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QUEEN ELIZABETH OAK, GREENWICH PARK, BLACKHEATH GATE, CHARLTON WAY, GREENWICH, LONDON

TREE-RING ANALYSIS

SCIENTIFIC DATING REPORT

Andy Moir

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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SUMMARY

Core samples from the main trunk, and sections from broken pieces of timber found under the fallen trunk of the Queen Elizabeth Oak in Greenwich Park were collected, as were samples from an adjacent oak tree for comparative purposes. A 233-year mean tree-ring series was established for the Queen Elizabeth Oak which was dated to AD 1569–1801, thus positively identifying that the tree was alive in the reign of Queen Elizabeth 1. As the tree was hollow it was not possible to determine a precise date of germination, but it is estimated that the tree germinated in the latter decades of the thirteenth century or possibly the early decades of the fourteenth century. Interpretation of sapwood suggests that the death of the tree occurred during the period AD 1827–1842.

CONTRIBUTOR

Dr A K Moir

ACKNOWLEDGEMENTS

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INTRODUCTION

Greenwich Park is situated on a hilltop 8.1km east-south-east of Charing Cross with impressive views across the River Thames. The park's centre is about 600m north-west of Blackheath, and 1km south-south-west of Greenwich (Fig 1). Greenwich Park covers 74 hectares (183 acres) and is the oldest enclosed Royal Park in England. Its origins are in the fifteenth century and it was formally laid out in the 1660s. At least part of the mid seventeenth-century restoration scheme was associated with the French designer Andre le Nôtre. The park, home of the Royal Observatory from 1676 to 1953, along with neighbouring properties and part of the town centre, is included on UNESCO's list of World Heritage sites.

The oak tree (***Quercus*** spp) in Greenwich Park, known as the Queen Elizabeth Oak (Fig 2) is thought to have been planted in the twelfth century and to have been hollow for many hundreds of years. The fallen trunk of the tree lies at the south end of Lover's Walk, near Maze Hill Gate. It has traditions linking it with Queen Elizabeth I and King Henry VIII, and it is also reputed to have been a lock-up for offenders who transgressed park rules. The tree is thought to have died in the mid-nineteenth century, although a strong growth of ivy supported it until it collapsed in June 1991. Webster (1902) reports that the tree produced its last living shoots around 1878 and had a girth of 20 feet (6.1m). In a letter dated 1990, Mr J A Dolwin notes the external girth at approximately 7.9m, but this includes up to 2ft (0.6m) thickness of ivy.

Tree-ring dating was requested by Dr Jane Sidell to confirm that the tree was alive in the reign of Elizabeth 1.

METHODOLOGY

The general methodologies used follow those described in English Heritage (1998). The methodology used for this analysis is further detailed below.

Sampling and preparation

Core samples, as opposed to cross-sectional slices, were taken using an electric drill, so as to minimise intervention to the surviving trunk of the Queen Elizabeth Oak. However, sections that had already broken away from the main trunk were sub-sectioned by handsaw. A neighbouring live oak tree was sampled by an increment borer to provide some indication of the potential growth rates associated with early growth that were missing from the hollow tree. All samples were then allowed to air dry after which they were sanded down with progressively finer papers to a 600 abrasive grit finish to reveal the tree rings. Any subsequent sanding necessary was done by hand.

Measuring and cross-matching

Tree-ring sequences were measured under a x20 stereomicroscope to an accuracy of 0.01mm using a microcomputer-based travelling stage. Series with 30 to 50 rings from the Queen Elizabeth Oak were included in the analysis, as short ring series were considered potentially dateable in these circumstances (English Heritage 1998).

All series measured from the Queen Elizabeth Oak were compared with each other and those found to cross-match combined to form an averaged series. Where possible, three methods of cross-matching were used to ensure reliability: statistical tests, visual matching, and replication. Cross-correlation algorithms were employed to search for the positions where tree-ring sequences correlated and possibly matched. The degree of affinity between tree-ring sequences is expressed by the Student's ***t***-value (Baillie and Pilcher 1973), using raw tree-ring measurements. Values of ***t*** in excess of 3.5 are quoted as significant and indicative of an acceptable position of match. The series from the Queen Elizabeth Oak and the living oak tree were then dated against reference chronologies, using the same criteria.

