DENDROCHRONOLOGICAL ANALYSIS OF A YEW TREE FROM ST MARYS CHURCHYARD, WEST HORSLEY, SURREY, ENGLAND.

Tree-Ring Services Report: WHCX/33/04

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A. K. MOIR, 2nd November 2004

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SUMMARY
The opportunity to carry out dendrochronological analysis on a full section from a 2.8m girth churchyard yew (Taxus baccata) arose due to the felling of the tree at St Mary's Church, West Horsley, Surrey. The section showed no indication of rot. Pith was measured and indicated that the tree germinated in AD 1691 and was 313 years old when felled. The analysis reveals a formative growth rate of 2.82mm/yr over the first 99 years and 0.89mm/yr for the subsequent 213 years mature growth. A comparatively lower rate of growth during the first 26 years highlights the possibility that the tree was transplanted. A narrow ring in AD 1705 suggests a possible year for planting. However, historical records would be necessary to support this hypothesis. The actual age of the St Mary’s tree demonstrates that the White/Tabbush equation underestimates the tree’s age by 19%. However, the study identifies that the radial growth rate of yew can increase once a mature stage of growth has been achieved. This analysis indicates that further research is required to establish whether the formative, mature and senescence stages of tree growth are generally applicable to yew.

KEYWORDS
Dendrochronology, Live tree, English yew, Taxus baccata.
Figures

Figure 1: Area location map ................................................................. 7
Figure 2: Site location map ..................................................................... 7
Figure 3: Plots of the two ring sequences established (WHCX01A and WHCX01B). ................................................................. 11
Figure 4: Average decadal radial growth of the yew tree ...................... 12
Figure 5: Plot of yew tree cumulative ring-widths over time .................. 13
Figure 6: The relationship between yew tree age and girth .................... 15

Tables

Table 1: Examples of yew chronology WHCX01-ed cross-matching against independent data sets ................................................................. 11
Table 2: Summary of dendrochronological analysis ................................. 12

Photos

Photo 1: North east aspect of St Mary's Church, West Horsley .............. 8
Photo 2: West aspect of the yew tree and church, taken 4 weeks prior to felling. (Photo by Anne Grace) ........................................................... 8
Photo 3: West aspect of the church, showing the yew tree on the left. (Water colour painting by J. Hassell in AD. 1823) ........................................ 8
Photo 4: Taking a V-section by circular saw ........................................... 9
Photo 5: Tree-ring sequences revealed through the sanding of part of the V-section WHCX01a cut from the full section ......................................... 9
INTRODUCTION

Tree-Ring Research
Dendrochronology has been defined as "the dating of annual growth layers in wood plants and the exploitation of the environmental information which they contain," (Fritts 1971). The science is based on the premise that the annual growth rings of trees vary from year to year, largely according to the climatic conditions. "Tree-ring Dating and Archaeology" and "A Slice Through Time" Baillie (Baillie 1982; Baillie 1995) provide interesting backgrounds into the science, while a free guidelines booklet on dendrochronology is offered by English Heritage (English Heritage 1998).

The fundamental basis of dendrochronology is the annual growth ring which forms inside the bark by division of cambial cells. Large, thin-walled wood or xylem cells (earlywood) are produced at the beginning of the growing season, and small, thick-walled wood cells (latewood) towards the end of the growing season. The abrupt change in cell size between the last-formed wood of one year and the first-formed wood of the next year usually delineates the boundary between the annual growth increments or annual rings (Fritts 1966).

A. E. Douglass pioneered tree-ring work on living trees in the early part of this century, developing a 3,220 year-long record of ring widths from the giant sequoia (Douglass 1919; Douglass 1928). Douglass demonstrated that the widths of annual rings in trees can correlate with variations in climate, and that their unique sequences of wide and narrow rings can be recognised and the same patterns cross-matched (cross-dated) in felled trees from adjacent areas. Cross-dating from living trees to dead trees made it possible to determine the actual year in which the dead trees were felled. The vigorous programme of tree-ring research that followed these discoveries led to the new discipline called dendrochronology. By statistically comparing timbers against established UK master chronologies dating back to 5289 BC it is now possible to obtain precise calendar year dates for timbers of various species by dendrochronological analysis.

