DENDROCHRONOLOGICAL ANALYSIS OF THREE OAK TREES AT THE NATIONAL TRUST'S LODGE PARK ESTATE, ALDSWORTH, GLOUCESTERSHIRE, ENGLAND.

Tree-Ring Services Report: GLLP/23/12

Dr Andy Moir

Tree-Ring Services
Plough House, 49 High Street,
Hungerford, Berkshire, RG17 0NE
Email: enquiries@tree-ring.co.uk
www.tree-ring.co.uk

DENDROCHRONOLOGICAL ANALYSIS OF THREE OAK TREES AT THE NATIONAL TRUST'S LODGE PARK ESTATE, ALDSWORTH, GLOUCESTERSHIRE, ENGLAND.

Dr Andy Moir

Tree-Ring Services Report: GLLP/23/12

SUMMARY
Three of four oak trees with girths of 3.31, 4.27 and 4.38 metres sampled from Lodge Park are used to form a 341-year mean chronology called ALDSW-LP, which spans from AD 1672 to AD 2012.

The piths of the trees were not reached, therefore a combination of mean growth rates are combined with the precisely dated series to estimate that the trees germinated in the 1720s, 1570s and 1490s and were respectively around 290, 440 and 520 years old at the time of sampling.

There appears to be little influence of management in the trees. Formative, mature and senescent growth rates of 1.88, 2.19 and 1.09 mm/yr respectively are identified from this analysis.

KEYWORDS
Dendrochronology, Veteran trees, English oak, *Quercus* spp.

Figures

Tables

Photos

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 (1982, 1995) provide interesting backgrounds into the science, while a free guideline booklet explaining methods of dendrochronology is offered by 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 recognized 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.

Live Tree Coring

An increment borer is a specialized tool designed to extract a section of wood tissue from a living tree with minimal injury. The core is typically 4–5 mm in diameter and can extend from the bark to the pith of a living tree. This sampling method has become a standard global procedure for determining tree age and examining patterns of annual ring widths, and is intrinsic to our understanding of tree growth–climate relationships, forest dynamics and natural hazards (Fritts 1976, Frelich 2002, Vaganov *et al.* 2006, Stoffel *et al.* 2010).

Understandably, there has been some concern over the potential impact core holes may cause. However, trees have natural defence mechanisms to help maintain their vitality (Shigo 1984, Loehle 1988). One important method of defence is the compartmentalization of injuries by which a boundary is developed to limit the spread of pathogenic micro-organisms (Shigo 1984). While tree coring typically leads to some discoloration of wood, discoloration, decay and wood-decaying fungi should never be equated with each other (Weber and Mattheck 2006). Wood-decay fungi may occur in the hole left from increment coring, but a tree may successfully compartmentalize or repel it.

The degree of sensitivity to tree coring damage appears to vary depending on species, and in general conifers are thought to be the most resistant (Grissino-Mayer 2003). Early studies in North America found that over 50% of core holes healed within 2–3 years; trees that did not heal well were typically short-lived species or suppressed individuals (Meyer and Hayward 1936, Lorenz 1944, Hepting *et al.* 1949). In the UK, tree-ring research has tended to concentrate on its three longest-lived tree species: Oak (*Quercus* spp.), Scots pine (*Pinus sylvestris*), and Yew (*Taxus baccata*). As conifers, both Scots pine and Yew are expected to be extremely resistant to coring damage (Grissino-Mayer 2003). Oak is also thought to have a high capability of compartmentalization (Dujesiefken and Liese 1991, Grissino-Mayer 2003)

It is highlighted that any risk of harm to a tree by coring is far less than that caused by tree surgery (Kersten and Schwarze 2005), and there is no evidence of tree mortality after increment coring (Meyer and Hayward 1936, Lorenz 1944, Hepting *et al.* 1949, Eckstein and Dujesiefken 1999, van Mantgem and Stephenson 2004, Weber and Mattheck 2006). However, as more research would be needed to conclude categorically that coring causes no significant harm, a number of methods are usually employed to help minimize any possible impact:

- Sampling is kept to a minimum, typically one core per tree, or two cores in the case of dendroclimatic studies.
- Corers are kept clean and sharp, as a blunt borer leads to greater damage (Smith 1988).
- Core holes are angled slightly upwards to help minimize water ingression.
- Core holes are left open to allow them to dry out and heal naturally, which is thought to help discourage infection by decay fungus (Kersten and Schwarze 2005). There is little evidence that plugging core holes reduces the discoloration of wood or prevents potential decay (Meyer and Hayward 1936, Lorenz 1944, Hepting *et al.* 1949) and some research indicates plugging hinders the natural healing process (Dujesiefken *et al.* 1999).