Felling dates and sapwood estimates

Series' dated by the process above provide calendar year dates for all the tree-rings present in the measured timber sample. The interpretation with respect to when the tree was felled (or died) then relies upon the nature of the final rings in the series. Where bark, or the readily recognisable surface immediately under the bark, survives intact on a sample, a felling date is given as the date of the last ring measured on the tree-ring series. Where bark, or the bark surface, 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 sapwood estimate of a minimum of 9 and a maximum of 41 annual rings. This sapwood estimate is currently applied to most of the south-east region and has been compiled by the Oxford Dendrochronology Laboratory (Miles 1997). Felling date ranges have been calculated by adding the sapwood estimate of minimum and maximum missing rings to the date of the heartwood/sapwood boundary.

Age estimates

Formative, mature, and senescent phases of growth normally occur during the development of a tree's crown (Mitchell ***et al*** 1994). The formative stage is generally characterised by relatively rapid growth, although this is often not apparent in historic assemblages. The mature phase which follows, is normally characterised by a reduction in the rate of growth, which then slowly further reduces over time. The growth of a younger

oak tree sampled from near to the Queen Elizabeth Oak is used to represent the younger growth missing from the hollow tree and to produce an age estimate (Tabbush and White 1996; White 1998), although this is clearly not precise.

The centre of tree (pith) date obtained by sampling at a height above the ground is unlikely to represent the year of germination. Nevertheless, the discrepancy between the pith date obtained from the usual breast height of sampling above ground and a precise germination date obtained from ground level is only likely to be significant in suppressed understory trees (Tucker ***et al*** 1987). Here five years is arbitrarily added to the age to account for the likely discrepancy between a precise pith date obtained at ground level and that obtained from the samples.

SAMPLING AND ANALYSIS

Queen Elizabeth Oak

The surviving trunk of the Queen Elizabeth Oak is 8.6m in length. The crown end of the tree lies pointing to the south-east. In its fallen position most of the bottom half of the trunk has rotted away (Fig 3), leaving only a half diameter of 3.25m which could be measured. Observations showed that the outermost rings tended to be rotten towards the root end of the tree where the innermost rings were best preserved, whereas nearer the crown end of the tree fewer inner rings remained but the outermost rings were better preserved. No surviving bark or sapwood was identified on the extant trunk of the Queen Elizabeth Oak.

Three core samples were taken at heights of 7.3m, 3.0m, and 1.0m from the root end, as shown in Figures 3, 4, and 5 respectively. Three slices were taken from sections found under the trunk which were presumed to have broken off from the main trunk. A previously collected 36mm long sample of sapwood from the tree was also included in this analysis. These samples were given a site code SEGR and sequentially numbered 01–07 (Table 1)

Sample SEGR02 contained periods of rot and insect damage which prevented the measurement of a continuous series, instead two series SEGR02A and SEGR02B were measured which avoided the damaged areas. Similarly sample SEGR06, representing the innermost extant growth rings, was too damaged for a series of useful length to be measured and was therefore discarded from analysis at this stage. While no surviving bark or sapwood was identified on the Queen Elizabeth Oak, sample SEGR01 was taken at the heartwood/sapwood boundary, and 26 rings were counted in the sapwood sample previously collected from the tree.

Six series' SEGR01, SEGR02A, SEGR02B, SEGR03, SEGR04, and SEGR05 were found to match well together (Table 2) and combined to form a 233-year mean tree-ring series named QE1OAK. Series QE1OAK was compared with reference chronologies from

throughout the British Isles and found to produce consistently high ***t***-values against reference chronologies, with the first ring of the series at AD 1569 and the final ring of the series at AD 1801 (Table 3). While the cross-matching of the QE1OAK series is not high (most ***t***-values ≤5) this is likely to be the result of tree specific growth disturbances found in this single tree series.

Younger oak tree

As the Queen Elizabeth Oak was hollow, it was clear that it would not be possible to determine a precise date of germination. However, to help refine an age estimate for the Queen Elizabeth Oak, it was agreed that one core sample (labelled SEGR08) could be taken from a neighbouring younger oak tree with a solid trunk to help establish the potential formative/mature growth rates at the site (Table 1).