English yew (Taxus baccata L.)
Yew is generally acknowledged as the British tree capable of longest life and many specimens are known to be well over 1,000 years old, although supporting dendrochronological evidence is currently scant. Yew trees can grow to around 28m in height, the oldest specimens are generally hollow, and many of the largest specimens are found in the churchyards of England and Wales. Yew has been observed to contain up to 40 rings in 10mm of growth and one yew in a Somerset churchyard has been reported to show more than 500 years continuous growth (Bowman 1837). More recently, coring of less than half the radius of the whole trunk of a reasonable sized cliff yew in North Wales revealed a ring count of over 500 years, (Larson et al 1999).

Range of yew
In Britain the yew is one of the few native conifers, along with juniper (Juniperus communis) and the Scots pine (Pinus sylvestris). It is particularly well suited to a mild oceanic climate and avoids regions of strong winter frost (Godwin 1975). Yews are slow growing but very shade and salt tolerant. Found growing naturally in the under-storey of deciduous woods they are able to withstand very low light-levels, on thin soil over limestone rock or chalk yew can develop extensive pure stands. Tittensor (1980) shows the probable native distribution of yew in Britain and Ireland.
Example Dendrochronological Report: Yew tree, West Horsley, Surrey

Climate and Elevation Effects on Yew

*Taxus baccata* is a western Atlantic species, characteristic of British rather than continental woods (Ratcliffe 1977). Native to Europe, it is also found from North Africa to Iran, extending over areas where the climatic extremes in both winter and summer are not exceptional. In the south of its European range yew is largely a montane tree, whereas in the north (as in Britain, Ireland and Scandinavia) it grows at low altitudes and often in rugged locations. A climate analysis study from yews located at Hampton Court indicates yew growth is positively correlated with rainfall and inversely related to late summer temperature (Moir 1999). Most species show significant correlations between growth and elevation (Nicholls 1981), and this is an important factor which might be addressed as more data is accumulated on yew.

Yew Management

Management (specifically the clipping of yew) has been shown not to remove the climatic signal contained within the annual growth increments (Moir 1999). This factor is especially important in the context of ancient yews in churchyards, where trees are more likely to have been exposed to periodic management.

Four yew bows recovered from peat deposits and dated by radiocarbon dating ranging from *circa* 4000BC to 1700BC testify to the usage of yew in prehistory (Bevan-Jones 2002). John Lowe (Lowe 1897) cites many charters and statutes pertaining to protecting and planting yews passed by various monarchs in Britain during the well-documented period of yew usage between 1200 and 1650. He also points to Cherkley Court, near Leatherhead in Surrey, where in 1897 over 90 acres of yew remained as a yew wood that is likely to have been planted and pollarded for late medieval bows. In 1999 T. Hindson studied ring counts from dead stumps there brought down in the storms of October 1987 and assessed the ages of some of the older yew stumps at *circa* 600 years (Bevan-Jones 2002). However, the extent of yew management largely remains unknown, and most authorities on bows are in general agreement that much Spanish yew was imported for battle bows between AD 1300 and AD 1650, as the English yew was found too often to be brittle and knotty.

Yew also used to be fed regularly to cattle on the Continent: "Mixed with three or four times their bulk of other food, green yew leaves are actually employed as fodder for cattle in times of scarcity" (Johnson 1908).

Tree Age Estimates

Britain's ancient trees, and the wildlife they support, are as much part of our heritage as the venerable buildings they often pre-date, and in whose grounds they often now reside (Green *et al* 1999). Although there is some variation between some species, in general, trees progress through three phases of growth: formative, mature and senescence (White 1998). Formative increment growth nourished by the increasing foliage tends to increase each year until optimum crown size is reached, usually achieved in 40 to 100 years. During the mature phase, (foliage, weather and all other factors being equal), the annual increment produced remains constant in terms of volume. However, as a tree's girth increases, the annual increment is spread over a larger area and hence its width progressively declines. Die back of the crown and branches occur during senescence, the final phase, and causes further reduction in the width of the annual increment.
Example Dendrochronological Report: Yew tree, West Horsley, Surrey

Exceptionally large trees have been analysed by a variety of methods in the past, and resulted in often wide variation in the age estimates. Tree age estimation in the UK has remained largely based on girth measurements of known date. However, age estimates made by external measurement and comparison with other trees of similar species has intrinsic problems in accuracy.