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 species, in general trees to progress through three phases of growth: formative, mature and senescent (White 1998). Formative incremental 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 reduces. Dieback of the crown and branches occurs during senescence, the final phase, and causes further reduction in the width of the annual increment.

Exceptionally large trees have been analysed by a variety of methods in the past, and this has 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 based on external measurement and comparison with other trees of the same 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 the increase in ring width towards the trees' centres. 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) have 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 (1998) 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 (a factor critical to the accuracy of an estimate) can be very subjective without precise increment information. Differences in growth due to specific local ecological conditions may also affect an individual tree's growth, and therefore a sample of a number of trees is recommended to increase the accuracy of estimates.

Until a new technique of non-intrusive tree-ring measuring is developed, dendrochronological analysis using complete or partial increment coring (cores that fall well short of a tree's pith) offers the least destructive means of accurately dating living trees and dispels a great deal of the uncertainty that remains about the age of many of our largest trees. 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, age estimates based on partial increment sampling still offer the most accurate empiric refinement to the estimation of a tree's age. A good example of the use of this method was by Nathan Stephenson, who successfully combined knowledge on tree size with information gained directly from partial increment cores to estimate the age of giant sequoias (Stephenson and Demetry 1995).

Aim of the Analysis

The main aims of this analysis were:

a) To determine the age of some of the largest oak trees at Lodge Park.
b) To extend to present day a county reference chronology for Gloucestershire and increase the replication of the chronology over the eighteenth century.

METHODOLOGY

Sampling and Preparation

Timbers were sampled using a 3-thread Halglof increment borer: 600 mm length × 5.15 mm core diameter. One core was taken from each tree, normally at breast height (approximately 1.3m) above the ground. Girth measurements were recorded at the sampling height. Extracted core samples were immediately taped and glued onto wooden laths on site, labelled, and left to dry for subsequent analysis (**Photo 1**).

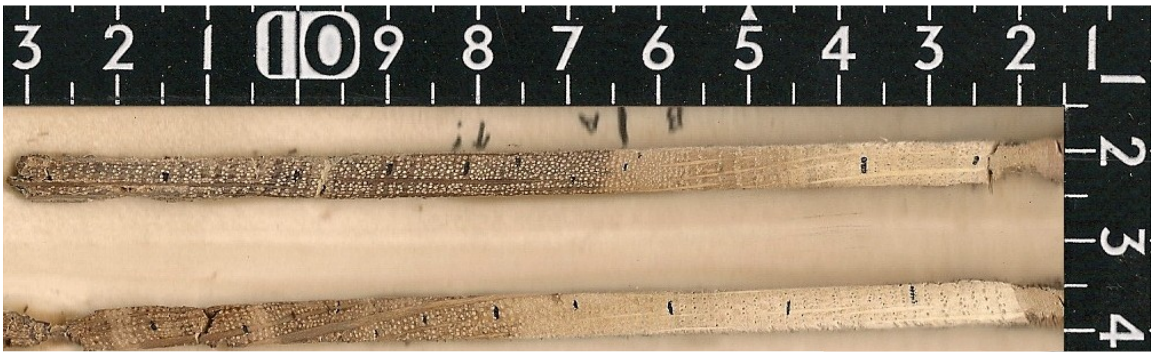
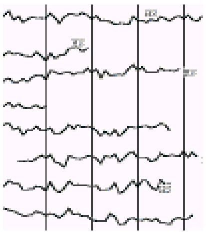


Photo 1: Two increment cores taken from trees GLLP02 (bottom) and GLLP03 (top)

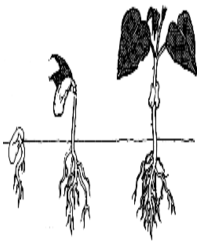
All tree-ring sequences were revealed through sanding, with progressively finer grits, to a 400 abrasive grit finish to produced results suitable for measuring.

Measuring and Cross-matching



Tree-ring sequences were measured under a ×20 stereo microscope to an accuracy of 0.01 mm using a microcomputer-based travelling stage. Each core sample was measured twice, wherever possible from the centremost ring to the outermost. The core samples from each core were measured and sets (e.g., GLLP01 and GLLP04) visually plotted to support or reject possible cross-matches and serve as a means of identifying measuring errors. The cross-matching search produces "*t*-values", and the higher this value, 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 mismatches (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.

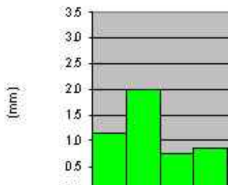
Determination of Germination Date



A method for determining the precise germination dates of trees is based on the wood's anatomical characteristics and dendrochronology. Unfortunately, the procedure requires the destructive sampling of the tree for an extensive analysis of the zone between the roots and the trunk (Telewski 1993) and is clearly inappropriate for this and most other investigations.