The first six rings to pith on sample SEGR08 were not measured due to a sudden growth reduction. As the park has been formally laid out since the 1660s, it is likely that most trees were planted, as opposed to having germinated naturally in there current positions. The sudden growth reduction identified in this tree's early growth is therefore assumed to be associated with the planting of the tree. Series SEGR08 was found to produce consistently high ***t***-values against reference chronologies, with the first ring of the series at AD 1906 and the final ring of the series at AD 2011 (Table 4). The cross-matching values of series SEGR08 (also a single tree series) are comparable with the QE1OAK series.

INTERPRETATION AND DISCUSSION

The dating of the first ring of a sample from the Queen Elizabeth Oak tree to AD 1569 positively identifies that the tree was alive in the reign of Queen Elizabeth 1. The final ring at the heartwood/sapwood boundary in sample SEGR01 occurs in AD 1801. Allowing for the 26 years of sapwood present on SEGR07, the death of the tree is estimated to have occurred within the range of AD 1827–1842. This date range is earlier than the reported last living shoots around 1878 by Webster (1902) but, as the tree was covered in ivy, observations of the last shoots may well have been obscured.

In order to obtain an age estimate for the Queen Elizabeth Oak it is necessary to combine the information obtained from the extant measured ring sequence with additional information (Table 5; Figs 6 and 7).

The mean decadal growth rate of series SEGR08 drops from 2.90mm/yr in the ten-year period commencing in AD 1981 to 2.04mm/yr in the ten-year period commencing in AD 1991 (Fig 6), which is interpreted as the date for transition from formative to mature growth. Between the period AD 1906 to AD 1990, series SEGR08 identifies a growth rate of 4.19mm/year, based on the decadal means, and thus this figure is used as representative for the first 100 years of formative growth of oak at this site (Fig 6). The formative growth for this oak at Greenwich Park compares reasonably with that of

3.50mm/year predicted for oak in parkland (White 1998). Therefore the radial growth produced by sample SEGR08 is used to represent the early growth of the Queen Elizabeth Oak. However, this clearly assumes that the growth conditions for this young tree were not markedly different in the twentieth century from those several centuries earlier when the Queen Elizabeth Oak was a young tree.

The mean decadal growth rate of series QE1OAK drops to under 1.00mm/yr in the ten-year period commencing AD 1771, which is interpreted as the date for transition from mature to senescent growth (Fig 7). Measured ring-widths over the period AD 1569–1770 are used to calculate a mature rate of growth of 1.44mm/year in series QE1OAK. Measured ring-widths over the period AD 1991–2011 are used to calculate a mature rate of growth of 2.11mm/year in series SEGR08. Therefore, mature growth rates of 1.44mm/year and 2.11mm/year are calculated from samples QE1OAK and SEGR08 (Figs 6 and 7), respectively, and used in subsequent analysis.

The total radial length of series QE1OAK is 319mm. However, the tree was measured to have a half girth of *c* 3250mm, and therefore a total girth of *c* 6500mm is calculated for the tree, with a radius of the *c* 1035mm to the heartwood/sapwood boundary. The total radial length of series SEGR08 is 401mm. Subtracting the known radial length of the measured core sample QE1OAK (319mm) and the younger (formative/mature) radial growth of sample SEGR08 (401mm) from the Queen Elizabeth Oak radius of 1035mm, leaves a 315mm section of radial growth unaccounted. If mature growth rates of 1.44 and 2.11mm/year are applied to the unaccounted section, 219 and 149 missing rings, respectively, are calculated. This shows a 69 year range of variation between the two individual mature growth rates. As the growth conditions for when the Queen Elizabeth Oak was young are not known, a mean of the 1.44 and 2.11mm/year mature growth rates (1.78mm/year) is used to estimate that 177 rings/years are likely to have been present in the 315mm unaccounted section of radial growth. A total of *c* 522 rings are therefore estimated for the 1035mm radius of the Queen Elizabeth Oak. Finally, 26 years was added for the known unmeasured rings of sapwood and five years to allow for the height of sampling to indicate that the tree was *c* 553 years of age. This estimate is rounded to indicate the tree was *c* 550 years of age when it died. Germination is therefore likely to have occurred around the latter decades of the thirteenth century. Although, if the tree grew quickly when it was young, germination could have occurred in the early decades of the fourteenth century.

