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Tree-ring Analysis of Oak Timbers

Martin Bridge and Cathy Tyers

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SUMMARY
Cores from 20 timbers and a slice from another timber taken for this study were analysed along with seven timbers sampled in the early 1990s. A total of 20 dated series were combined into a site master dating to the period AD 1339–1422, with an additional sequence independently dated to AD 1272–1334.

One timber retained complete sapwood and was from a tree felled in the very early spring of AD1419. It appears that most of the dated samples form a coherent group, most likely felled at about the same time, although the dates of the final measured rings demonstrate that they cannot all have been felled at exactly the same time and some must have been felled in the 1420s at the earliest. The likely felling date range of AD 1421–53, modified to AD 1428–53 in light of one sample retaining the ring for AD 1428, and this not being the final ring, can be applied to most of the dated timbers.

CONTRIBUTORS
Martin Bridge and Cathy Tyers

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The Historic England Archive
The Engine House
Fire Fly Avenue
Swindon SN2 2EH

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Essex Historic Environment Record
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County Hall
Chelmsford
Essex CM1 1QH

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CONTACT DETAILS
Martin Bridge
Oxford Dendrochronology Laboratory
Mill Lane
Mapledurham
Oxfordshire RG4 7TX
marbrdg@aol.com

Cathy Tyers
Historic England
4th Floor
Cannon Bridge House
25 Dowgate Hill
London EC4R 2YA
cathy.tyers@historicengland.org.uk

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INTRODUCTION

The Guildhall is situated in the centre of Thaxted (Fig 1) and is listed at Grade I (LEN 1112905 here). The list description suggests that it was built between AD 1390 and 1410 and mentions it as being related to a Cutler's Guild. A limited programme of dendrochronology undertaken the early 1990s (Tyers and Hibberd 1993), however, suggested that it contained timbers felled in the mid/late-fifteenth century, and recent research indicates it is likely to have been a moot hall (Andrews 2019 unpubl). The building has been the subject of various campaigns of repair, alteration, and restoration including in the early eighteenth century, in about 1910, and in 1978. Further repairs were being undertaken at the time of this study.

The building is timber-framed and plastered with an exposed frame, red plain tile double-hipped roofs, three storeys, and a cellar. The ground floor forms an open flagged market area with an open timber ceiling, and heavy cross beams are supported on a great centre post. The two upper storeys are jettied on three elevations with moulded bressumers and curved brackets. The first floor has arcading of two-centred arches. The roofs are of simple crown-post form and were originally gabled onto Town Street.

There is some confusion over the orientation of the building, with plans in the Essex County Council archives having a north point suggesting that the site is aligned north–south with the front of the building on the south side, and this orientation was used in the field when recording the sampling positions, but it was subsequently found that the front is located to the south-east, so there is about 45° between 'site north' and true north.

METHODOLOGY

An assessment of the timbers for dendrochronological study sought accessible oak timbers with more than 50 rings and where possible traces of sapwood, although slightly shorter sequences are sometimes 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. In addition, the ring-width data obtained in the early 1990s was made available by Ian Tyers.

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 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*-values in the range 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 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.

Ascribing felling dates and date ranges

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. 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* or felled-after date.

A review of the geographical distribution of dated sapwood data from historic 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). 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

A total of 21 cores and one *ex situ* cross-sectional slice were obtained from various elements of this building (Table 1a; Figs 2–11). One of the cores (txgh20) and the slice (txgh21) were from the sole plate at the front of the open covered market area (site south) and are presumed to be relatively modern replacements on the basis of known repair phases. One timber (txgh10) was cored twice in an attempt to maximise the number of rings and sapwood obtained. Another sample (txgh05) had approximately 35 rings but fractured in several places and so was discarded from further analysis. Sample txgh15 contained a band of very narrow rings which could not be distinguished with certainty, so only the inner section was used in the

analysis. The approximate number of rings, including the narrow band has been added after this, which reaches the heartwood/sapwood boundary, resulting in a generous felling date range to take account of the unknown number of rings in the narrow band. A number of series were shorter than would normally be considered suitable for reliable dating purposes (at least 50 rings preferred) but, given the number of samples obtained, some of these were included in the analysis. Also included in this analysis were ring-width data from seven timbers (Table 1b) taken in the early 1990s when access for sampling purposes was restricted. The measured ring-width series are presented in the Appendix.

Mean ring-width series were calculated for the two timbers which had been sampled twice before further analysis: txgh10 (txgh10a and txgh10b cross-matching with a *t*-value of 10.7 with 50 years overlap) and GRSPmean (GRSP and GRSP2 cross-matching with a *t*-value of 12.9 with 125 years overlap).

The ring-series from 20 timbers crossed-matched (Table 2). Many of these had overlaps of less than 50 rings, but as they were from an integral structure, and visual matches were good, the matches were considered acceptable. These were combined to form an 84-ring site master chronology, TXTGHt20. This has been dated to the period AD 1339–1422 (Table 3). The ring-width series from the six other measured timbers were compared individually with an extensive database of reference chronologies for oak, resulting in the dating of the inner part of core txgh15i to the period AD 1272–1334 (Table 4).

Two of the samples originally analysed in the early 1990s remain undated (2STP and GRSPmean), as does one of the studs in the partition wall (txgh09) which may have anyway been re-used. Sample txgh12, with only 31 rings, also remains undated. Neither of the two samples from the front sole plates were dated (txgh20 and txgh21), so no dating evidence is available for these later replacement timbers. One timber, tentatively dated in the early 1990s, has been firmly dated at a different position, made possible by the more extensive sampling undertaken for this study and the much larger number of reference chronologies for the area now available.

DISCUSSION

One timber (txgh04) retained complete sapwood and was from a tree felled in the very early spring of AD 1419. Most other samples retained their heartwood/sapwood boundaries and five had some sapwood rings. It appears that the dated samples form a relatively coherent group (Fig 12), most likely felled at about the same time, although it is clear that they cannot have all been felled at exactly the same time as txgh04 was felled in AD 1419 and txgh07 and 2ETB have last measured rings of AD 1421 and AD 1422 respectively.