The centre-of-tree (pith) date obtained by sampling at a height above the ground may not necessarily represent the absolute age of the tree or the year of germination (Telewski and Lynch 1991). Nevertheless, the discrepancy between the pith date obtained at a sampling height of approximately 1.37m/4.5ft above ground and a precise germination date obtained at ground level is only likely to be significant with suppressed understorey trees, which can grow for 100 years before attaining a height over 1m (Tucker *et al.* 1987). Here 5 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 increment cores and sections.

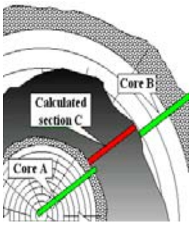
Growth Rates



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 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 to have occurred over a relatively short period in some trees. Ten-year averages of ring width are plotted to help demonstrate overall patterns of tree growth. Using them, it is sometimes possible to identify the probable changes between phases of growth or other changes in rates of growth related to management or the relative state of health of the tree.

For most purposes, the senescent phase of growth equates to the term overmaturity, which is generally said to occur in oak at around 250 years (Evans 1984). Here we use decadal of growth $\leq$1.00 mm/yr to identify the onset of senescent growth. Trees are identified as likely to be in terminal decline where consecutive decades have mean growth of ≤0.50 mm/yr, which is a level that most species of tree can barely survive (White 1998).

Site-specific Age Estimates



In terms of general UK tree species growth, higher maximum mean annual increments are achieved in the climatically favoured south-west of England and, to a lesser extent, in Wales and southern and eastern England, although the variation between region is small (Evans 1984). However, a tree's radial growth rate may vary enormously according to site, effects of exposure, rooting depth and soil nutrient status, and where site-specific evidence is absent, mean average radial growth rate curves to predict tree age should only be used in the most general terms.

Nevertheless, site-related average growth rates "yield classes" is in standard use by the Forestry Commission (James 1982), and the use of a younger tree on the same site to represent the missing younger growth of hollow trees has been reasonably established (White 1998, Tabbush and White 1996). The dendrochronological analysis of increment cores can provide precisely known age and rate of growth information for solid trees. This information, when combined with the partial increment core information from larger trees, is used to represent the missing younger core growth of these usually hollow trees. This combination of full and partial increment cores is then used to produce empirical information on the radial growth rates specific to the site and to calculate an age estimate for hollow trees.

Tree-Ring Services - Methods and Criteria

TREE-RING SERVICES

Tree-ring analysis and graphics are achieved via a dendrochronological program suite developed by Ian Tyers of Sheffield University (Tyers 1999).

RESULTS

Lodge Park was visited on the 3rd October 2012. A brief survey identified four oak trees, which it was agreed could be sampled. The samples were given a site code GLLP and numbered sequentially 01–04 (**Table 1 & Photos 2 to 5)**. All the trees appeared to be maiden, with few signs of management. The approximate depth of bark was also recorded on the trees.

Table 1: Summary of tree sampling details

Tree code	Girth (m)	National grid reference	Sampling Notes
GLLP01	4.27	SP14071230	Solid trunk, considerable crown dieback & loss of some large branches
GLLP02	4.38	SP14121242	Hollow trunk, some crown dieback, but no obvious loss of large branches
GLLP03	5.48	SP14121242	Hollow trunk, collapsed crown and a visibly "stag-headed"
GLLP04	3.31	SP14131255	Solid trunk, good full crown

Photo 2: Tree GLLP01

Photo 3: Tree GLLP02

Photo 4: Tree GLLP03

Photo 5: Tree GLLP04

Four core samples were recovered. All the samples were recovered with bark and could be measured accurately with the exception of sample GLLP03. Sample GLLP03 contained some periods of extremely narrow rings which meant the section could not be accurately measured. Consequently this sample was rejected from further analysis at this stage.

The three series measured were all found to cross-match together (see **Table 2 & Figure 1**) and combined to form a 341-year mean chronology called ALDSW-LP.