Subtracting the measured radial growth back to AD 1603 indicates that the Queen Elizabeth Oak had a girth of around 4.8m at the time of Queen Elizabeth I's death in AD 1603. Today specimens of oak with a girth of more than 4.7m are considered notable (Read 1999), therefore this analysis does not dispute the tradition that both Queen Elizabeth I and King Henry VIII had links with the tree, as it was already a large tree on the succession of King Henry VIII.

The smaller oak sampled (SEGR08) is identified to have germinated around AD 1895: a sudden ring reduction in the early unmeasured section suggests this tree was planted at the Greenwich Park site in AD 1903.

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FIGURES

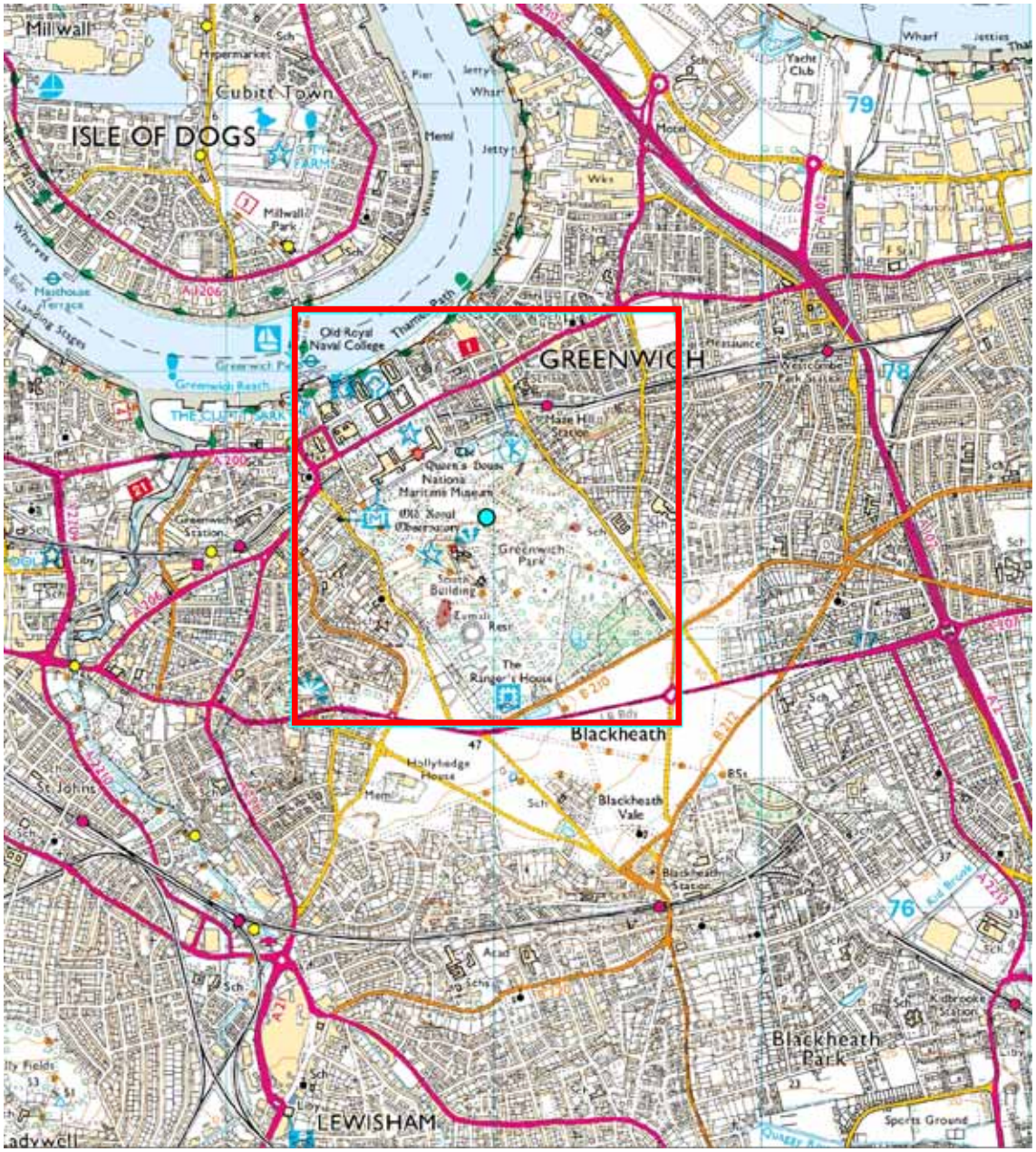

Figure 1. Map to show the location of Greenwich Park. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2. Map to show the location of the Queen Elizabeth oak (adapted from source at: http://www.royalparks.org.uk/parks/greenwich-park)