Age estimates based on simple linear extrapolation of average girth yield age overestimates because they take no account of increase in ring width towards the tree's centre. Conversely, age estimates based on an assumption that basal area increment is constant, (i.e., trees add a constant amount of basal area each year), has been shown to underestimate the trees’ ages (Hartesveldt et al 1975). Some estimates have unfortunately also suffered from poor quantitative descriptions on the method of estimating, particularly in respect to calculation of the probable rate at which rings increase in size toward the centre. John White (Mitchell et al 1994) makes good provision for the effects of tree growth stages in his tree age estimating. However, his assessment of the age when optimum crown development is achieved is very subjective without precise increment information: a factor critical to the accuracy of an age estimate. Differences in growth due to specific local ecological conditions also affect a tree's growth, detracting from the precision of estimates.

Currently the only precise way to determine the age of a living tree is to count the annual tree rings from a section or increment core which intersects the pith of the tree. The use of a narrow (5.14mm) diameter increment corer provides the means to take a sample from a live tree with almost no damage, and can result in the same astonishing impact of absolute tree-ring dates which has been achieved with the dating of historic timber-framed buildings in this country. While the girth of our very largest trees (and hence the trees of greatest interest) often makes it impossible to reach their piths with hand-driven increment borers, increment sampling still offers the most accurate empiric refinement to the estimation of a tree's age.

Until a new technique of non-intrusive tree-ring measuring is developed, dendrochronological analysis of sections or using complete or partial increment coring offers the only accurate method of dating individual living trees. The method offers a means to dispel the great deal of uncertainty that remains about the age of many of our largest trees. A good example of its use was by Nathan Stephenson, who successfully combined knowledge on tree size with information gained directly from partial increment cores (cores that fall well short of a tree's pith) to estimate the age of giant sequoias (Stephenson and Demetry 1995).

The general hollowing characteristic of yew trees over 4.57m girth (Mitchell 1972) makes their dating impossible by totally empirical means. In the case of large, hollow ancient yew trees particularly, age estimates have varied widely due to reliance on tentative average projections from painstakingly gathered girth measurements of trees scattered throughout the UK.

Tabbush (1996; 1997), refined the age estimating method of White (1994) in respect of yew and concludes that although the growth of individual yew trees is evidently variable, the age of churchyard yews appears to be fairly estimated by the equation: Tree age = Girth² / 310.
When, as part of a Surrey Dendrochronology Project, the dendrochronological assessment of the church of St Mary’s was made (Photo. 1), a section of yew was pointed out which had been saved from a yew tree recently felled in the churchyard. The former location of the tree was indicated to be approximately a couple of metres from the north west corner of the church, just to the west of the north porch (Photo. 2).

A water colour picture painted in AD 1823, shows an earlier relationship of the tree to the church and indicates that the path to the church changed position (Photo. 3). When the north aisle was doubled in width in c. AD 1850, the north west buttress was built close to the yew (A. D. Grace pers comm.). Following a crack appearing in the masonry at the north west corner of the church, the tree was pruned at intervals. (A.D. Grace pers comm.)
St Mary's is based on Newmarket series of soils, shallow coarse loamy soils which develop over chalk or chalk rubble at less than 40cm depth and classified with the brown rendzinas. This is a well drained soil, cereal crops suffer moisture stress in dry seasons only, but grass yields are reduced in most years (Fordham 1986).

The girth of the section taken from the St Mary yew is 2.80m. The application of the White/Tabbush equation to the St Mary’s yew estimates the tree to be 253 years old.
Example Dendrochronological Report: Yew tree, West Horsley, Surrey

Aim of the Analysis
The main aim of this analysis was to take advantage of a rare opportunity to determine the precise age of the yew tree when felled and to record its growth history; also to compare actual age with that calculated and to obtain further evidence to test and possibly refine current age estimates based on girth measurement.