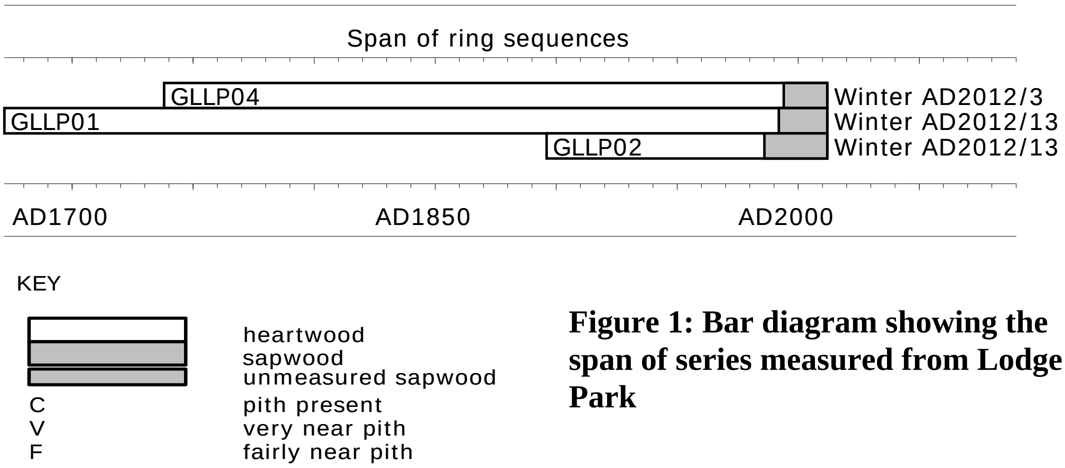


Figure 1: Bar diagram showing the span of series measured from Lodge Park

Table 2: Cross-matching between series from Lodge Park

Filenames	Start date	End date	GLLP02	GLLP04
GLLP01	AD1672	AD2012	4.98	7.74
GLLP02	AD1896	AD2012	*	4.17
GLLP04	AD1738	AD2012	*	*

KEY: - = *t*-values less than 3.50. \ = overlap < 30 years.

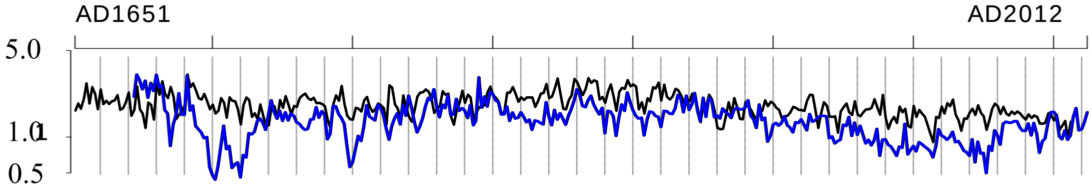
The ALDSW-LP chronology spans from AD 1672 to AD 2012, the annual resolution of this chronology is confirmed by cross-matching against a wide number of previously established oak reference chronologies from across the south of England (**Figure 2** & **Table 3**).

Table 3: Cross-matching of ALDSW-LP against reference chronologies

ALDSW-LP dated AD1672 to AD2012					
File	**Start Date**	**End Date**	**t-value**	**Overlap (yr.)**	**Species & Reference chronology**
ENGLAND	AD404	AD1981	8.46	310	England Master Chronology (Baillie and Pilcher 1982 unpubl)
EAST_MID	AD882	AD1981	8.19	310	East Midlands (Laxton and Litton 1988)
SAVENAKE	AD1651	AD2006	8.16	335	Savenake Forest - Wiltshire (Briffa, unpublished)
OXFORD	AD1781	AD1978	7.92	198	Oxford Oak - Oxfordshire (Pilcher and Baillie 1980)
STONE-1	AD1387	AD1998	7.76	327	Stoneleigh Abbey - Warwickshire (Howard *et al.* 2000)
LANGLEY	AD1856	AD2011	7.15	340	Langley Park - Buckinghamshire (Agin 2011)
SOTTERLY	AD1586	AD1981	7.10	310	Sotterley Park - Suffolk (Briffa *et al.* 1986)
EYNSF-LL	AD1737	AD2011	7.06	275	Lullingstone Country Park - Eynsford - Kent (Moir 2012)
WINCHSTR	AD1635	AD1972	6.93	301	Winchester - Hampshire (Barefoot 1975)
HUNGF-2	AD1823	AD2010	6.73	188	Hungerford - Berkshire (Moir, unpulished)
SLG	AD1764	AD1993	6.44	322	Scarles Grove - Sotterley Estate - Suffolk (Moir 1996)
SHERWOOD	AD1426	AD1981	6.21	310	Sherwood Forest - Nottinghamshire (Briffa *et al.* 1986)

KEY: **Bold** = indicates a composite reference chronology consisting of multiple site chronologies.

Figure 2: Plot of site chronologies ALDSW-LP (blue) and SAVENAKE (black) from oak trees located in Savenake Forest - Wiltshire, which cross-match together with a *t*-value of 8.16



Note: The ring width (mm) is plotted on a (y axis) logarithmic scale using common axis for both samples

Cumulative ring widths (**Figure 3**) and decadal growth rates (**Appendix II**) were plotted to help identify phases of growth and variations in growth. Bar charts of decadal growth rates are plotted in **Appendix II**, and **Appendix III** contains a table with further details of the age estimation calculations.

INTERPRETATION

The following age estimates are based on either full recovery of rings or a combination of partial increment cores and the use of mean growth rates.