Figure 3. The Queen Elizabeth oak showing the location of sample SEGR01 taken from the crown end of the tree (photo Andy Moir)

Figure 4. The Queen Elizabeth oak showing the location of sample SEGR02 (photo Andy Moir)

Figure 5. The Queen Elizabeth oak showing the location of sample SEGR03, taken from the root end of the tree (photo Andy Moir)

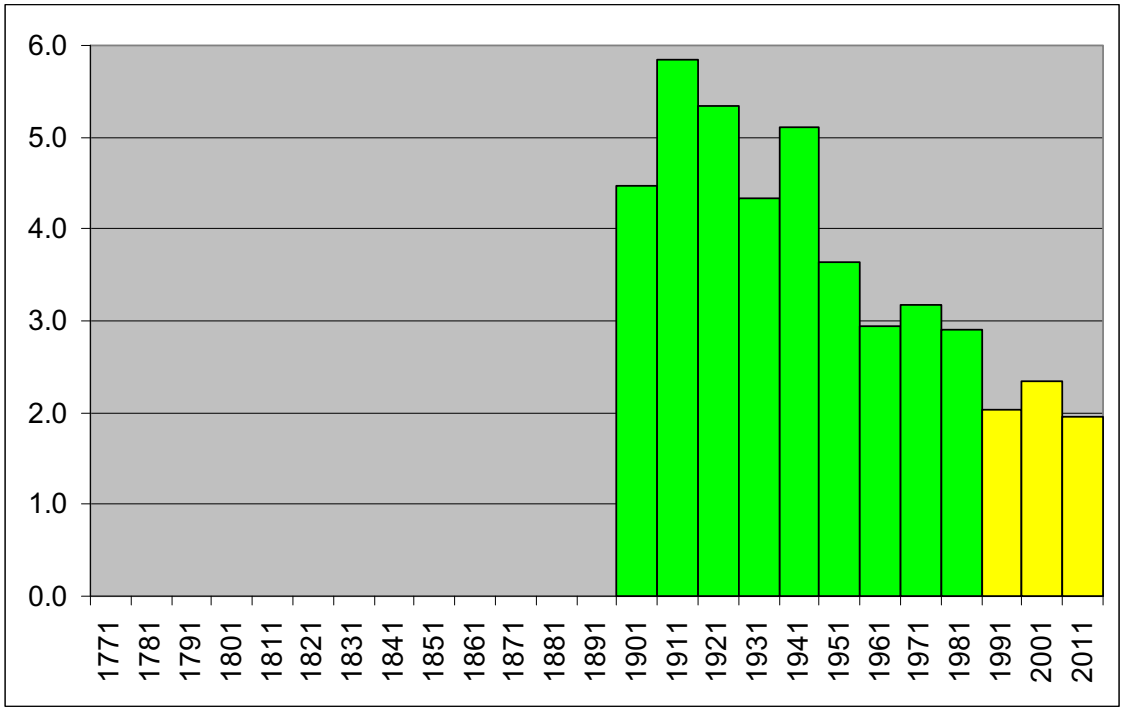

Figure 6: Mean decadal growth rates of SEGR08. Green and yellow denote formative and mature growth, respectively