The dated timbers have been sub-divided into the separate areas of the building sampled (Fig 13) to ascertain if any clear differences in date could be detected. There are clearly no striking differences in the date profiles of the groups, but perhaps it took a while for enough timbers to be gathered for this extensive building with felling having been carried out over a number of years and some timbers being

stockpiled. The variation in felling date ranges for the individual timbers (txgh08: AD 1411–43 to txgh07: AD 1430–62), along with the precise felling date identified for one timber (txgh04) of spring AD 1419 suggest that felling could have extended over a number of years towards the middle of the first half of the fifteenth century.

It is notable that the partition wall between the Small Room and the Council Chamber on the first floor contains a number of studs, some of which have mortices and trenches that do not relate to their current position, and at least some of which are likely to be re-used. The two dated by dendrochronology, however, appear to be contemporaneous with the rest of the main structure. Richard Till, author of 'The cutlers of Thaxted 1350–1420' (Till 2018) suspects that construction was more likely in the early part of the date range (Till pers comm) and notes that the Cutler's Guild was at its strongest in the second quarter of the fifteenth century, but that a number of nearby properties were in a poor state of repair and being replaced at around the same time, perhaps providing some of the re-used timbers.

All the timbers used appear to be of local origin, as indicated by the sites against which they match most strongly.

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TABLES

Table1a: Details of the tree-ring samples taken from Thaxted Guildhall, Thaxted, Essex in 2020

Sample No	Location	Number of rings	Date of sequence (AD)	Sapwood	Mean ring width (mm)	Mean sensitivity	Felling date range (AD)
txgh01	Collar purlin	58	1361–1418	h/s	1.97	0.19	1427–59
txgh02	Rear brace from king post to collar purlin	38	1366–1403	h/s	2.46	0.28	1412–44
txgh03	Wallplate, right hand side, in front of tiebeam	43	1376–1418	2+10NM	2.80	0.19	1428–57
txgh04	Central valley wallplate at front of building	39	1380–1418	18¼C	2.41	0.24	spring 1419
txgh05	Left hand side front wallplate	c35*	-	h/s	NM	-	-
txgh06	Left hand side, side wallplate	49	1368–1416	h/s	2.72	0.22	1425–57
txgh07	Left hand side central tiebeam	50	1372–1421	h/s	1.99	0.18	1430–62
txgh08	Small Room: first stud in from door (partition wall to Council Chamber)	65	1339–1403	1	1.65	0.28	1411–43
txgh09	Small Room: second stud in from door (re-used?)	50	-	h/s	1.48	0.18	-
txgh10a	*Small Room: second ceiling joist rear of partition wall*	*50*	*1355–1404*	-	*1.79*	*0.22*	-
txgh10b	*ditto*	*53*	*1355–1407*	*h/s*	*1.92*	*0.26*	-
txgh10	*ditto* a and b combined	53	1355–1407	h/s	1.85	0.23	1416–48
txgh11	Small Room: third ceiling joist rear of partition wall	47	1365–1411	1	1.70	0.22	1419–51
txgh12	Small Room: seventh ceiling joist rear of partition wall	31	-	h/s	2.15	0.18	-
txgh13	West door jamb - post	48	1363–1410	h/s	2.39	0.19	1419–51
txgh14	Left hand side, first post from back wall	69	1341–1409	h/s	2.33	0.26	1418–50
txgh15i	Left front corner post – inner rings	63 +*c*60-75NM	1272–1334	+h/s	2.55	0.24	*c*1403-50
txgh16	Braced transverse beam, left hand side	54	1366–1419	h/s	1.88	0.24	1428–60
txgh17	First joist behind transverse beam	49	1357–1405	h/s	2.27	0.22	1414–46
txgh18	Right hand side, first post in from RHS front	56	1361–1416	h/s	3.10	0.20	1425–57
txgh19	Right hand side, rear post (supporting brace to	53	1360–1412	h/s	2.48	0.18	1421–53

	transverse beam)						
txgh20	Left hand side front sole plate	52	-	-	3.69	0.19	-
txgh21	Slice – ex *situ* right hand side front sole plate	84	-	-	2.28	0.25	-

Table1b: Details of the tree-ring samples taken from Thaxted Guildhall, Thaxted, Essex by Ian Tyers in the 1990s

GECP	Ground Floor, east central post	42	1369–1410	?h/s	1.84	0.22	?1419–51
GNWP	Ground Floor, north-west post	65	1342–1406	?h/s	3.33	0.22	?1415–47
GRSP	Ground Floor rear storey post	125	-	-	1.53	0.12	-
GRSP2	ditto	125	-	-	1.53	0.13	-
1JOIST	First Floor, north-east room joist	55	1357–1411	?h/s	1.71	0.19	?1420–52
1ETP	First Floor, north-east room, east top plate	62	1357–1418	3	2.67	0.24	1424–56
2ETB	Second Floor, east tiebeam	64	1359–1422	2	1.89	0.23	1429–61
2STP	Second Floor, south top-plate	56	-	-	1.50	0.18	-

Key: h/s = heartwood/sapwood boundary; *= core fractured; NM = not measured; ¼C = complete sapwood, felled the following spring