METHODOLOGY

Sampling and Preparation
There are a number of particular problems in the dendrochronological study of yew, for example, slow growth in this species may lead to extremely narrow rings, and in some cases, locally absent or "missing" rings which can cause potential ring counting errors during measurement. Another problem is the common irregular and lobate growth pattern of the trunk and the consequent risk of missing rings from core samples (Moir 1999). This has been considered a potentially critical difficulty in cross-matching core samples of yew because, unlike using complete cross-sections, it is not possible to trace each growth ring around the circumference of the trunk to identify where tree-rings are locally absent. However, recent research from generally non-hollow yew trees has demonstrated that yew may be successfully core sampled from lobe sections of growth and dendrochronologically analysed (North 2000; Yadav and Singh 2002; Moir 2003).

The analysis of complete sections is sometimes impractical or hazardous due to their great size and weight. In these instances two V-sections are cut from the full section to provide samples suitable for dendrochronological analysis. Tree-ring sequences are revealed by the use of a belt sander, using progressively finer grits, to a 600 abrasive grit finish to produce results normally suitable for measuring. When required, for example where bands of narrow rings occur, further preparation to a 1000 abrasive grit is performed manually.
Measuring and Cross-matching

Tree-ring sequences are measured under a x20 stereo microscope to an accuracy of 0.01mm using a microcomputer based travelling stage. Samples are measured twice along different paths wherever possible from the centermost ring to the outermost. The two opposing core samples are measured and both sets (e.g., WHCX01A and WHCX01B) visually plotted to support or reject possible cross-matches and serve as a means of identifying measuring errors. Where sequences visually match satisfactorily at the appropriate offset they are averaged and the resulting average used in subsequent analysis (e.g., sequence WHCX01). Where samples do not contain bark of known date to act as a datum point for cross-matching, statistical cross-correlation algorithms are employed to search for the positions where tree-ring sequences correlate. The search produces “t-values”, and the higher this value then the more certain the correlation. Those t-values in excess of 3.5 are taken to be significant and indicative of acceptable matching positions, this value happening by chance about once in every 1000 miss-matches (Baillie 1982). Visual comparisons of sequences are again employed to support or reject possible cross-matches between samples and serve as a means of identifying measuring errors.

Determination of Germination Date

Pith was recovered and could be measured on the section of yew analysed. As the section appears to have been taken very close to the ground the precise germination date quoted is assumed to be the first year the tree was growing.

Stages of Growth

Using the overall patterns of growth it is sometimes possible to identify the change from formative to a mature phase, and from mature growth to senescence. Plots of average decadal radial growth and cumulative ring-widths are used to help interpret the overall patterns of tree growth. These stages of growth are related to the development of a tree’s crown: the formative stage being generally characterised by relatively rapid growth and more or less constant ring width. The mature phase which follows is normally characterised by a reduction in the rate of growth, further reducing over time. The transition between the formative and mature phases of growth is gradual, but may be identified over a relatively short period in some trees.

Tree-Ring Services - Methods and Criteria

Tree-ring analysis and graphics are achieved via a dendrochronological programme suite developed by Ian Tyers of Sheffield University (Tyers 1999). 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. Pointer years (years of exceptionally narrow or wide rings) and climate response analysis are important tools available in dendrochronology to help establish the relative influence of specific climatic variables, however this depth of analysis is outside the scope of this report.
RESULTS

The full yew section needed two people to move it, and therefore two far more manageable V-sections were taken from the complete cross-section of the yew to provide samples suitable for dendrochronological analysis (WHCX01A and WHCX01B). The steep angle of the sides of the yew section suggested that it had been cut from the base of the tree. The centre of the section showed no evidence of rot and the V-section WHCX01B included pith. Both V-sections were measured and the resulting sequences cross-matched together (see Figure 3), producing a $t$-value of 8.58. The sequences were therefore combined to form a 312-year mean sequence called WHCX01, spanning 1691 to 2002.

Figure 3: Plots of the two ring sequences established (WHCX01A and WHCX01B).

The earliest part of the sequence WHCX01 contains a period of growth disturbance with two exceptionally narrow rings and therefore the first 15 rings were removed to assist inter-site cross-matching. This resulted in a 138-year mean yew tree chronology spanning 1865 to 2002, which was called WHCX01-ed.

Table 1: Examples of yew chronology WHCX01-ed cross-matching against independent data sets.