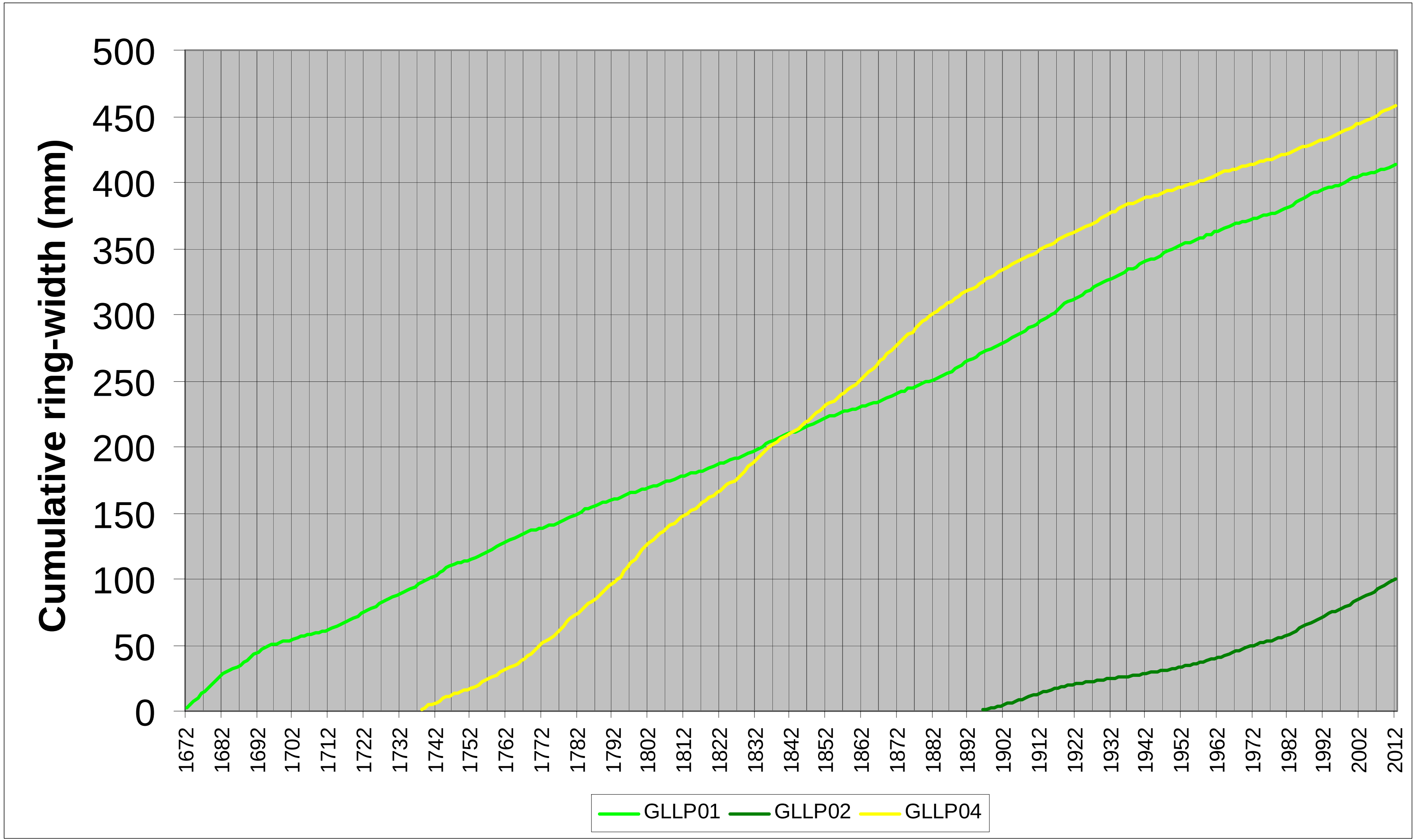
Mean Growth Rates

Tree GLLP04 was sampled quite close to its pith (within 19 years) and its age calculated to be 294 years. A mean formative growth rate of 1.18 mm/yr for the first 90 years of growth is calculated. This formative rate is unexpectedly low, parkland trees having an expected formative growth rate of 3.5 mm/yr for the first 100 years of growth (White 1998). Two trees GLLP01 and GLLP04 are assessed to show mature growth rates of 2.33 and 2.04 mm/yr respectively, and used to calculate a mean mature growth rate for the site of 2.19 mm/yr.

Table 4: Summary of growth phases interpreted from the plots of decadal growth rates and cumulative ring width.