Table 2: Cross-matching between the dated samples included in the site master chronology (TXTGHt20). Values of t above 3.5 are statistically significant. Note the number of years of overlap (not shown) is below 50 rings in most cases

	t – values																		
Sample	txgh02	txgh03	txgh04	txgh06	txgh07	txgh08	txgh10	txgh11	txgh13	txgh14	txgh16	txgh17	txgh18	txgh19	GNWP	GECP	1JOIST	1ETP	2ETB
txgh01	2.6	6.6	4.6	4.5	4.1	4.8	4.8	4.9	2.1	6.6	2.6	2.0	2.7	2.5	1.9	3.3	3.5	2.9	4.5
txgh02		1.6	2.9	5.0	3.9	5.5	3.9	6.0	2.6	3.8	5.2	4.1	4.9	3.8	1.5	5.0	4.3	2.5	3.3
txgh03			2.9	4.7	3.2	3.2	2.4	2.4	2.3	2.1	1.6	2.3	2.5	1.4	2.0	2.4	2.0	1.1	3.2
txgh04				3.3	3.1	2.5	3.2	4.4	1.4	4.0	3.0	1.2	2.6	2.0	2.1	2.5	1.6	2.6	4.5
txgh06					4.4	4.7	3.0	5.1	2.5	2.7	3.4	3.8	3.6	4.7	2.1	5.2	3.7	3.2	2.9
txgh07						5.3	4.9	3.8	3.1	4.0	4.7	2.5	3.6	3.1	2.5	2.5	1.6	3.4	4.9
txgh08							3.8	5.0	2.3	5.9	4.9	2.3	3.9	4.8	1.1	5.2	2.8	2.3	3.7
txgh10								7.1	2.8	4.4	3.1	3.0	2.3	1.7	3.4	2.1	3.6	4.5	4.4
txgh11									2.6	3.7	4.9	1.8	1.9	3.2	2.1	4.3	4.0	3.9	5.3
txgh13										3.5	3.3	2.8	2.2	1.9	6.8	2.7	2.6	0.9	2.9
txgh14											4.5	2.2	5.6	2.7	3.9	2.9	3.9	2.4	5.0
txgh16												2.8	4.3	3.9	2.8	3.6	2.4	3.3	4.7
txgh17													3.1	1.5	4.3	2.3	2.0	2.4	2.6
txgh18														3.1	1.9	3.6	4.8	1.1	2.9
txgh19															2.4	8.7	1.9	1.1	2.4
GNWP																2.7	1.0	0.2	4.1
GECP																	2.5	1.3	3.5
1JOIST																		2.1	1.4
1ETP																			2.3

Table 3: Dating evidence for the site chronology TXTGHt20, AD 1339–1422

Source region	Chronology:	Publication reference:	Filename:	Span of chronology (AD)	Overlap (years)	*t*-value
Northamptonshire	Apethorpe Hall, Apethorpe	Arnold *et al* 2008	APTASQ01	1292–1639	84	9.2
Essex	Thaxted Church	Tyers 1990	THAXTED2	1345–1526	78	7.8
Essex	Red Lion Hotel, Colchester	Bridge and Miles 2017	REDLIONC	1287–1475	84	7.7
Essex	Ashdon Street Farm, Ashdon	Bridge and Miles 2015	ASHDONXW	1353–1467	70	7.6
Hampshire	Mary Rose 'original' timbers	Bridge and Dobbs 1996	ORIGINAL	1334–1503	84	7.3
Essex	Netteswellbury barn, Harlow	Tyers 1997a	NETTLESB	1245–1439	84	7.3
Essex	Woodbarns Farm, Belchamp St Paul	Bridge 2020 unpubl	WOODBN1	1346–1416	71	7.3
Object	Henry VIII cupboard door	Tyers 1997b	OS0046	1334–1469	84	7.3
Essex	9 Market End, Coggeshall	Tyers 2011	C09MET04	1230–1422	84	7.0
London	Outer Gates, Byward Postern Sally Port, Tower of London	Bridge and Miles 2017	ToLBx2	1339–1446	84	7.0

Table 4: Dating evidence for the inner part of sample txgh15i, AD 1272–1334

Source region	Chronology:	Publication reference:	Filename:	Span of chronology (AD)	Overlap (years)	*t*-value
Essex	St Martin's Church, Colchester	Tyers 1998	STMARTIN	1218–1349	63	6.9
Oxfordshire	20 Bell St, Henley	Miles *et al* 2009	HENLEY5	1188–1324	53	6.7
Suffolk	Bury St Edmunds Guildhall	Bridge and Tyers 2019	BURYGDHL	1263–1376	63	6.3
Essex	Coggeshall Abbey	Arnold and Howard 2015	COGASQ01	1225–1354	63	6.2
Essex	Normans Hall, Wakes Colne	Tyers *et al* 2003	NORMHLL	1229–1368	63	6.2
Norfolk	Castle Acre Priory	Tyers 2000	CAP-LOW	1237–1356	63	6.0
Bedfordshire	Chicksands Priory	Howard *et al* 1998	CHKSPQ01	1200–1541	63	6.0
Oxfordshire	The Great Barn, Lewknor	Haddon-Reece *et al* 1990	LEWKNORx	1188–1343	63	5.9
Hampshire	The Priory, Odiham	Miles and Worthington 2000	ODIHMPRY	1207–1448	63	5.9
Suffolk	Great Bricett Hall	Bridge and Miles 2016	GTBRCTT1	1119–1326	55	5.9

