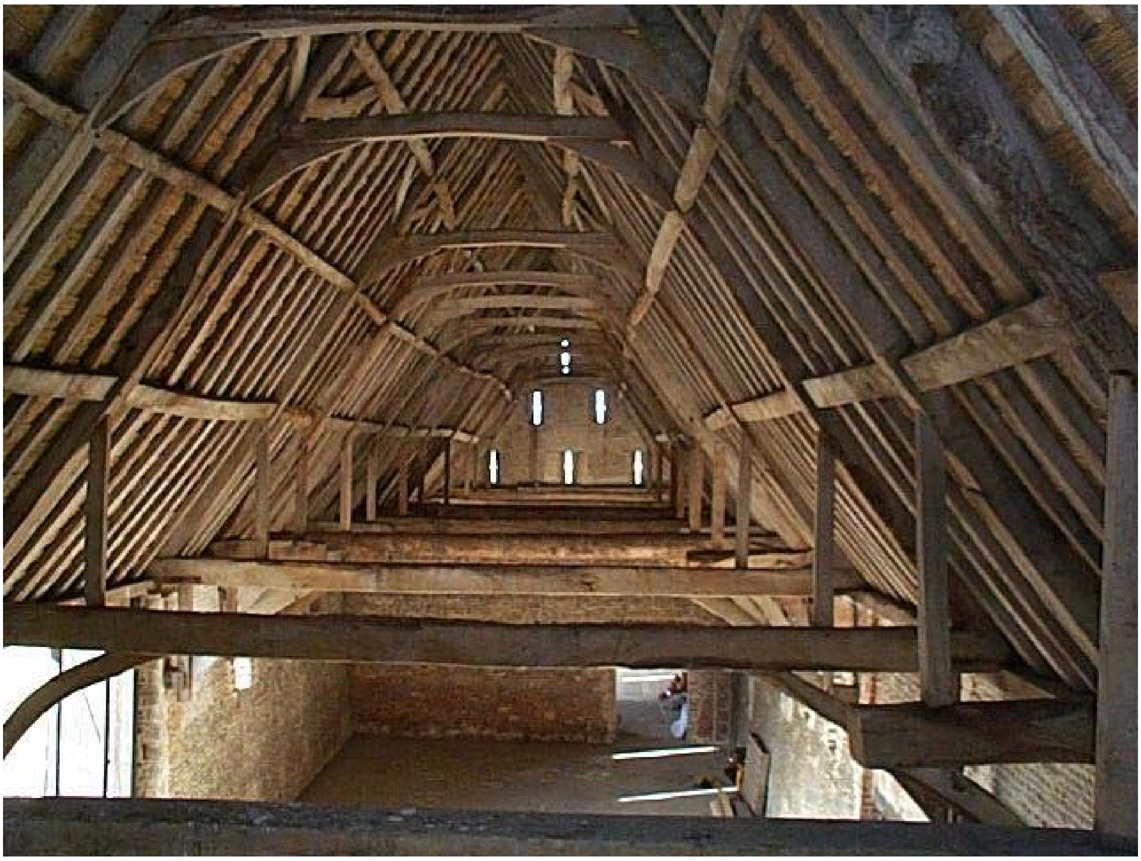
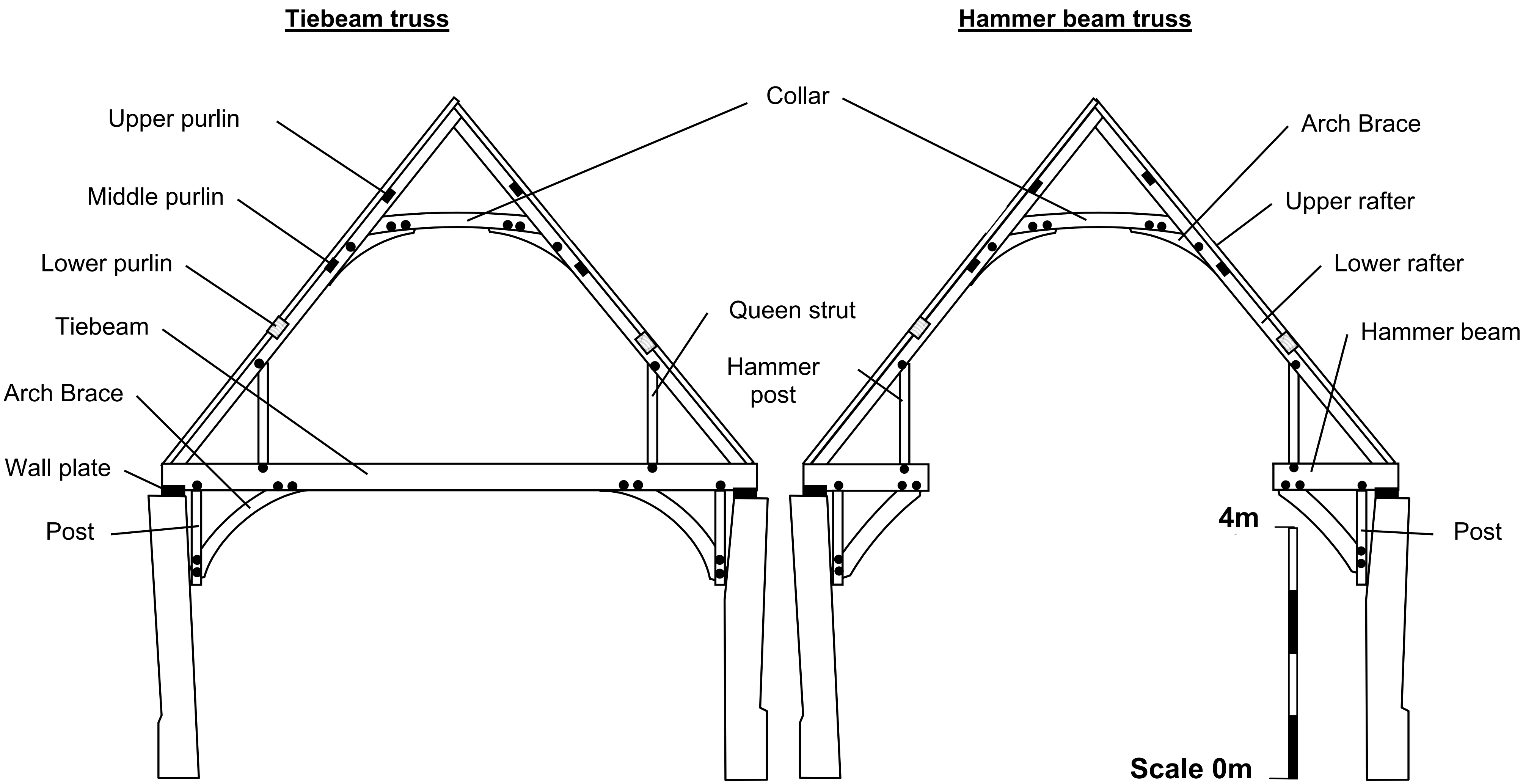