Tree code	Girth (m)	Interpreted growth phases
GLLP04	3.31	Formative for the 1st 9 decades (1.88 mm/yr, Mature for the next 9 decades (2.04 mm/yr), Senescent for the end 13 decades (1.19 mm/yr)
GLLP01	4.27	Mature for the 1st decade (2.33) mm/yr), Senescent for 34 decades (1.17 mm/yr)
GLLP02	4.38	Senescent for last 13 decades (0.91 mm/yr)

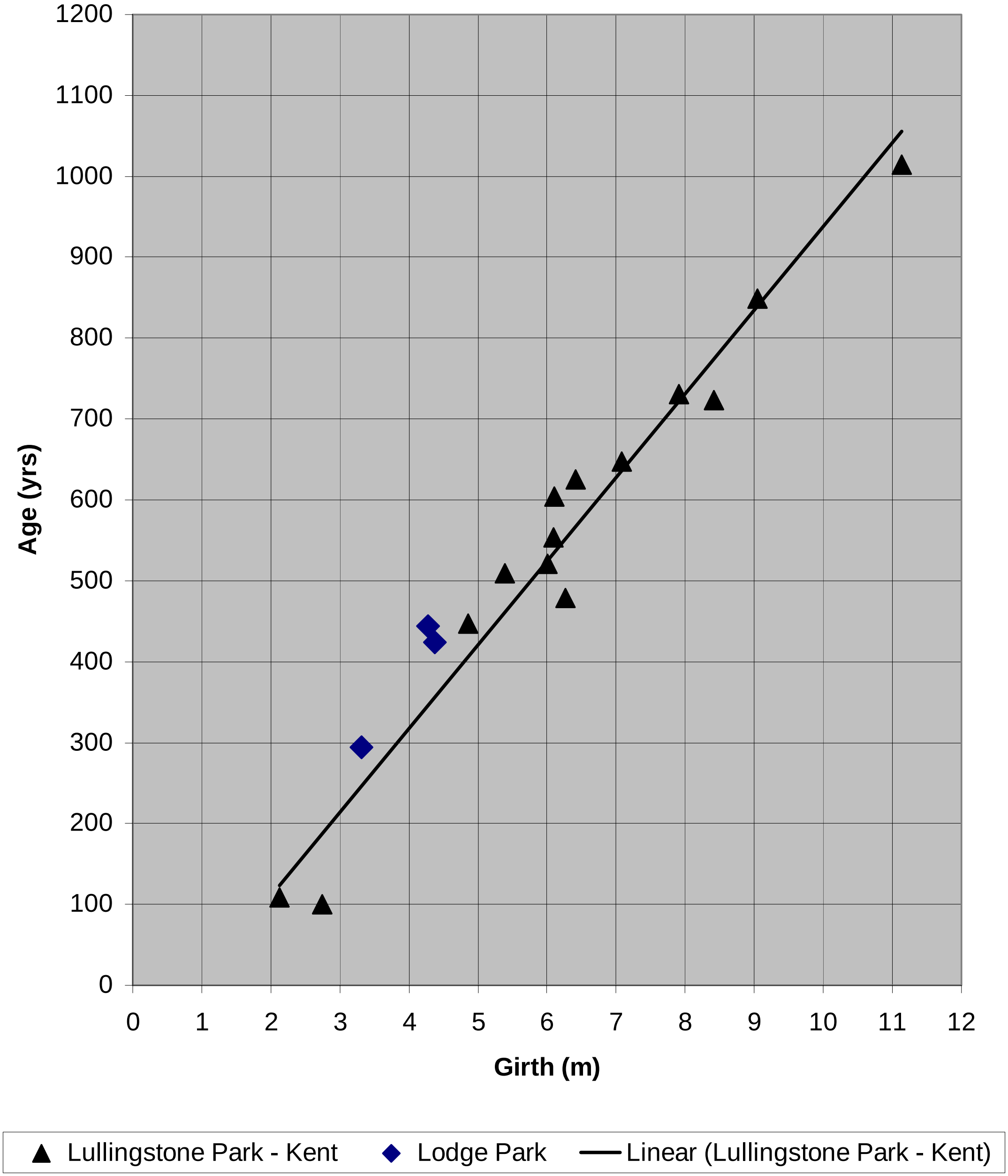
Figure 3: Cumulative ring width plots of the cross-matched series sampled from Lodge Park



Age Estimation

The tree-ring series recovered from oak at this site provide a long record of annual growth back 341 years to AD 1672. However, due to the hollow nature of tree GLLP02 and the inability of the corer to reach the centre of tree GLLP01, the ages of these trees was estimated using a combination of partial increment cores and mean growth rates. The ages of the three trees successfully measured, i.e., GLLP04, GLLP01 and GLLP02, are calculated to be around 290, 440 and 520 years old, respectively. The age calculations are shown in **Appendix III**, and the results plotted below (**Figure 4**). Due to possible variations in the growth of individual trees, it must be recognised that the age estimates presented here are not precise, and should only be used as a best approximation.