FIGURES

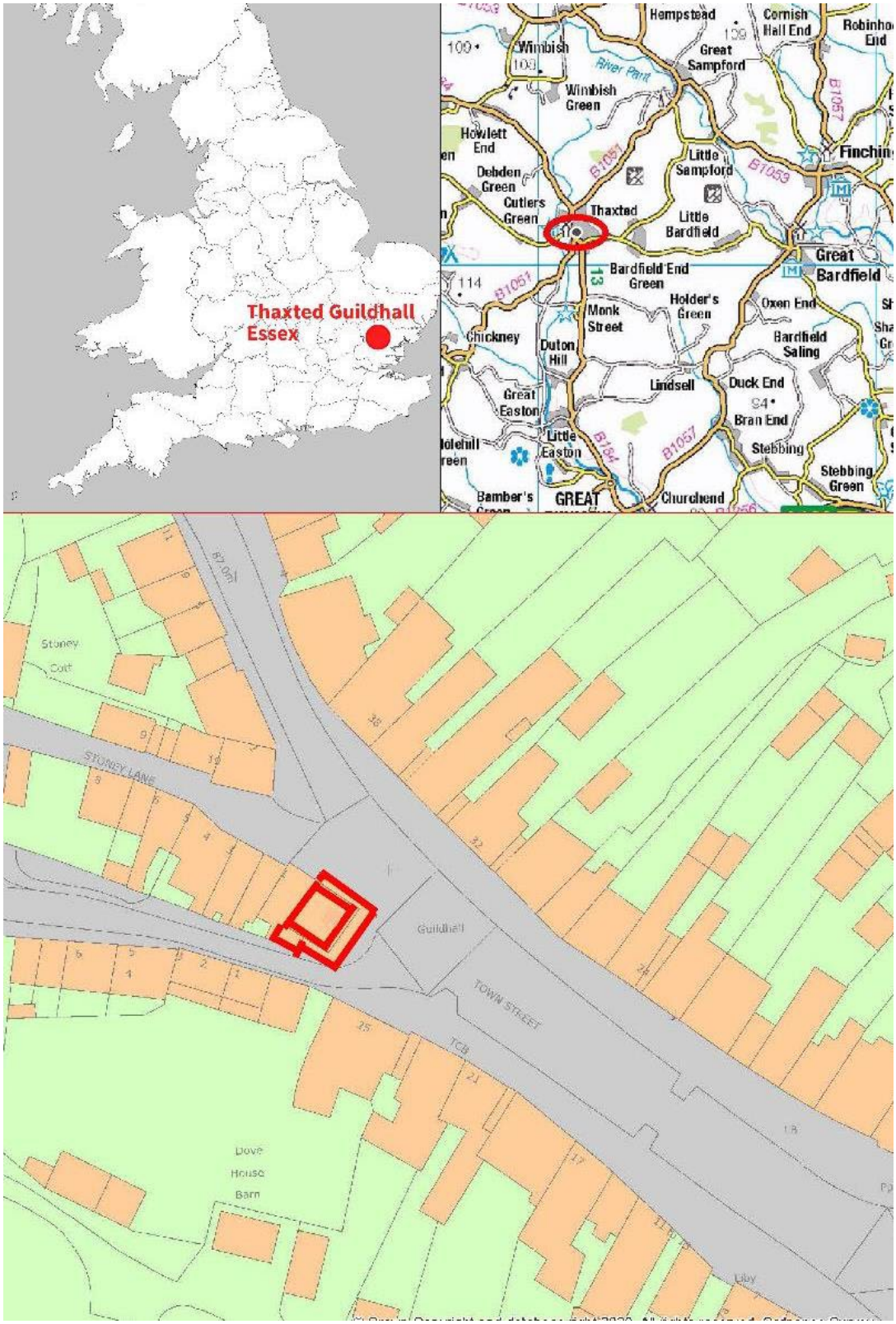

Figure 1: Maps to show the location of Thaxted Guildhall in Essex, marked in red. Scale: top right 1:150,000, bottom 1:750 © Crown Copyright and database right 2022. All rights reserved. Ordnance Survey Licence number 100024900

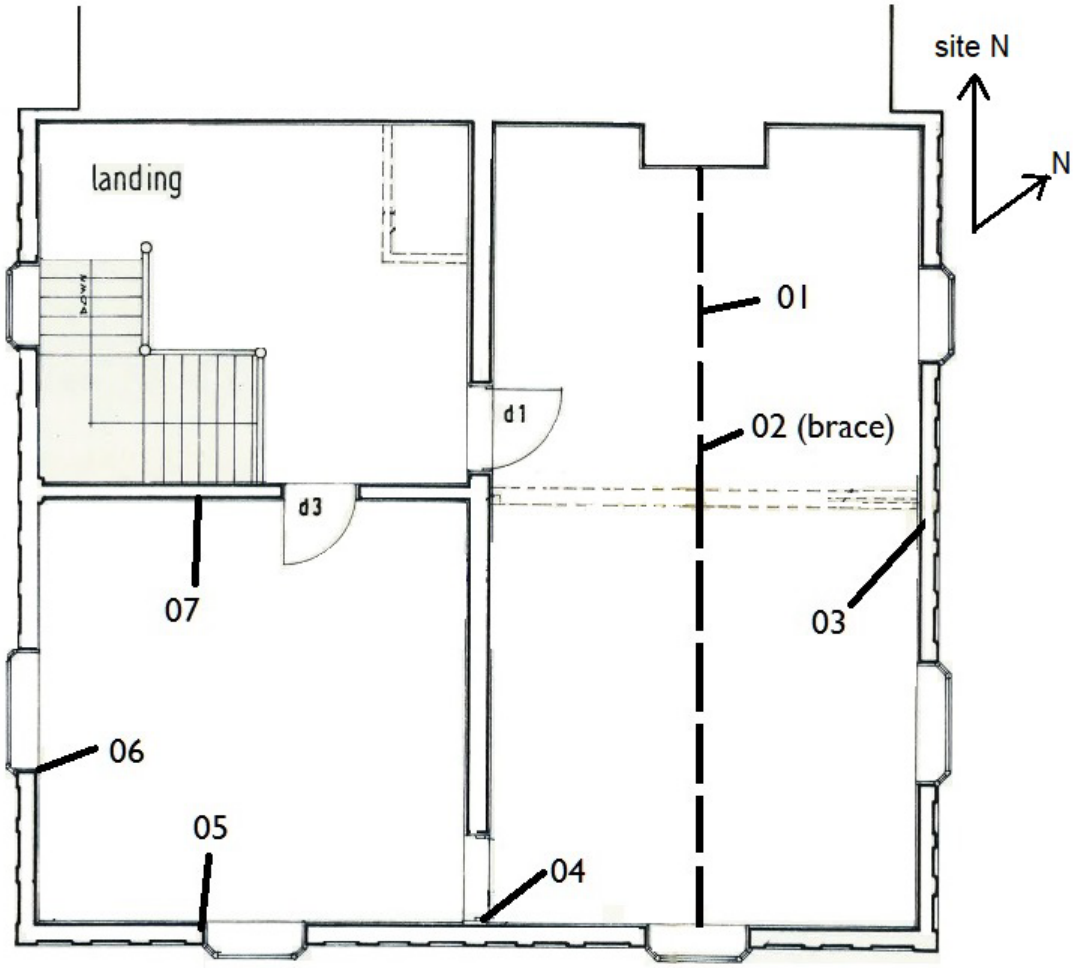

Figure 2: Second-floor plan showing the approximate positions of timbers sampled for dendrochronology (adapted from Essex County Council plans drawn by R Crowe, 1974)