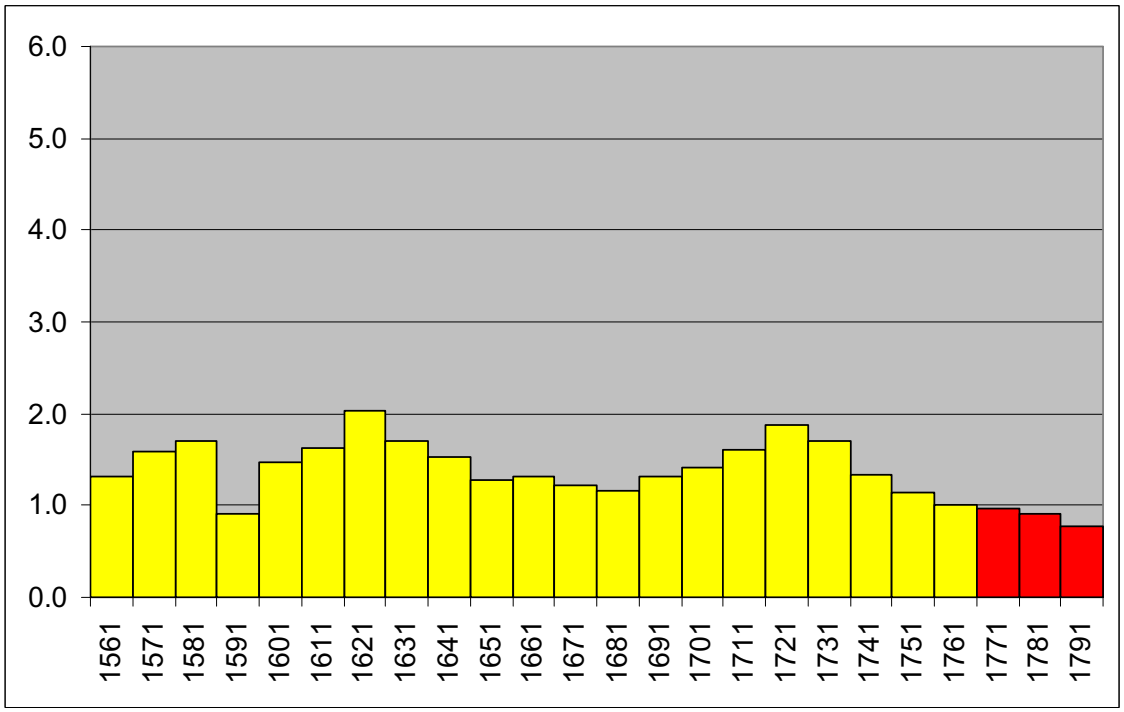

Figure 7: Mean decadal growth rates of QE1OAK. Yellow and red denote mature and senescent growth, respectively

TABLES

Table 1: Details of the oak samples taken from Greenwich Park

Sample	Rings	Sapwood	Average Growth Rate (mm/yr)	Sequence Date Range (AD)
SEGR01	125	+HS	1.28	1677–1801
SEGR02A	33	-	1.47	1637–1669
SEGR02B	34	-	1.18	1682–1715
SEGR03	57	-	1.74	1577–1633
SEGR04	77	-	1.47	1634–1710
SEGR05	160	-	1.38	1569–1728
SEGR06	NM	-	-	-
SEGR07	NM	26	-	-
SEGR08	6NM+106	10+Bw	3.78	1906–2011

KEY: NM = not measured, HS = heartwood/sapwood boundary, Bw = winter bark

Table 2: Cross-matching between six series' from the Queen Elizabeth Oak, which combine to form the mean series QE1OAK

Filenames	Start date (AD)	End date (AD)	SEGR02A	SEGR02B	SEGR03	SEGR04	SEGR05
SEGR01	1677	1801	\	6.33	\	5.95	5.99
SEGR02A	1637	1669		\	\	6.58	5.91
SEGR02B	1682	1715			\	\	4.23
SEGR03	1577	1633				\	4.23
SEGR04	1634	1710					13.58
SEGR05	1569	1728					

KEY: \ = overlap < 30 years

Table 3: Results of the cross-matching of series QE1OAK against some relevant reference chronologies, the first-ring date is AD 1569 and the last-ring date is AD 1801