<table>
<thead>
<tr>
<th>Reference chronology</th>
<th>File</th>
<th>Start Date</th>
<th>End Date</th>
<th>$t$-value</th>
<th>Overlap (yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVYEW00 - COULSDON - G.LONDON (North 2000)</td>
<td>hvyew00</td>
<td>AD1789</td>
<td>AD2000</td>
<td>5.05</td>
<td>212</td>
</tr>
<tr>
<td>NORBURY PARK - MICKLEHAM - SURREY (Author, unpublished)</td>
<td>nopk05</td>
<td>AD1824</td>
<td>AD1987</td>
<td>4.00</td>
<td>164</td>
</tr>
<tr>
<td>THORLEY YEW - HEREFORDSHIRE (Moir 2003)</td>
<td>thor-yew</td>
<td>AD1879</td>
<td>AD2002</td>
<td>4.07</td>
<td>124</td>
</tr>
<tr>
<td>UK YEW MASTER CHRONOLOGY (Moir, unpublished)</td>
<td>ukyew5</td>
<td>AD1690</td>
<td>AD2002</td>
<td>4.32</td>
<td>312</td>
</tr>
</tbody>
</table>

KEY: Bold = components of the ukyew5 chronology.

Cross-matching of the yew chronology against independent reference chronologies helps confirm that no rings were missing from the sequence, (see Table 1).
Table 2: Summary of dendrochronological analysis

<table>
<thead>
<tr>
<th>Tree section</th>
<th>Sequence Date Range</th>
<th>Rings</th>
<th>Years to pith</th>
<th>Age (yrs)</th>
<th>Date of germination</th>
<th>Av ring width (mm)</th>
<th>Sapwood</th>
<th>Tree girth (m)</th>
<th>Tree radius (m)</th>
<th>Max bark width (mm)</th>
<th>Radius - bark (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>whcx01</td>
<td>AD1691-AD2002</td>
<td>312</td>
<td>0</td>
<td>313</td>
<td>1691</td>
<td>1.50</td>
<td>25¼B</td>
<td>2.80</td>
<td>0.446</td>
<td>8</td>
<td>0.438</td>
</tr>
<tr>
<td>whcx01a</td>
<td>AD1741-AD2002</td>
<td>262</td>
<td>50</td>
<td>313</td>
<td>1691</td>
<td>1.58</td>
<td>25¼B</td>
<td>2.80</td>
<td>0.446</td>
<td>7</td>
<td>0.439</td>
</tr>
<tr>
<td>whcx01b</td>
<td>AD1691-AD2002</td>
<td>312</td>
<td>0</td>
<td>313</td>
<td>1691</td>
<td>1.28</td>
<td>19¼B</td>
<td>2.80</td>
<td>0.446</td>
<td>8</td>
<td>0.438</td>
</tr>
</tbody>
</table>

Figure 4: Average decadal radial growth of the yew tree

interpreted boundary between formative and mature growth stages boundary

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Figure 5: Plot of yew tree cumulative ring-widths over time
INTERPRETATION AND DISCUSSION

The measurement of pith identifies that germination of this tree occurred in AD 1691. The comparative rapid reduction in ring-widths approaching AD 1791 and slow reduction after this date is indicative of the change between formative to mature growth and this is interpreted as the formative/mature stage boundary. The tree had a mean tree-ring growth rate of (2.816mm/yr.) during its first 99 years of growth during the tree’s full development of its crown. The tree had a mean mature growth rate of 0.886mm/yr. over the next 213 years of growth until felling. Under the microscope, bark occurs just after the initial development of a ring in AD 2003. This indicates that the tree was felled in spring/summer AD 2003, which with the pith evidence identifies that the tree was 313 years old when felled.

Mean growth for the first 26 years is 0.571mm/yr, which is a very much lower rate than would normally be expected for this site, particularly in comparison to the 3.616mm/yr mean rate of formative growth over the subsequent 73 years. The tree may have germinated in its current position, possibly protected within the graveyard from grazing. A yew hedge planted at the back of the churchyard using seedlings in the 1990's which has now reached a height of over 1.5m, testifies that yew can currently naturally establish itself from seed. (A.D. Grace pers comm.).