Figure 3: Photograph of the east side of the second floor looking north, showing the timbers sampled for dendrochronology (photograph Martin Bridge)

Figure 4: Photograph of the south (front) end of the central valley wallplate showing the position of coring through complete sapwood (photograph Martin Bridge)

Figure 5: Photograph of the west side of the second floor, looking west, showing timbers sampled (photograph Martin Bridge)

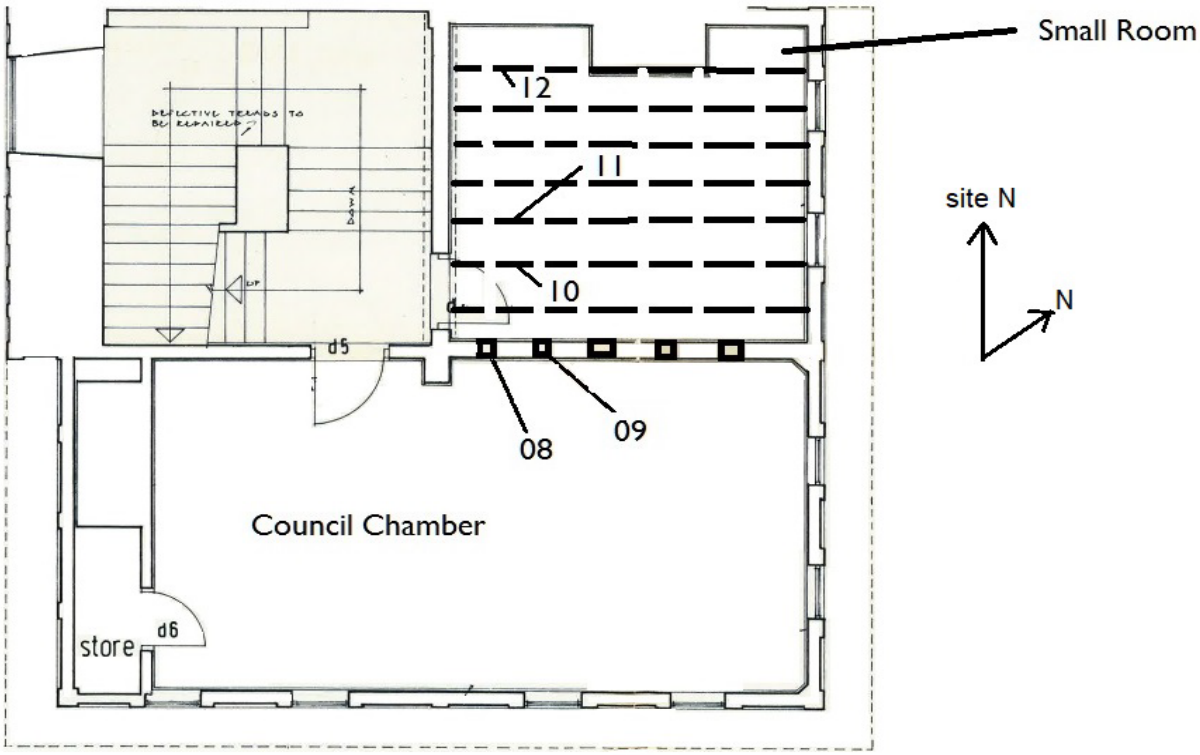

Figure 6: First-floor plan showing the approximate positions of timbers sampled for dendrochronology (adapted from Essex County Council plans drawn by R Crowe, 1974)

Figure 7: Photograph of the wall separating the Small Room and the Council Chamber on the first floor, showing some of the timbers sampled for dendrochronology (photograph Martin Bridge)

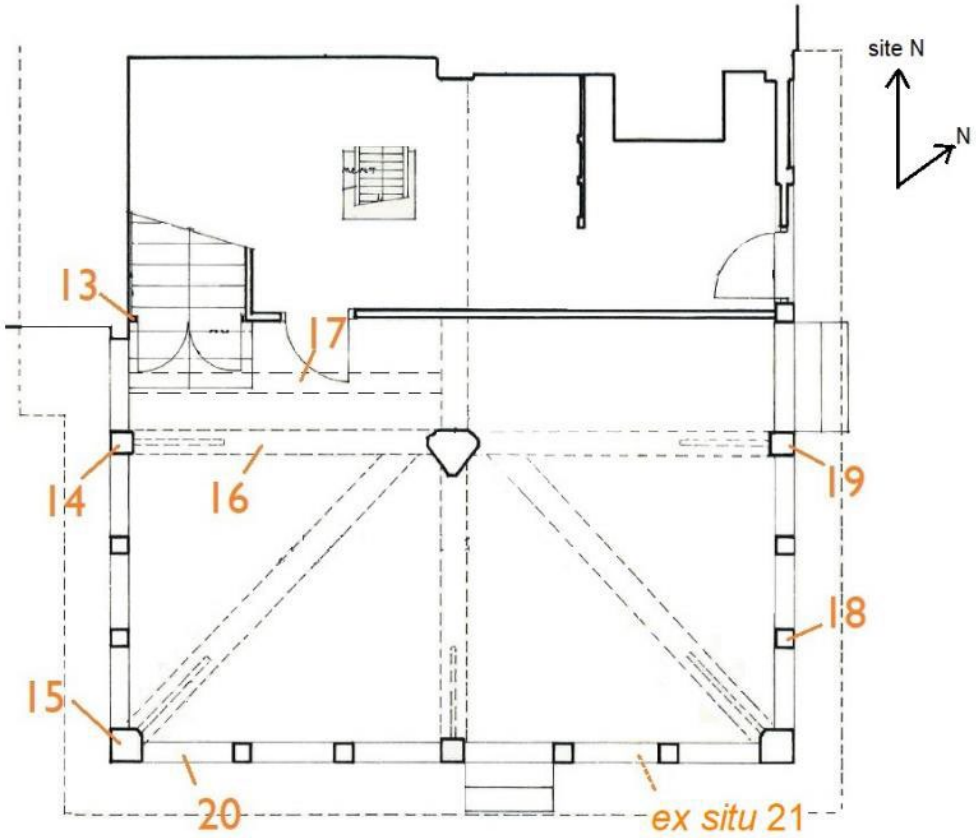

Figure 8: Ground-floor plan, showing positions of the timbers sampled for dendrochronology (adapted from Essex County Council plans drawn by R Crowe, 1974)