Figure 5: Section of trusses at Waxham Great Barn, showing the nomenclature employed in the report (adapted from Heywood)



METHODOLOGY

The general methodology employed by Tree-Ring Services are those described in English Heritage guidelines (English Heritage 1998). Details of the precise methods employed for the analysis of this building are described below. Tree-ring analysis and graphics are achieved via a dendrochronological programme suite developed by Ian Tyers of Sheffield University (Tyers 1999a). Location maps are produced via *Auto Street Navigator,* software produced by ISYS Systems Ltd which uses Ordnance Survey digital map data © Crown Copyright 1999-2000.

Sampling and preparation

During the assessment stage timbers containing more than 50 rings were actively sought for sampling, this being the minimum number generally considered necessary for analysis (English Heritage 1998). Timbers were sampled using purpose-made 12mm and 15mm diameter corers attached to an electric drill. Sampling was located as discreetly as possible in what appeared to be original timbers and in the most suitable direction to maximise the numbers of rings for subsequent analysis. The smaller 12mm corer was used preferentially to keep the core extraction holes as unobtrusive as possible. The larger 15mm corer was used when either core or sapwood recovery was found to be, or indicated might be, problematic. Extracted core samples were immediately taped and glued onto wooden laths on site and then labelled and left to dry ready for subsequent analysis. Tree-ring sequences were revealed through sanding with progressively finer grits to a 400 abrasive grit finish to produce a clean cross-sectional surface suitable for measuring.

Measuring and cross-matching

Samples with 40-50 rings may be dated in some circumstances, therefore if sequences of this length are recovered, they are measured and considered for matching. Tree-ring sequences are measured under a x20 stereo microscope to an accuracy of 0.01 mm using a microcomputer based travelling stage. Samples are measured twice and the two sets of measurements, eg, WBSP03a and WBSP03b cross-matched and plotted visually to facilitate visual comparison as a means of identifying measuring errors. Where sequences match satisfactorily they are averaged and the resulting sequence used in subsequent analysis, eg, WBSP03.

Cross-correlation algorithms are then employed to search for the positions where tree-ring sequences correlate and therefore possibly match. All statistical correlations are reported as *t*-values derived from the original CROS73 algorithm (Baillie and Pilcher 1973). Those *t*-values in excess of 3.5 are taken to be significant and indicative of acceptable matching positions (Baillie 1982). However, due to the risk of high *t*-values being produced by chance, all indicated correlations are further checked to ensure that corroborative results are obtained at the same relative position against a range of other tree-ring sequences. Visual comparisons of sequences are also employed to support or reject possible cross-matches.

Tree-ring analysis is also used to investigate the likelihood of same-tree groups between samples based on a combination of high levels of matching and similar longer-term growth patterns or anatomical anomalies. Timbers derived from the same parent tree are generally expected to have *t*-values over 10, although lower *t*-values do not exclude the possibility that timbers are from a single tree, as it is the range of information that provides the link. Tree-ring sequences producing *t*-values of 9 or above are examined for same-tree relationships, and where other evidence does not dispute this, the sequences are averaged to produce a single tree-ring sequence to avoid bias in the final site mean.

Chronology building and cross-dating
The process of cross-matching compares all tree-ring sequences from a single building or phase against one another, and those found to cross-match satisfactorily together are combined to create an average sequence. This site mean(s) and remaining unmatched ring sequences are tested against each other and a range of established reference sequences (reference chronologies); *t*-values over 3.5, replicated against a wide range of sequences at the same position with satisfactory visual matching are similarly used to establish cross-matches with reference chronologies.

Felling dates and sapwood estimates
Where bark survives intact on a sample the exact date of felling of the tree used may be determined. Based on the completeness of the final ring it is sometimes possible to distinguish between spring, summer or winter fellings, corresponding to approximately March to May, June to September and October to February respectively. Where timbers were felled in either spring or summer the final ring is incomplete and therefore not measured, so allowance has to be made for the discrepancy between the end of the measured sequence and the actual year of felling. It is not always possible to distinguish between an incomplete ring and a complete narrow ring and therefore the season may be indistinct. In cases where it is either thought probable that bark edge was present, or recorded that bark edge was present, but a few of the delicate outer rings become damaged or lost, a circa (*c*) date is applied. In case such as these, the felling dates are probably accurate to within a few years. Where bark is present within a group of timbers and other evidence does not dispute the date, it is assumed that all the trees within the group were felled in the same year.

Where bark is missing from oak samples, as long as either sapwood or the heartwood/sapwood boundary has been identified, an estimated felling date range can be calculated using the maximum and minimum number of sapwood rings that were likely to have been present. This report applies a minimum of 9 and maximum of 41 annual rings sapwood estimate (Miles 1997). Felling date ranges are calculated by adding the sapwood estimate of minimum and maximum missing rings to the date of the heartwood/sapwood boundary, though this may be refined by the presence of surviving sapwood where appropriate. In the absence of any sapwood, the minimum number of sapwood rings from the appropriate sapwood estimate is added to the last measured ring to give a *felled after* date. This represents the date after which the timber is likely to have been felled, although the actual date of felling could be much later depending on the number of heartwood rings that have been removed.