Figure 4: The relationships between oak tree girth and age at Lodge Park and Lullingstone Country Park as established by tree-ring analysis



Variations in Radial Growth

Due to the sampling of just three trees the mean growth rates calculated must be considered tentative, and due to this no linear trend is calculated. It is interesting to note that this initial sample suggests that the oaks at the Lodge Park site are slower grown during their formative years of growth than those recently similarly sampled at Lullingstone Country Park in Kent (Moir 2012). One Lodge Park oak tree indicates a formative growth rate of 1.88 mm/yr achieved for the first 90 years of growth. This compares to an expected growth rate of 3.50 mm/yr for the first 100 years of growth for parkland trees (Evans 1984). The histograms of decadal growth show a mean senescent growth rate of 1.09 mm/yr, which compares well with that identified in oak at Lullingstone Country Park - Kent (Moir 2012)

CONCLUSIONS

Three of four oak trees with girths of 3.31, 4.27 and 4.38 metres sampled from Lodge Park are used to form a 341-year mean chronology called ALDSW-LP, which spans from AD 1672 to AD 2012.

The piths of the trees were not reached, therefore a combination of mean growth rates are combined with the precisely dated series to estimate that the trees germinated around the 1720s, 1570s and 1490s respectively, and were 290, 440 and 520 years old at the time of sampling.

There appears to be little influence of management in the trees. Formative, mature and senescent growth rates of 1.88, 2.19 and 1.09 mm/yr respectively are identified from this analysis.

ACKNOWLEDGEMENTS

This report was funded by Tree-Ring Services as part of research into the dating of veteran trees and to improve the current dearth of 18th century reference chronologies. I would like to thank Nigel Fordham and Paul Mason for highlighting the oak at Lodge Park and making the arrangements for sampling. I am grateful to Mike Robinson of the National Trust for permission to sample, and to Nigel Fordham, Mike Robinson and Alan Carpenter for their help and enthusiasm during sampling.

REFERENCES

Agin, B., 2011 A dendrochronological and dendroclimatological analysis on modern oak (*Quercus* spp.) trees in Happy Valley, Hedgerley Park and Langley Park, England, Unpublished MSc, Brunel University.

Baillie, M G L, 1982 *Tree-ring dating and archaeology*, London (Croom-Helm).

Baillie, M G L, 1995 *A slice through time: Dendrochronology and Precision Dating*, London (Batsford).

Baillie, M G L, and Pilcher, J R, 1982 unpubl A master tree-ring chronology for England, unpubl computer file *ENGLAND*, Belfast (Queen's Univ)

Barefoot, A C, 1975 A Winchester dendrochronology for 1635-1972 AD - its validity and possible extension, *J Instit Wood Sci*, **7**(1), 25-32.

Briffa, K R, Wigley, T M L, Jones, P D, Pilcher, J R, and Hughes, M K, 1986 The Reconstruction of past circulation patterns over Europe using Tree-ring Data, *Final. Report. to European. Communities. Contract. CL. 111. UK.*

Douglass, A E, 1919 Climatic cycles and tree-growth I: a study of the annual rings of trees in relation to climate and solar activity, *Carnegie Institution of Washington Publication*, **1**(289)

Douglass, A E, 1928 Climatic cycles and tree-growth II: a study of the annual rings of trees in relation to climate and solar activity, *Carnegie Institution of Washington Publication*, **II**(289)

Dujesiefken, D and Liese, W, 1991 Holzbiologische Untersuchungen zu Methoden der Baumpflege [Wood biological studies with regard to Methods of Arboriculture], *Naturschutz und Landschaftspflege in Hamburg*, **35**, 85-109.

Dujesiefken, D, Rhaesa, A, Eckstein, D, and Stobbe, H, 1999 Tree wound reactions of differently treated boreholes, *Journal of Arboriculture*, **25**(3), 113-23.

Eckstein, D and Dujesiefken, D, 1999 Long-term effects in trees due to increment borings, *Dendrochronologia*, **16-17**, 205-11.

Evans, J, 1984 *Silviculture of Broadleaved Woodlands*, London (HMSO).

Frelich, L E, 2002 *Forest Dynamics and Disturbance Regimes: Studies from Temperate Evergreen-Deciduous Forests*, Cambridge (Cambridge University Press). Cambridge Studies in Ecology.

Fritts, H C, 1966 Growth-ring of trees: Their correlation with climate, *Science*, **154**, 973-9.

Fritts, H C, 1971 Dendroclimatology and dendroecology, *Quaternary Research*, **1**, 419-49.

Fritts, H C, 1976 *Tree Rings and Climate*, New York (New York Academic Press).

Green, T, Alexander, K, and Key, R, 1999 *Managing Our Ancient Trees*, The Tree Council, **http://www.treecouncil.org.uk/tnews/ancient.htm**

Grissino-Mayer, H D, 2003 A manual and tutorial for the proper use of an increment borer, *Tree-ring Research*, **59**, 63-79.