Figure 9: Photograph looking west showing some of the timbers sampled from the covered market area (photograph Martin Bridge)

Figure 10: Photograph of the right-hand side of the covered market area showing timbers sampled for dendrochronology (photograph Martin Bridge)

Figure 11: Photograph of the front left side of the covered market area, showing the sill plate sampled for dendrochronology (txgh20) (photograph Martin Bridge)

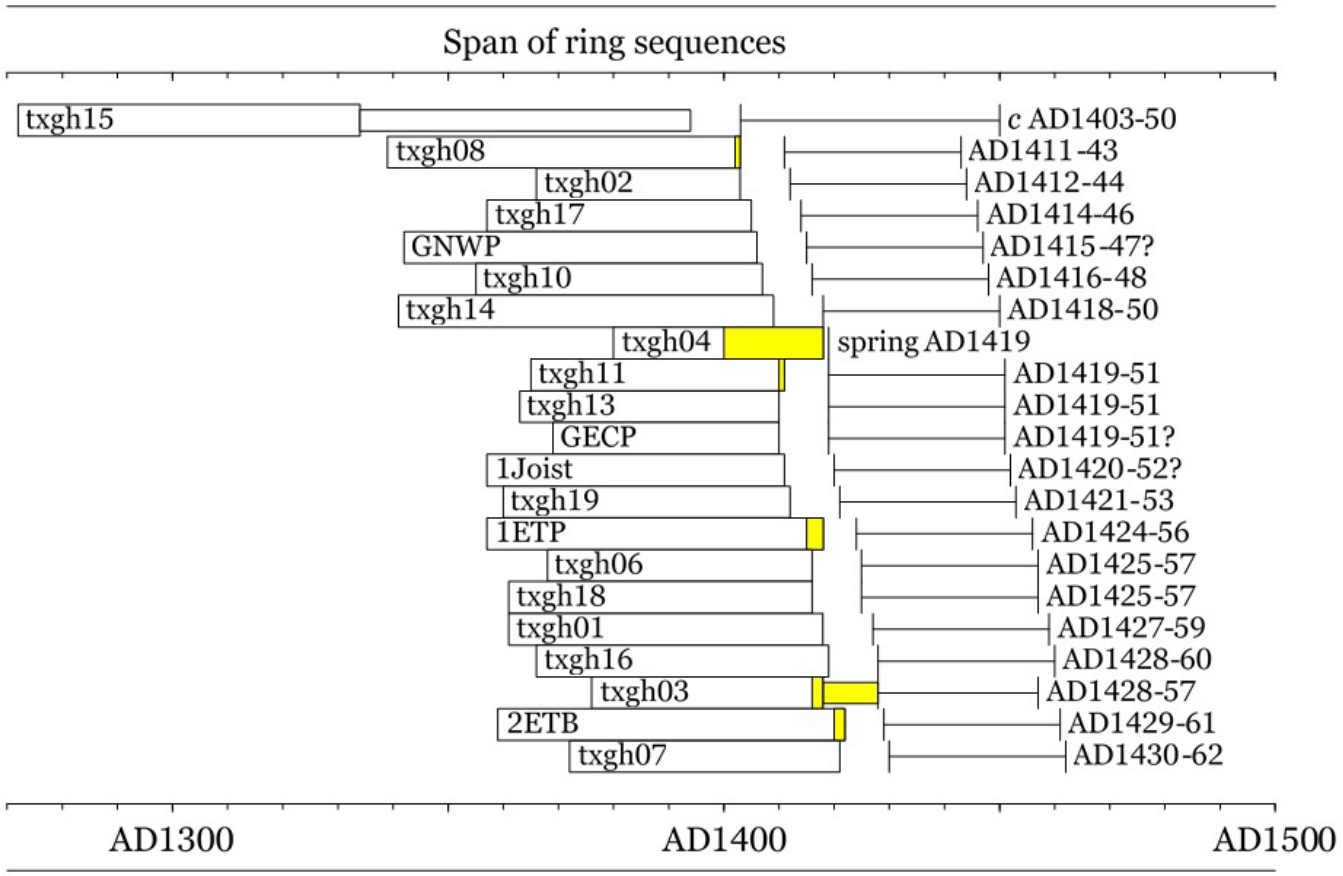

Figure 12: Bar diagram showing the relative positions of overlap of the dated samples, along with their individual interpreted felling date or felling date range, sorted by felling date/date range. White bars represent heartwood rings; yellow bars represent sapwood rings; narrow sections of bars represent additional unmeasured rings