File name	Start date (AD)	End date (AD)	*t*-value	Overlap (years)	Reference chronology
STONELGH	1387	1998	5.77	233	Stoneleigh Abbey, Warwickshire (Howard ***et al*** 2000)
SHERWOOD	1426	1981	5.71	233	Sherwood Forest, Nottinghamshire (Briffa ***et al*** 1986)
ALBAN-F1	1508	1680	5.56	112	150 Fishpool Street, St Albans, Hertfordshire (Moir 2007)
HRSTMNCX	1711	1813	5.13	91	Post Mill, Windmill Lane, Herstmonceux, East Sussex (Bridge 2005)
EAST_MID	882	1981	4.75	233	East Midlands (Laxton and Litton 1988)
FLITN-DM	1510	1721	4.21	153	De Grey Mausoleum, Flitton, Bedfordshire (Arnold ***et al*** 2003a)
HOUGHTON	1683	1806	4.20	124	Houghton Mill, Cambridgeshire (Loader pers comm)

Table 4: Results of the cross-matching of series SEGR08 against some relevant reference chronologies, the first-ring date is AD 1906 and the last-ring date is AD 2011

File name	Start date (AD)	End date (AD)	*t*-value	Overlap (years)	Reference chronology
KENT48	1101	2011	5.07	106	County mean for Kent (Moir, unpublished)
COBHAM	1770	2001	4.91	96	Modern trees, Cobham, Kent (Arnold ***et al*** 2003b)
CAPEL-C1	1814	2002	4.83	97	Oak tree, St John the Baptist churchyard, Capel, Surrey (Moir 2003)
HEDGE-S4	1847	2010	4.76	105	Modern trees, Hedgeley, Buckinghamshire (Moir, unpublished)
STONELGH	1387	1998	4.66	93	Stoneleigh Abbey, Warwickshire (Howard ***et al*** 2000)
YATLY-OE	1856	2003	4.52	98	Six oak trees, Old Ely, Yateley, Hampshire (Moir, unpublished)
EYNSF-LL	1737	2011	4.51	106	Lullingstone County Park, Eynsford, Kent (Moir 2012)

Table 5: Age estimation details for Queen Elizabeth's Oak

Mean tree sequence	Sequence date range	Rings	Pith	Sen-sitivity	Mean ring width (mm)	Tree girth# (mm)	Tree radius# (mm)	Core length (mm)	Formative growth rate (mm/yr)	Age at transition from Formative to Mature growth	Mature growth rate (mm/yr)	Unacc-ounted radius (mm)	Estimated missing rings	Estima ted age*	Estimated germ-ination
SEGR08	1906-2011	106	Yes	0.29	3.78			401	4.19	100	2.11		6	117	1895
QE1OAK	1569-1801	233	No	0.22	1.37	6500	1035	319			1.44	315	177	553	1274

KEY: # = approximated from the measured girth, * = age includes plus 5 rings for the sampling height as well as 26 unmeasured sapwood rings for sample QE1OAK and also 6 unmeasured rings to pith on sample SEGR08.

DATA OF MEASURED SAMPLES

Unit of Measurement 0.01mm

SEGR01

199	152	174	103	140	98	154	146	154	135
153	141	155	102	122	130	156	105	89	135
154	120	107	100	101	113	110	151	77	86
115	116	148	194	151	168	197	116	114	205
156	280	133	156	229	187	162	199	144	203
220	231	255	189	205	137	140	159	179	121
150	209	196	207	133	117	101	80	135	235
149	148	132	96	128	100	91	133	115	118
112	136	90	113	100	66	108	94	83	98
138	128	96	99	99	84	99	115	90	125
117	78	68	98	67	112	59	128	93	93
101	76	101	83	67	87	63	76	120	50
97	73	75	58	73					

SEGR02A

153	193	158	197	186	203	166	220	190	225
170	144	116	122	112	124	109	98	134	117
117	189	125	115	114	129	200	76	134	135
151	124	120							

SEGR02B

37	42	46	53	50	64	69	131	87	88
137	139	96	88	113	141	123	95	116	102
114	124	170	114	138	130	111	154	217	167
216	238	115	189						

SEGR03

200	140	264	331	178	194	196	186	245	276
135	56	47	58	76	64	77	90	159	138
84	101	102	129	165	154	216	201	122	127
102	292	179	224	204	325	244	141	156	117
127	178	129	112	248	281	197	252	214	176
207	202	250	226	226	172	215			

SEGR04

177	168	106	128	166	146	171	142	160	147
187	139	125	111	127	116	123	130	160	121
103	122	147	135	208	157	154	129	162	216
118	145	155	158	147	142	147	114	126	104
163	107	96	224	168	116	107	118	89	121
172	164	141	140	145	184	136	122	152	176
112	113	161	220	152	118	128	160	141	168
225	155	160	188	166	199	198			