Hartesveldt, R J, Harvey, H T, Shellhammer, S H, and Stecker, R E, 1975 *The giant sequoia of the Sierra Nevada. U.S. Department of the Interior, National Park Service, Washington D.C.*, Washington D.C. (U.S. Department of the Interior). National Park Service.

Hepting, G H, Roth, E R, and Sleeth, B, 1949 Discoloration and decay from increment borings, *Forestry*, **47**, 366-70.

Hillam, J, 1998 *Dendrochronology: Guidelines on producing and interpreting dendrochronological dates*, London (English Heritage).

Howard, R E, Laxton, R R, and Litton, C D, 2000 *Tree-ring analysis from the timbers from the buildings and living trees at Stoneleigh Abbey, Stoneleigh, Warwickshire*, English Heritage, Centre for Archaeol Rep, **80/2000**

James, N D G, 1982 *The Forester's Companion*, Oxford (Basil Blackwell).

Kersten, W and Schwarze, F W M R, 2005 Development of Decay in the Sapwood of Trees Wounded by the Use of Decay Detecting Devices, *Arboriculture Journal*, **28**(3)

Laxton, R R and Litton, C D, 1988 *An East Midlands master tree-ring chronology and its use for dating vernacular buildings*, University of Nottingham, Dept of Classical and Archaeol Studies, Publication Monograph Ser, **3**

Loehle, C, 1988 Tree life history strategies: the role of defences, *Canadian Journal of Forest Research* , **18**, 209-22.

Lorenz, R C, 1944 Discoloration and decay resulting from increment borings in hardwoods, *Forestry*, **42**, 37-43.

Meyer, W H and Hayward, S B, 1936 Effect of increment boring on Douglas fir, *Journal of Forestry*, **34**, 867-9.

Mitchell, A F, Schilling, V E, and White, J E J, 1994 *Champion trees of the British Isles*, Edinburgh (Forestry Commission). Forestry Commission Technical Paper 7.

Moir, A K, 1996 *A dendrochronological analysis of 9 oak compartments from the Sotterley Estate, Suffolk England: An interim report*,

Moir, A K, 2012 *Dendrochronological analysis of oak trees at Lullingstone County Park, Eynsford, Kent, England.*, Tree-Ring Services, Dendro Rep, **BRLL/01/12**

Pilcher, J R and Baillie, M G L, 1980 Eight modern oak chronologies from England and Scotland, *Tree-ring Bulletin*, **40**, 45-58.

Shigo, A L, 1984 Compartmentalization: a conceptual framework for understanding how trees grow and defend themselves, *Ann. Rev. Phytopathol.*, **22**, 189-214.

Smith, K T, 1988 Wounding, compartmentalization, and tradeoffs, *Journal of Arboriculture*, **14**, 226-9.

Stephenson, N and Demetry, A, 1995 Estimating ages of giant sequoias, *Canadian Journal of Forest Research*, **25**, 223-33.

Stoffel, M, Bollschweiler, M, Butler, D R, and Luckman, B H, 2010 *Tree Rings and Natural Hazards: A-State-of-the-Art*, (Springer).

Tabbush, P and White, J E J, 1996 Estimation of tree age in ancient yew woodland at Kingley Vale, *Quaterly Journal of Forestry*, **90**(3), 197-206.

Telewski, F W, 1993 Determining the germination date of woody plants: a proposed method for locating the root/shoot interface, *Tree-ring Bulletin*, **53**, 13-6.

Telewski, F W and Lynch, A M, 1991 Measuring growth and development of stems, in *Techniques and Approaches in Forest Tree Ecophysiology* (eds J P Lassoie, and S Jiang), Boca Raton (CRC Press)

Tucker, G F, Hinckley, T M, Leverenz, J W, and Jiang, S, 1987 Adjustments in foliar morphology in the acclimation of understory Pacific silver fir following clearcutting, *Forest Ecology and Management*, **21**, 249-62.

Tyers, I, 1999 *Dendro for Windows Program Guide 2nd Edition*, ARCUS Rep, **500**

Vaganov, E A, Hughes, M K, and Shashkin, A V, 2006 *Growth Dynamics of Conifer Tree Rings: Images of Past and Future Environments*, (Spriger). Ecological Studies.

van Mantgem, P J and Stephenson, N L, 2004 Does coring contribute to tree mortality?, *Canadian Journal of Forest Research*, **34**, 2394-8.

Weber, K and Mattheck, C, 2006 The effects of excessive drilling diagnosis on decay propagation in trees, *Trees Structure and Function*, **20**, 224-8.

White, J E J, 1998 *Estimating the age of large and veteran trees in Britain*, Forestry Commission, Information Note, **250**