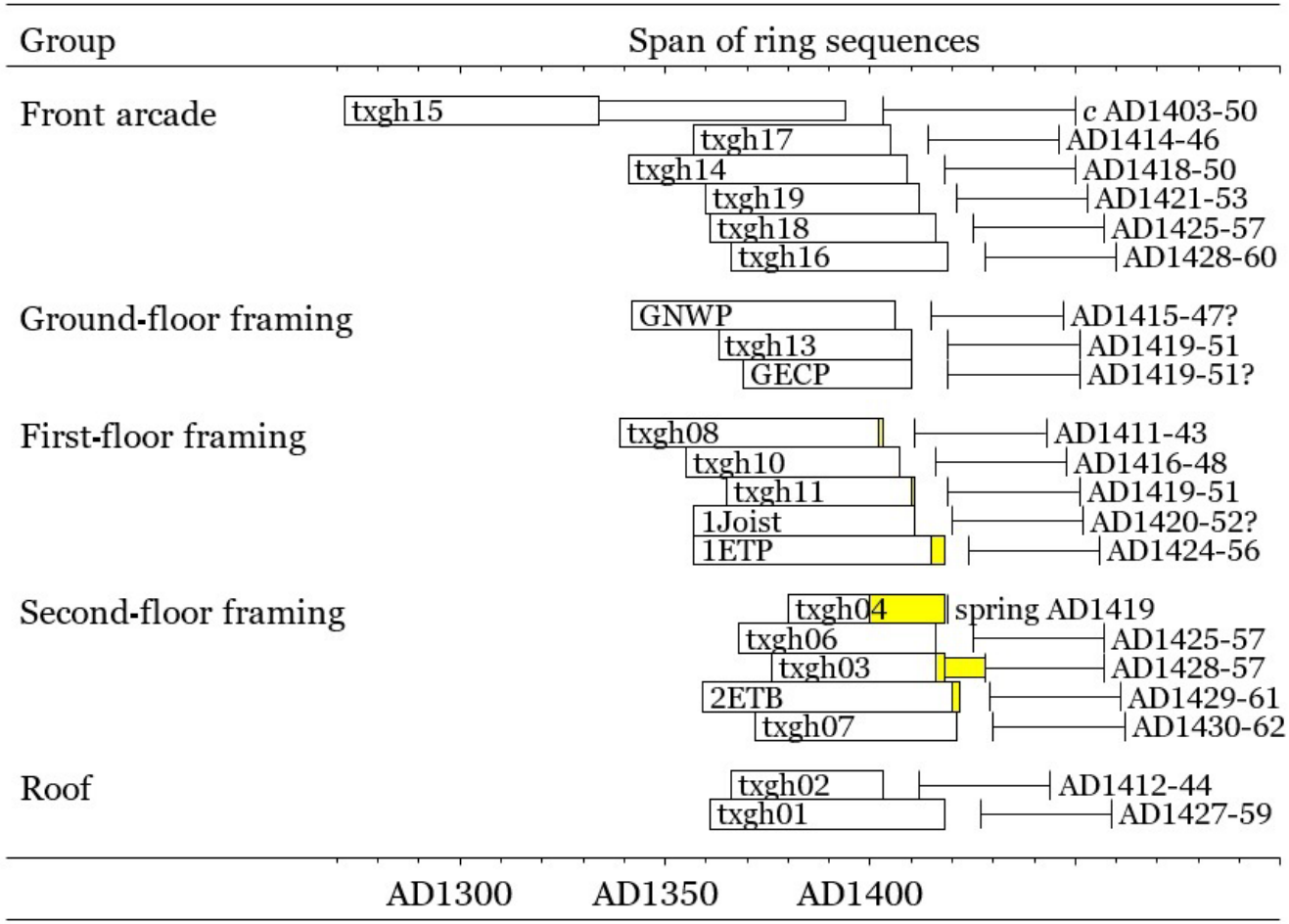

Figure 13: Bar diagram showing the relative positions of overlap of the dated samples, along with their individual interpreted felling date or felling date range, sorted by area and felling date/date range. White bars represent heartwood rings; yellow bars represent sapwood rings; narrow sections of bars represent additional unmeasured rings

APPENDIX

Ring width values (0.01mm) for the sequences measured

a) Data from 2020

txgh01

161	212	285	262	242	160	122	128	261	262
181	133	120	126	135	243	285	357	279	375
348	318	291	207	268	295	311	322	198	199
161	154	208	166	170	244	197	225	181	141
143	151	181	218	180	220	164	139	125	95
103	112	154	103	83	102	95	120		

txgh02

231	157	303	420	291	220	285	137	136	195
308	294	390	455	391	472	441	291	186	312
280	432	427	357	296	169	110	112	86	126
138	104	203	171	116	89	114	109		

txgh03

431	433	460	420	389	457	388	353	299	363
390	368	338	270	360	209	301	274	229	192
304	268	325	190	184	187	213	257	316	278
359	257	260	198	177	169	175	246	144	122
181	134	152							

txgh04

185	240	351	343	237	398	310	406	290	230
279	309	213	255	245	213	293	281	326	312
199	143	180	225	216	263	277	194	243	214
129	191	207	218	159	96	155	230	161	

txgh06

472	461	352	243	299	210	243	255	288	439
465	429	393	300	368	264	185	274	346	436
431	342	338	184	182	175	171	212	261	236
340	217	228	163	227	208	269	219	359	223
193	233	157	177	241	260	119	132	101	

txgh07

110	107	147	156	275	257	312	244	188	174
197	179	147	173	200	249	271	240	232	192
192	206	126	127	150	179	302	272	211	148
196	194	266	259	286	233	260	229	189	178
168	191	121	139	133	118	210	180	249	181

txgh08

252	149	145	128	201	178	234	265	254	241
121	80	210	166	327	258	398	291	292	205
212	245	157	231	388	303	205	179	159	225
267	218	156	128	110	71	111	134	149	218

125 146 118 106 89 63 116 136 185 161
123 90 52 62 64 52 56 70 78 148
111 72 59 100 95

txgh09
249 178 132 123 168 204 212 172 152 142
119 226 176 186 221 243 164 147 141 116
98 127 132 173 173 145 128 165 179 134
123 118 142 168 181 143 112 113 151 106
76 93 106 130 179 137 105 94 87 93

txgh10a
244 219 258 240 347 286 244 317 351 308
322 197 126 132 234 182 132 175 117 89
77 146 218 172 194 180 189 161 160 132
139 178 198 221 195 206 177 118 108 72
61 89 106 164 171 126 96 91 138 165

txgh10b
267 249 284 296 403 299 185 286 295 193
269 160 115 125 245 160 134 195 147 105
90 165 262 366 337 201 242 240 196 173
213 216 238 247 246 270 228 138 126 64
50 86 86 143 131 81 73 57 111 127
132 225 194

txgh11
234 172 129 163 273 233 143 160 81 64
108 150 208 252 286 249 232 238 189 147
192 257 261 221 195 191 167 131 107 95
88 127 125 200 171 150 104 124 164 165
155 195 161 153 195 123 82

txgh12
367 371 351 259 241 223 251 226 170 222
240 213 307 221 153 122 145 170 220 194
244 156 138 155 157 199 186 239 172 186
171

txgh13
388 370 433 515 356 406 468 473 412 594
366 406 267 331 310 259 222 185 190 162
141 146 232 245 275 198 224 154 146 151
150 82 122 194 171 157 203 168 93 133
146 138 138 117 114 91 103 124

txgh14
417 400 406 365 455 453 404 462 497 319
375 255 395 419 363 311 374 291 349 308
172 320 361 369 264 169 123 178 246 203
133 82 89 72 87 148 169 198 155 245
240 269 227 176 247 260 370 321 190 148
108 69 110 70 91 157 132 207 153 142