Date of construction
Green or freshly felled wood is far easier to work, and it is standard practice to assume that (until relatively recently) timbers were felled as required and used green (Rackham 1990; Miles 1997). Nevertheless, some caution must be used in interpreting precise felling dates in isolation, as dendrochronological analysis provides dates for when trees were felled but not necessarily when their timbers were used. Many instances have been noted where timbers used in the same structural phase have been felled one, or two or more years apart. The use of wind-fallen, leftovers or

re-used timbers can also give rise to discrepancies between precise felling dates and the period of construction. Wherever possible, a group of precise felling dates should be used as a more reliable indication of a period of construction.

RESULTS

Assessement

Waxham Great Barn was visited on the 8th November AD 2002 and prior to sampling, a brief dendrochronological assessment was undertaken in the company of Stephen Heywood (Norfolk County Council) and Cathy Groves (EH/Sheffield University Dendrochronology Laboratory). The timbers were assessed for their potential use in dendrochronological study. Oak timbers with more than 50 rings, traces of sapwood, and accessibility were the main considerations. Due to the extreme height of the roof (the collars being at some 9m above ground) a hydraulic cradle, commonly termed a "cherry picker", was required to give access to the timbers. The problems associated with the moving of the cherry picker resulted in the initial assessment being mostly undertaken from ground level and a necessary reduction of the areas closely examined.

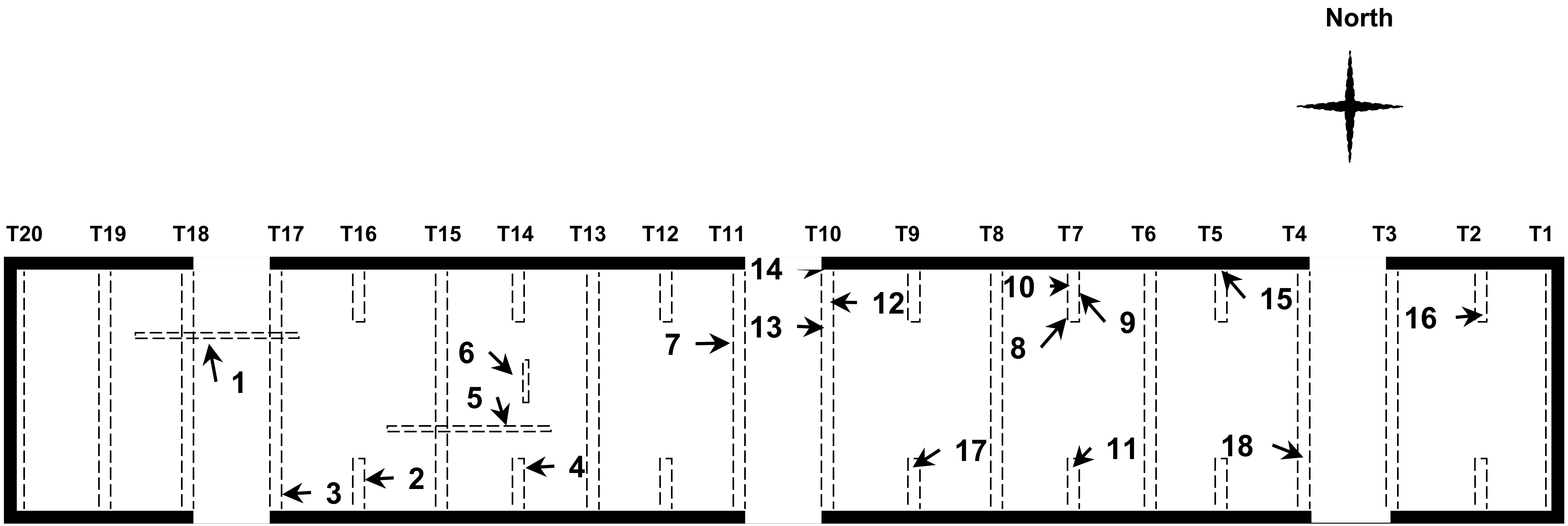
Bark was identified on many timbers. Tree-rings were observable in section at the ends of the hammer beams, which indicated these oak timbers as suitable for analysis. The principal rafters and other roof timbers examined were fast grown, and it was immediately apparent they probably had insufficient number of tree-rings for analysis. In view of the associated problems of access, these timbers were considered less suitable for sampling. With the exception of a conifer tiebeam in truss 13, all the timbers appeared to be oak. The tiebeams in Trusses T6, T8, and T13 (the last of which appeared to be a re-used ship's mast), were highlighted as replacements (Heywood pers comm) and so were excluded from the brief. Replacement timbers, presumably from repairs following the AD 1987 damage, were more common at the eastern end of the barn, an example being the braces in trusses T3 and T4. Most of the posts supporting the hammer beams were missing or replaced. After some discussion on hammer beam construction, it was agreed to sample one truss with a view to establishing whether or not there was a same tree relationship between the opposing hammer beams.

Though the roof structure is thought to be of one phase, due to the barn’s extreme length prudent procedure required sampling along its entire length to identify any possible variation in the felling dates of timbers. However, the timbers at the eastern end of the barn appeared to be more affected by damp, and this appeared to be confirmed by greater difficulties in core recovery. The wall plates were also inaccessible for coring, except at the south side of bay 3, but this timber was obviously rotten and so was not sampled. Storage of reclaimed stone in the barn meant that bays 1 to 3 were inaccessible to the cherry picker and could only be sampled up to tiebeam level by ladder.

Sampling and Dating

Trusses were numbered one to twenty from east to west in accordance with the carpenters' marks previously noted by Heywood and Ayton (1994). Samples, prefixed by WBSP, were taken from 18 timbers on the 8th and 9th November. Details of the samples are provided in Table 1. The locations of the samples are shown in Figures 6 and 7.

Figure 6: Sketch plan of Waxham Great Barn, showing the truss numbering scheme followed in this report and the approximate location of cores WBSP01 to WBSP18. (Adapted from Heywood)



Note: Not to scale.

Figure 7: Section of trusses T7 and T10 at Waxham Great Barn, showing the multiple cores sampled from these trusses (adapted from Heywood).