Initial slow growth may have been due to the church foundations affecting root development and/or the lower light levels from close proximity to the church. An alternative explanation is that the tree germinated in a different locality (possible in woodland) and was subsequently transplanted to its current location. The relationship of a yew standing just opposite or adjacent to the porch (in this instance porches) is common and implies that the yew was planted. The planting of the yew Privy Garden at Hampton Court Palace c. AD1700 to AD 1703 {Moir 1994} suggests a fashion for the planting of yew during a period of Protestant succession to the throne, in the reigns of William & Mary (AD 1686 to AD 1702) and Queen Anne (AD 1703 to AD 1714).

Narrow rings occur in AD1714, AD 1715 and AD 1716, but these can be attributed to known years of drought (Moss and Simons 1992). The narrowest tree-ring of the sequence occurs in AD 1705. If the tree was planted, it would probably have been in this year, at a time when the trunk (discounting bark) was about 12mm in diameter.

The sections WHCX01A and WHCX01B span difference periods, but when compared over their common period, AD 1741 to AD 2002, they reveal mean growth rates of 1.582mm/yr and 1.056mm/yr respectively. The high growth rate of one section in comparison to the other (see Figure 5) suggests that the tree was growing asymmetrically. This characteristic was also identified in a yew sampled at Thorley, Herts (Moir 2003). However, as no orientation data was recorded for the St Mary’s tree section it is impossible to identify the favorable direction of growth. It is suggested that close proximity to the church and the footpath could be a factor causing asymmetric growth. It is considered unlikely that the laying of foundations and subsequent building of the north west buttress in such close proximity to the yew tree in c. AD 1850 had no detectable effect on the radial growth rate of the tree.

Although little evidence has been accumulated on the timing of growth phases changes in yew, this analysis concurs with previous indications that the transition from formative to
mature growth occurs between 80 and 100 years old. The growth rates of formative growth at the previous sites studied are 2.75mm/yr at Capel and 2.52mm/yr at Thorley, (both these trees were under 2.74m in girth). To date, the yew trees studied at Hampton Court Palace (a managed garden site) reveal the lowest growth rate. However, the last three decades of growth indicate that the radial growth rate of yew can still increase, once a mature stage of growth has been achieved.

This analysis contributes to a growing body of dendrochronological data on the growth rates of yews in different environments. Yews from a woodland valley at Happy Valley, (in Greater London), have produced the highest growth rates. The growth rates identified in this study are remarkably consistent with those of the churchyard sites analysed at Thorley in Hertfordshire (Moir 2003) and Capel in Surrey {Moir 2003}.

**Figure 6: The relationship between yew tree age and girth**

CONCLUSIONS

The opportunity to dendrochronologically analysis a full section of a 2.8m girth churchyard yew (*Taxus baccata*) arose due to the felling of the tree at St Mary's, West Horsley, Surrey. The section showed no indication of rot. Pith was measured and the results indicated that the tree germinated in AD 1691 and was 313 years old when felled.

The analysis reveals a mean formative growth rate of 2.816mm/yr over the first 99 years, and 0.886mm/yr for the subsequent 213 years of mature growth. A comparatively low rate of growth during the first 26 years highlights the possibility that the tree was transplanted. A narrow ring in AD 1705 suggests a possible year for planting, though historical records would be required to support this hypothesis.
Example Dendrochronological Report: Yew tree, West Horsley, Surrey

The actual age of the St Mary’s tree demonstrates the White/Tabbush equation underestimates the tree’s age by 19%. However, the study identifies that the radial growth rate of yew can increase once a mature stage of growth has been achieved. This analysis indicates that further research is required to establish whether the formative, mature and senescence stages of tree growth are generally applicable to yew.

ACKNOWLEDGEMENTS

I would like to thank all the "churchyard gang” at St Mary’s Church for their kind hospitality, and for submitting the yew sample for analysis. I am particularly grateful to Anne Grace for her comments on the earlier draft of this report, and for supplying some useful additional information on the history of the church and the yew. This research was entirely funded by Tree-Ring Services.

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APPENDIX I: Raw ring-width data

Title: YEW TREE - ST MARY'S - WEST HORSLEY - SURREY [WHCX01]
Raw Ring-width TABA data of 312 years length
Dated AD1691 to AD2002
Measurement 100 = 1mm
25 sapwood rings and spring/summer bark surface
Average ring width 149.83 Sensitivity 0.23

Raw Data Removed from PDF file versions