88 109 124 164 184 126 51 79 77

txgh15i
243 381 348 187 140 350 222 153 135 198
255 309 262 340 373 232 223 373 420 325
363 404 489 520 391 318 242 215 290 291
331 177 206 173 198 259 314 266 244 143
166 137 207 325 286 270 192 174 199 281
311 291 248 250 126 182 194 202 136 197
120 130 130

txgh16
451 284 334 321 296 204 157 125 100 148
177 205 272 295 260 185 220 170 104 178
192 228 180 198 241 172 157 139 99 133
191 133 234 222 149 86 158 167 348 223
209 128 192 161 144 152 162 132 118 125
101 115 140 117

txgh17
461 281 343 336 216 451 325 277 333 327
336 258 331 317 250 358 247 270 169 244
201 282 320 241 190 182 112 102 141 138
173 151 165 158 107 104 166 114 176 201
177 203 190 135 178 194 167 184 140

txgh18
332 487 447 472 462 443 431 538 480 505
389 426 412 337 349 376 384 436 389 440
390 510 361 250 392 329 495 445 361 315
192 136 158 127 184 272 233 310 244 183
172 97 86 155 165 188 125 250 233 216
203 195 237 164 223 222

txgh19
242 179 349 360 288 277 255 338 371 335
275 205 213 183 148 191 229 242 266 212
263 218 231 251 175 252 278 325 320 271
208 182 228 183 178 222 243 221 267 322
266 239 249 226 299 227 355 239 268 254
172 167 189

txgh20
357 250 305 227 291 268 250 336 240 315
400 288 216 434 516 509 591 417 509 428
547 375 402 333 396 435 374 395 526 448
395 279 376 327 391 398 290 274 290 440
477 428 333 345 359 359 428 329 354 370
296 268

txgh21
150 141 338 311 357 480 651 546 397 294
283 225 521 270 434 479 291 282 276 308

199 264 233 339 353 280 311 266 334 466
240 254 205 164 181 186 227 165 170 206
256 234 299 186 209 240 194 230 261 177
143 225 235 207 196 246 262 268 207 71
75 81 99 100 241 89 83 61 93 123
150 92 156 149 111 106 89 110 111 104
114 187 137 76

b) early 1990s data from Ian Tyers

1ETP
315 275 334 380 228 432 318 497 534 320
234 188 243 247 238 220 164 97 70 86
115 135 193 166 193 182 354 364 406 546
568 461 466 458 360 229 255 294 278 304
225 520 414 260 186 256 240 275 232 362
229 242 202 148 156 148 145 88 108 89
166 111

1JOIST
371 184 159 148 86 90 112 149 139 89
98 92 126 96 75 114 84 84 96 107
151 139 147 161 211 191 166 154 204 227
260 238 245 237 215 151 216 153 191 231
192 232 219 215 226 172 155 212 169 231
181 232 260 178 167

2ETB
259 229 136 259 272 171 263 353 210 262
333 311 177 152 111 92 110 154 140 201
152 154 152 140 146 120 197 226 237 288
220 216 189 145 150 137 87 158 151 228
209 250 136 198 185 290 283 302 193 274
190 170 192 186 201 141 109 112 89 100
118 166 173 120

2STP
183 131 155 160 127 153 153 121 122 131
84 119 111 134 112 120 86 112 72 78
84 78 103 80 88 125 125 133 98 99
102 142 154 205 230 140 184 310 282 258
308 240 163 190 209 253 205 134 112 116
119 123 162 189 185 180

GECP

159 202 127 153 113 101 128 150 148 221
209 254 212 216 188 128 246 218 269 266
197 153 118 147 120 131 170 217 217 250
245 204 154 155 163 199 154 299 149 203
220 155

GNWP

340 489 286 292 178 190 244 425 365 546
242 476 715 620 639 532 460 479 478 339
630 445 352 369 522 451 490 477 415 350
422 359 388 245 343 308 320 293 290 237
227 191 180 280 314 375 257 250 186 199
175 220 118 151 271 258 221 252 245 155
173 226 229 232 211

GRSP

163 187 175 177 144 138 126 211 194 212
202 199 178 183 190 151 174 148 168 181
138 124 122 125 120 107 100 104 102 94
82 80 98 103 105 110 124 139 130 136
125 155 201 155 181 158 140 140 177 146
123 143 121 126 92 106 96 95 100 128
95 103 94 128 166 148 168 182 194 197
213 210 228 221 189 216 134 142 178 136
202 181 173 163 179 187 171 179 165 176
173 154 122 141 142 161 159 173 177 155
149 146 151 156 149 124 142 129 204 153
154 138 131 147 144 149 183 219 232 173
204 185 161 160 175

GRSP2

177 225 169 178 143 130 145 205 187 209
214 205 195 183 173 161 149 117 151 158
121 122 106 136 123 119 107 106 91 100
76 92 98 100 101 115 135 141 152 136
125 151 190 146 161 166 147 139 157 146
138 146 116 129 93 103 87 99 108 123
99 93 92 127 161 165 174 161 192 211
199 218 226 228 188 217 130 152 177 137
197 177 182 150 191 177 170 176 166 167
181 146 112 129 155 151 166 171 170 158
157 146 150 147 150 130 146 133 168 149
153 137 135 145 131 157 207 187 250 176
183 200 184 133 177

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