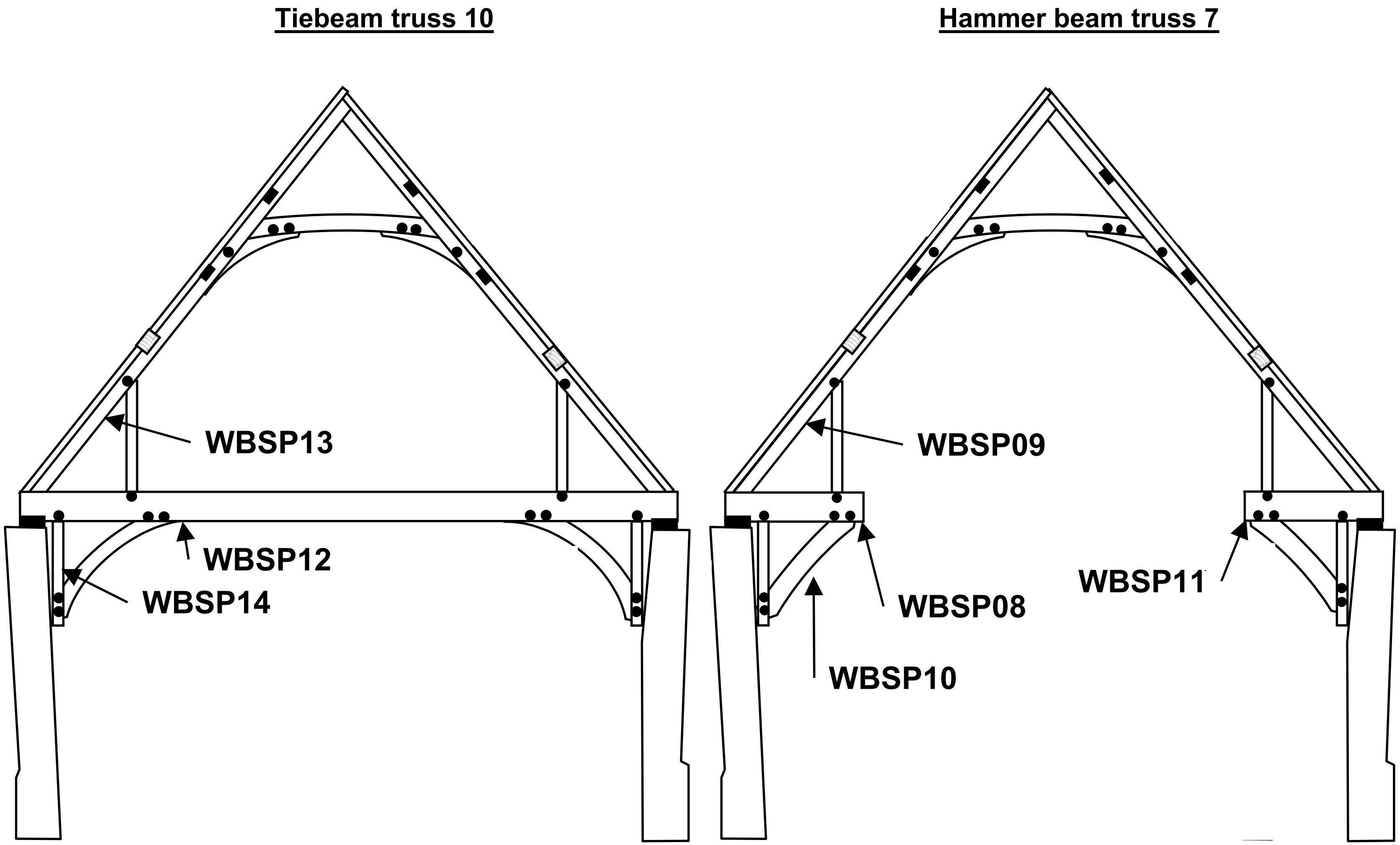


Table 1: Summary of dendrochronological analysis

Timber and position	Timber Conversion	Timber dimensions (mm)	Rings	Pith	Sen-sitivity	Average Growth (mm/year)	Sapwood	Additional Sapwood	Sequence Date Range	Felling Dates
Middle purlin [north] - Bay 17	C2	? x ?	71	G	0.28	1.84	HS	+10mm	AD1501-AD1571	AD1580-1612
Hammer beam [south end] - Truss 16	A2	335 x 255	141	G	0.15	1.73	21	+Bw	AD1443-AD1583	AD1583/4 winter
Tiebeam [south end] - Truss 17	A2	320 x 280	48	G	0.27	1.88	HS		AD1513-AD1560	AD1569-1601
Hammer beam [south] - Truss 14	A2	325 x 210	81	G	0.20	2.57	14		AD1494-AD1574	AD1574-1601
Middle purlin [south] - Bay 14	C2	110 x 140	37	F			HS			
Collar - Truss 14	C2	160 x 140	65	G	0.25	1.69	17	+Bw	AD1519-AD1583	AD1583/4 winter
Tiebeam [north end] - Truss 11	C2	330 x 240	115	G	0.17	1.40	27	+5mm#	AD1465-AD1579	AD1583/4 winter
Hammer beam [north] - Truss 7	B2	325 x 240	120	V	0.20	1.59	28	+Bw	AD1464-AD1583	AD1583/4 winter
Principle rafter [north] - Truss 7	C2	210 x 200	49	V	0.24	4.67	HS	+1	AD1521-AD1569	AD1578-1610
Brace [north] - Truss 7	B2	225 x 75	117	G	0.19	0.94	14		AD1457-AD1573	AD1573-1600
Hammer beam [south] - Truss 7	A2	340 x 245	80	F	0.20	1.90	22	+Bw	AD1504-AD1583	AD1583/4 winter
Tiebeam [north end] - Truss 10	C2	320 x 245	147	G	0.20	1.61	32	+Bw	AD1437-AD1583	AD1583/4 winter
Principle rafter [north] - Truss 10	C2	220 x 240	139	G	0.27	1.52	12	+2 to B?	AD1442-AD1580	*c* AD1582
Post [north] - Truss 10	C2	115 x 190	142	V	0.18	1.40	23	+Bw	AD1442-AD1583	AD1583/4 winter
Post [north] - Truss 5	C2	120 x 175	72 (+21)	F	0.21	1.59		+15	AD1450-AD1521	After AD1557ф
Hammer beam [north] - Truss 2	B2	330 x 230	88	G	0.20	1.19	5	+12mm	AD1477-AD1564	AD1568-1600
Hammer beam [south] - Truss 9	B2	360 x 245	64	V	0.20	3.33	2	+8	AD1503-AD1566	AD1574-1605
Tiebeam [south end] - Truss 4	A2	350 x 245	6							

KEY:

*: 15mm cores

Timber Conversion: A2 = box-heart / trimmed, B2 = halved / trimmed, C2 = quartered / trimmed.