SEGR05

104	158	153	136	166	138	103	101	144	128
176	192	129	119	193	158	209	177	179	188
261	237	150	54	56	59	65	70	58	90
84	113	124	94	111	98	76	112	87	172
143	140	148	184	161	121	190	124	142	170
140	141	191	198	169	256	172	171	185	165
152	159	214	157	141	153	213	126	157	207
191	146	136	165	148	204	172	173	141	124
109	118	113	151	119	103	92	108	100	171
114	100	99	101	166	97	134	146	119	96
101	89	73	96	83	137	87	77	195	130
117	85	128	77	106	150	122	97	96	135
144	123	133	159	166	109	123	189	179	182
118	109	120	132	145	188	88	109	112	125
158	140	127	120	137	90	121	145	148	173
154	157	145	138	127	135	133	201	178	227

SEGR08

284	359	502	462	625	515	699	527	562	542
552	747	639	561	506	555	615	326	558	520
408	905	449	645	354	538	506	537	425	524
374	363	255	296	508	538	378	460	341	926
421	759	296	335	655	328	495	345	231	216
300	343	329	578	480	265	240	258	366	437
373	265	248	217	279	390	233	305	189	314
137	284	321	407	595	434	529	412	253	313
203	217	164	218	156	212	271	240	160	158
145	166	269	176	239	295	203	266	264	198
207	295	219	203	188	196				

QUEEN ELIZABETH OAK MEAN TREE SERIES

QE1OAK

AD1569									104	158
	153	136	166	138	103	101	172	134	220	261
	153	156	194	172	227	226	157	122	154	147
	113	59	66	74	112	104	71	95	93	121
AD1601	144	124	163	149	99	119	94	232	161	182
	176	254	202	131	173	120	134	174	134	126
	219	239	183	254	193	173	196	183	201	192
	220	164	178	165	190	116	146	188	165	171
	154	176	153	203	167	174	140	131	113	121
AD1651	118	145	116	101	116	124	117	189	132	123
	114	130	194	97	137	145	142	122	121	118
	93	111	93	150	97	86	206	150	135	98
	128	75	105	128	123	105	113	122	153	112
	116	144	159	105	103	149	173	144	109	113
AD1701	120	125	136	183	108	123	136	129	164	187
	148	168	190	107	141	175	152	226	143	156
	187	162	144	167	138	202	199	229	255	189
	205	137	140	159	179	121	150	209	196	207
	133	117	101	80	135	235	149	148	132	96
AD1751	128	100	91	133	115	118	112	136	90	113
	100	66	108	94	83	98	138	128	96	99
	99	84	99	115	90	125	117	78	68	98
	67	112	59	128	93	93	101	76	101	83
	67	87	63	76	120	50	97	73	75	58
AD1801	73									

ENGLISH HERITAGE RESEARCH AND THE HISTORIC ENVIRONMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for the protection and sustainable management of the resource, and to promote the widest access, appreciation and enjoyment of our heritage. Much of this work is conceived and implemented in the context of the National Heritage Protection Plan. For more information on the NHPP please go to http://www.english-heritage.org.uk/professional/protection/national-heritage-protection-plan/.

The Heritage Protection Department provides English Heritage with this capacity in the fields of building history, archaeology, archaeological science, imaging and visualisation, landscape history, and remote sensing. It brings together four teams with complementary investigative, analytical and technical skills to provide integrated applied research expertise across the range of the historic environment. These are:

* Intervention and Analysis (including Archaeology Projects, Archives, Environmental Studies, Archaeological Conservation and Technology, and Scientific Dating)
* Assessment (including Archaeological and Architectural Investigation, the Blue Plaques Team and the Survey of London)
* Imaging and Visualisation (including Technical Survey, Graphics and Photography)
* Remote Sensing (including Mapping, Photogrammetry and Geophysics)

The Heritage Protection Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support community engagement and build this in to our projects and programmes wherever possible.

We make the results of our work available through the Research Report Series, and through journal publications and monographs. Our newsletter *Research News*, which appears twice a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities.

A full list of Research Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

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