Timber Dimensions: Generally taken at core sample location and therefore not necessarily the maximum dimension.

Pith: V = very near, F = Fairly near, G = Not near.

Rings: (+21) = 21 rings of unmeasured heartwood. Note the sapwood is additional to this number of unmeasured rings.

Sapwood: HS = heartwood/sapwood boundary, + = number of sapwood rings not measured in the sequence, B? = bark probably present, +Bw = bark present, # = but also see wbsp12, ф = additional rings detached so only possible to provide a felled after date.

In six instances the cores obtained had complete sapwood. Cores WBSP01 and WBSP07 lost about 10mm and 5mm sapwood respectively during coring. Core sample WBSP16 from the hammer beam in truss T2 lost 12mm of its sapwood during recovery. Core WBSP15 from a post in truss T5 broke in half during coring and it was unknown if rings were lost at the break. The second half of this core contained only 32 measurable rings plus 4 unmeasurable. The core WBSP18 from the tiebeam in truss T4 was abandoned after all sapwood was lost, and the core broke into fragments after only a 30mm length had been recovered. Both the north and south hammer beams from T7 were sampled in order to examine the possible same tree relationship of the hammer beams in this truss.

All samples from the barn were confirmed during preparation to be oak (*Quercus* spp.). Samples WBSP05 and WBSP18 contained insufficient number of rings and were rejected. Of the original eighteen core samples taken (Appendix 1), sixteen samples contained sufficient rings to be considered for further dendrochronological analysis. All these sequences were successfully cross-matched statistically (Table 2).

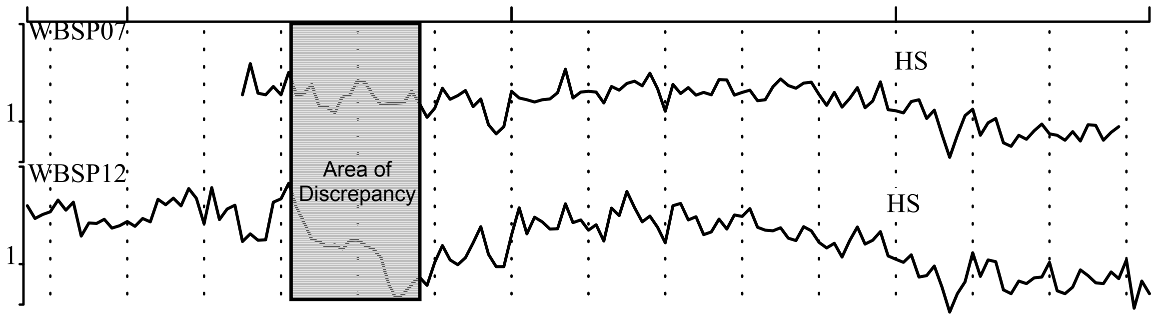
Table 2: Cross-matching between series from Waxham Barn

File-names	wbsp 02	wbsp 03	wbsp 04	wbsp 06	wbsp 07	wbsp 08	wbsp 09	wbsp 10	wbsp 11	wbsp 12	wbsp 13	wbsp 14	wbsp 15	wbsp 16	wbsp 17
wbsp01	3.86	-	-	-	-	4.91	3.61	3.90	3.92	-	-	-	-	-	-
wbsp02		4.15	3.87	3.70	-	-	-	3.64	3.82	-	4.39	4.69	-	5.61	3.52
wbsp03			-	-	-	-	-	-	-	-	-	3.63	\	4.74	4.17
wbsp04				-	-	4.55	-	5.44	-	-	-	4.51	3.98	-	-
wbsp06					4.40	4.37	7.81	5.34	4.94	6.32	4.33	5.62	\	3.73	5.84
wbsp07						4.26	4.86	3.94	-	9.44	4.25	5.35	4.10	4.57	4.96
wbsp08							3.86	4.97	6.02	4.28	-	6.51	4.00	5.33	-
wbsp09								4.79	3.64	5.84	5.36	5.83	\	4.03	6.45
wbsp10									-	-	3.84	5.57	3.87	4.49	-
wbsp11										4.19	4.76	-	-	5.50	-
wbsp12											5.52	4.65	3.71	3.54	4.49
wbsp13												3.88	-	3.94	4.73
wbsp14													6.84	6.38	5.10
wbsp15														5.02	-
wbsp16															-

KEY: \ = overlap < 15 years, - = *t*-value less than 3.50.

The two sequences WBSP07 and WBSP12 displayed a high *t*-value of 9.44. The sequences share very similar short and longer term growth patterns except for one 20-year period which appears from core WBSP12 to be explained by a small growth disturbance, possibly a knot (Fig 8). It was concluded that both timbers probably derived from the same parent tree. Sequences WBSP07 and WBSP12 were therefore averaged to produce a single tree-ring sequence called WBSP07&12 for inclusion in the final site mean sequence to avoid bias.

Figure 8: Ring width plots of same tree sequences



The fifteen sequences representing 16 timbers which cross-matched were combined to form a 147-year site mean chronology called WAXHAMBN. This site mean sequence was found to cross-match with a wide range of reference chronologies with the first ring of the sequence at AD 1437 and the final ring at AD 1583 (Table 3).

Table 3: Examples of cross-dating evidence for site mean chronology WAXHAMBN

WAXHAMBN dated AD 1437 to AD 1583					
File	**Start Date**	**End Date**	***t*-value**	**Overlap (yr.)**	**Reference chronology**
devizesb	AD1447	AD1647	5.58	137	St. Johns Alley, Devizes, Wiltshire (Miles and Haddon-Reece 1990)
drinkstn	AD1464	AD1586	4.87	120	Post Mill, Drinkstone, Suffolk (Bridge 2001)
lydd4	AD1359	AD1564	4.81	128	Lydd, Kent (Moir 2001)
hillhal1	AD1425	AD1564	4.65	128	Hill Hall, Essex (Bridge 1999)
fenny	AD1468	AD1591	4.62	116	Fenny, Nr. Lathbury, Bucks (Bridge 1993)
marriots	AD1310	AD1583	4.53	147	Marriot's Warehouse, King's Lynn, Norfolk (Tyers 1999b)
crowle3	AD1497	AD1589	4.49	87	Crowle Court Barn 3, Worcs (Hillam 1997)
littley2	AD1347	AD1648	4.47	147	Littley Green, Essex (Moir 2000)
east_mid	AD882	AD1981	4.16	147	East Midlands (Laxton and Litton 1988)
hereworc	AD1341	AD1636	3.74	147	Hereford & Worcester (Siebenlist-Kerner 1978)

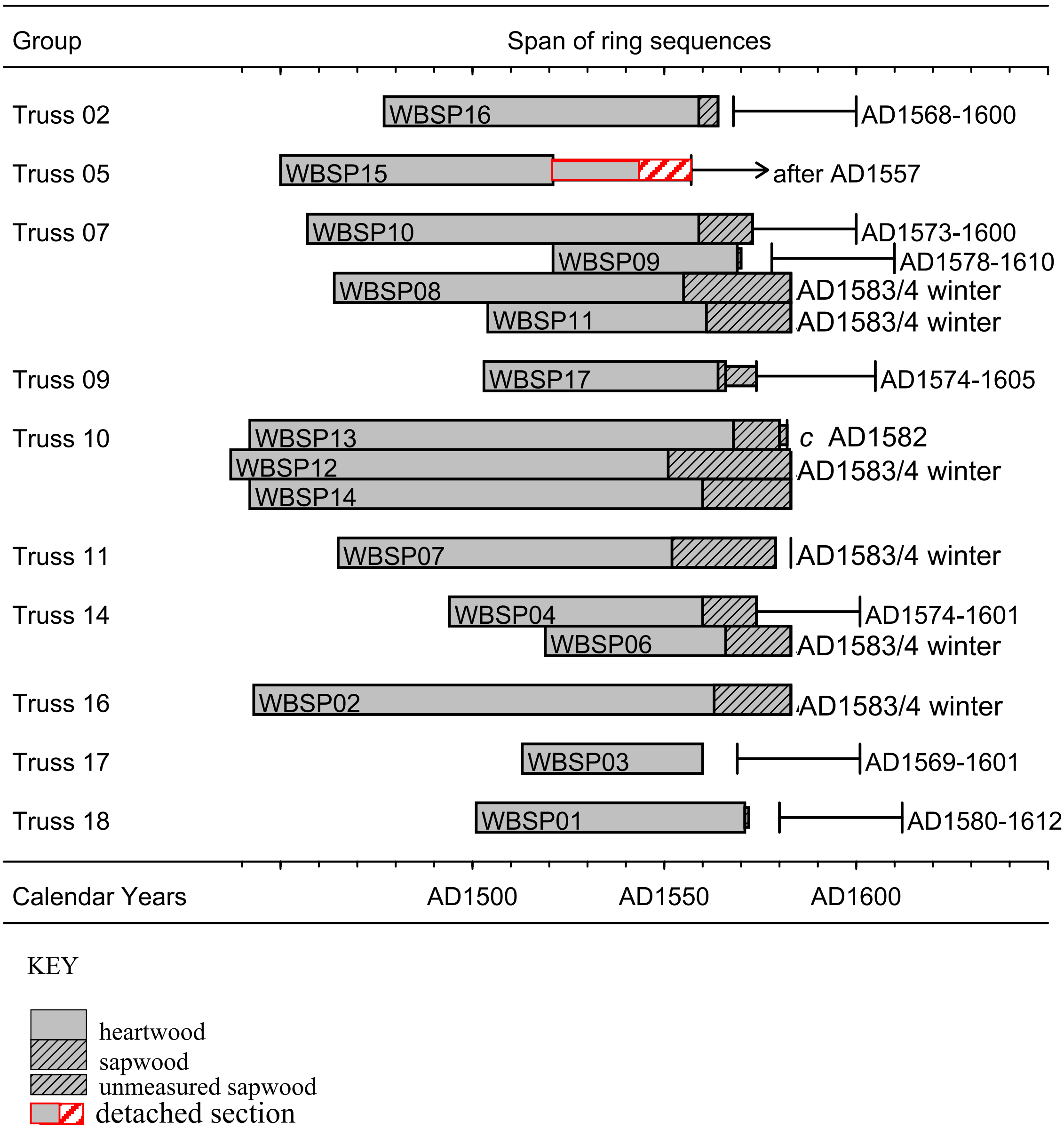
Once the site mean chronology WAXHAMBN was dated, calendar dates were assigned to its component sequences (Table 1). The data for the individual sequences are given in Appendix 1 and the site chronology in Appendix II.

INTERPRETATION AND DISCUSSION

Felling Dates

The felling dates are presented in Figure 9 and Table 1 and are discussed below. The presence of bark provides precise felling dates. Six of the timbers sampled, WBSP02, WBSP06, WBSP08, WPSP11, WBSP12, and WBSP14, were converted from trees felled in the winter of AD 1583/4. Under the microscope the summer cell growth for AD 1583 is evident in all six samples, thus, the trees used were felled late in that year, or in the early part of AD 1584 during winter dormancy.

Figure 9: Bar diagram showing the date interpretations for components of WAXHAMBN



One other timber, WBSP13, gives a probable felling date in *c* AD 1582. The sequence was recorded to have lost approximately two final sapwood rings during sampling, but it is quite possible that three rings were lost and therefore this felling date is considered consistent with, rather than detracting from the precise date of felling established. Thirty six additional rings, including fifteen rings of sapwood were recovered in the end section which broke off of core WBSP15. The break was not clean so it is possible that some rings were lost therefore this additional information is used to calculate a felled after date of AD 1557 for the sequence WBSP15 rather than a felling date range. This felled after date is clearly consistent with the precise date of felling established.

A sufficient range and extent of elements of the original structure have been dated to indicate that such a date should be applicable to the barn as a whole. All of the dated sequences display heartwood/sapwood boundaries in a narrow 18-year range, which suggests that all the timbers were from a single felling in AD 1583/4. The results therefore indicate that construction of Waxham Great Barn was likely to have commenced shortly after felling in winter AD 1583/4.

Timber Analysis
The timbers forming the alternating tiebeam and hammer beam construction of the barn are uniformly sized, although they consist of box heart, half round, and quarter converted timbers. Samples WBSP07 and WBSP12 are identified as probably from the same tree and indicate that quartered sections of a single large tree were converted to make the adjacent tiebeams in trusses T10 and T11, located either side of the central door of the barn.

Two samples, WBSP08 and WBSP11, were taken from the north and south ends respectively of the hammer beam truss T7. These sequences cross-match with a *t*-value of 6.02 which indicates that each hammer beam is likely to be from a separate tree. This supports the conclusion of Heywood and Ayton (1994) made from constructional detail, that the middle of a tiebeam was not cut away to create the hammer beam truss, as has previously been conjectured. A possible example of such modification may be seen at Thorley Hall, Hertfordshire (Arnold *et al* 2001).

The cross-matching between the sequences is reasonably good (see Table 2) and suggests that the source trees of the timbers sampled came from a relatively discrete area, possibly a small woodland. The site master chronology is well replicated but fails to produce any particularly high *t* values with the network of reference chronologies in the surrounding regions. It is therefore not possible to determine the likely source for these timbers but, assuming the timbers are local, this is probably explained by the lack of coeval reference chronologies in the county.

CONCLUSIONS AND RECOMMENDATIONS

Sixteen of a total eighteen oak timbers sampled form Waxham Great barn were dated dendrochronologicaly to form a 147-year site chronology (WAXHAMBN), spanning AD 1437 to AD 1583. The analysis demonstrates that the primary timbers were probably all felled in the winter of AD 1583/4, and assuming the timbers were used green, which was common practice at the time (Rackham 1990), construction shortly afterwards is implied. The range and extent of the timbers dated, provides good evidence that construction of the barn occurred as a single phase. However, given the barn's extreme length and the lack of samples obtained from the roof east of T9, it would be advisable to take advantage of any future work to the roof and obtain samples, in order to confirm the roof structure is all of one phase.

Analysis on opposing ends of one hammer beam truss indicates the timbers to be from separate trees and thereby helps to confirm the findings of Heywood and Ayton (1994) that the unusual alternate queen-strut and hammer beam arrangement of the trusses are an original feature and were not created at a later date by sawing though the centre section of a tiebeam.

It is likely that the primary phase timbers sampled were local, however without data from other chronologies in the area it is not possible to categorically state that the timbers were locally sourced.

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Appendix I: Raw ring-width data

Units of Measurement 100 = 1mm
Earliest ring listed first

wbsp01.d

77	80	48	40	39	26	29	30	56	39
35	48	41	40	80	132	102	154	123	101
121	169	125	224	107	197	164	124	217	245
285	163	166	223	192	136	197	167	207	387
159	182	185	152	229	195	173	231	451	315
320	371	368	314	481	303	188	184	226	349
209	365	226	158	151	163	200	265	299	308
233									

wbsp02.d

282	247	229	307	427	343	352	339	261	256
291	270	268	247	224	235	199	194	224	255
215	218	162	182	189	165	220	179	178	229
313	219	219	200	183	181	185	191	172	133
163	183	188	192	162	96	139	172	134	141
153	259	217	289	175	130	180	225	211	193
235	246	163	165	130	127	205	161	158	156
134	186	205	260	198	210	184	174	178	163
105	162	107	79	73	72	83	76	90	98
117	134	139	140	182	129	184	141	101	100
98	109	117	124	112	132	144	127	119	113
125	123	141	164	110	112	151	159	158	136
94	90	100	116	104	122	159	199	171	152
158	135	134	135	125	140	159	158	123	118
126									

wbsp03.d

326	240	244	292	216	151	289	154	259	226
143	307	215	169	109	263	225	272	252	268
188	190	265	214	178	163	253	207	152	174
131	193	255	184	139	174	172	126	137	89
75	104	89	89	84	84	125	186		

wbsp04.d

319	364	486	195	213	251	391	373	504	378
406	278	342	253	294	450	309	322	337	287
317	343	281	349	388	335	192	275	367	197
215	149	180	217	272	217	239	315	292	260
261	332	302	256	244	212	238	286	324	425
421	323	270	188	256	276	254	218	238	189
112	157	189	131	173	186	110	122	129	134
141	149	182	139	141	195	168	162	121	152
155									

wbsp06.d

206	140	235	316	199	228	152	69	53	51
66	70	109	108	95	100	116	117	170	216
186	197	126	235	200	141	210	167	146	214
190	142	148	276	221	180	257	160	106	108
178	229	179	182	205	126	133	188	173	188
203	205	186	185	161	233	166	206	173	219
165	259	117	137	151					

wbsp07.d

154	255	158	154	176	154	221	154	157	181
127	126	115	149	155	194	186	153	132	134
134	135	163	134	107	124	171	143	152	165
127	144	95	82	92	163	146	142	137	142
144	159	233	146	161	163	161	135	176	166
185	192	178	218	170	118	182	157	173	153
160	154	197	196	153	160	166	140	142	175
199	179	171	186	189	155	130	160	126	145
173	125	139	190	121	119	115	138	142	105
120	81	56	80	110	122	80	98	105	71
67	80	75	86	96	82	80	74	85	73
95	94	74	84	92					

wbsp08.d

486	372	418	248	157	146	284	406	328	287
218	279	133	209	273	242	209	281	178	215
241	242	237	256	204	228	182	236	226	181
166	188	259	147	111	145	188	177	256	233
229	190	132	150	117	177	153	148	122	121
149	133	138	155	134	108	76	93	126	123
148	106	132	93	83	96	90	123	112	105
98	119	125	143	119	155	122	85	84	124
127	136	125	99	122	141	105	132	140	166
126	170	112	114	99	134	187	164	185	175
113	104	115	98	96	124	103	103	95	115
105	87	87	50	83	93	99	55	58	54

wbsp09.d

642	546	557	765	393	283	403	445	449	492
561	528	396	578	798	596	642	684	733	494
386	535	458	424	751	572	379	502	478	281
234	393	317	359	463	349	232	223	324	559
438	470	494	337	269	382	356	482	463	

wbsp10.d

100	80	67	89	106	118	106	126	82	103
73	110	121	122	110	86	79	76	47	59
55	72	104	122	155	92	74	110	148	141
111	83	49	50	86	71	66	65	93	113
55	51	60	89	95	111	106	88	86	73
45	77	96	96	92	82	96	81	81	126
134	129	100	77	118	131	102	118	86	82
101	77	93	82	117	124	104	95	101	101
103	94	100	87	66	89	110	92	98	107
72	85	86	70	72	78	95	85	106	87
79	78	84	97	104	109	119	70	83	99
96	106	111	128	127	99	129			

wbsp11.d

279	232	207	239	240	326	205	197	201	146
279	253	305	241	210	155	105	186	229	273
330	224	233	144	169	156	170	212	260	214
206	207	197	214	125	212	258	238	287	246
181	199	158	157	163	145	104	126	169	171
170	177	145	106	132	174	244	198	185	182
108	112	128	143	196	176	205	138	148	164
234	169	149	143	209	194	168	109	120	107

wbsp12.d

257	209	223	233	281	239	272	157	194	193
206	179	186	199	184	209	198	285	261	290
256	339	289	192	344	205	243	259	144	163
147	148	272	287	369	251	195	150	143	132
136	127	146	147	135	127	112	73	57	62
72	81	71	103	135	107	99	111	141	183
117	96	96	160	248	163	213	198	176	177
265	195	204	173	189	145	247	219	323	249
198	217	181	141	257	266	204	215	161	168
207	176	221	216	245	181	173	171	180	152
146	183	171	142	130	140	112	146	182	138
147	169	114	108	103	116	81	83	97	69
46	62	75	120	82	107	104	66	62	76
73	80	81	103	65	62	69	91	83	74
73	88	79	107	49	76	62			

wbsp13.d

411	367	278	253	286	247	158	220	106	102
92	62	130	194	234	213	206	125	90	123
92	110	118	57	59	79	66	112	67	68
48	41	50	50	45	60	94	126	68	72
38	46	126	88	128	115	98	107	78	64
84	91	122	95	98	71	62	85	109	199
140	127	91	47	85	115	105	117	119	117
127	102	113	146	209	182	205	76	60	122
128	93	181	69	101	73	110	112	123	171
301	266	244	368	193	175	191	167	107	122
100	153	133	183	122	84	96	98	92	85
105	129	159	156	112	60	98	253	417	420
525	396	238	200	276	210	236	349	286	206
205	244	313	274	205	299	229	223	195	

wbsp14.d

422	519	448	456	368	327	289	364	250	196
187	201	213	201	238	213	162	121	93	137
151	120	104	107	100	85	72	76	121	157
140	152	109	113	88	96	106	120	124	164
97	110	82	130	132	125	91	81	74	99
93	93	127	119	152	85	90	102	115	115
110	117	104	102	100	90	74	121	92	123
109	108	106	97	127	101	121	124	105	127
126	112	120	75	66	56	79	63	69	108
101	94	100	127	139	145	185	192	133	123
155	111	110	172	166	130	147	194	153	143
129	135	139	232	150	119	138	190	175	148
159	179	107	153	176	136	123	185	157	131
126	166	128	101	100	87	73	96	122	71
66	61								

wbsp15.d

340	417	229	286	300	297	329	344	208	233
194	175	160	194	190	168	199	120	106	138
177	192	147	152	110	168	160	163	154	180
146	207	102	158	128	213	231	224	141	130
140	211	120	122	114	123	148	80	64	64
113	111	107	105	101	75	118	101	74	141
106	130	96	114	94	104	110	92	104	122
113	124								

wbsp16.d

195	177	221	151	180	88	97	108	165	138
132	100	101	116	105	91	75	110	109	113
75	62	70	86	101	86	108	90	95	82
87	87	109	82	116	88	95	113	97	120
109	97	114	84	131	108	95	134	103	112
77	125	100	113	151	124	104	120	105	128
120	101	160	146	130	113	96	127	166	152
124	163	138	88	101	149	165	136	169	122
107	118	165	184	147	192	149	107		

wbsp17.d

376	261	251	276	303	227	317	293	263	263
364	317	273	255	306	328	412	316	447	366
251	393	317	192	263	381	432	525	490	516
518	456	605	405	340	431	508	350	362	498
458	475	405	309	273	362	382	280	206	257
264	263	350	262	145	163	242	282	257	303
326	209	206	186						

Appendix II: Mean ring-width data

WAXHAM BARN - SEA PALLING - NORFOLK [WAXHAMBN]
Timber mean with signatures Ring-width QUSP data of 147 years length
Dated AD1437 to AD1583
Units of Measurement 100 = 1mm
15 timbers raw data mean
Average ring width 180.92   Sensitivity 0.15

AD1437							257	209	223	233
	281	357	360	282	283	288	301	242	280	246
AD1451	232	194	207	239	244	267	225	205	172	142
	184	163	164	214	156	181	135	118	157	171
	201	167	172	135	144	116	135	149	166	147
	173	108	123	135	158	162	155	115	115	115
	136	118	113	157	160	202	109	96	116	164
AD1501	165	173	182	175	143	147	149	135	191	151
	156	147	165	171	177	198	182	188	180	130
	218	229	183	250	161	146	144	174	178	196
	227	225	198	212	261	211	215	216	246	215
	176	216	208	202	244	198	158	201	215	160
AD1551	153	188	180	168	218	165	116	127	180	235
	201	234	214	144	143	174	157	185	213	185
	152	133	151	173	145	138	135	148	145	158
	87	95	93							