TREE-RING ANALYSIS OF LIVING TREES FROM SIX WOODLANDS IN NORTHAMPTONSHIRE, OXFORDSHIRE, AND WARWICKSHIRE ON THE LINE OF THE HIGH-SPEED RAIL LINK (HS2)

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SUMMARY

Dendrochronological analysis was undertaken on samples obtained from 41 living oak trees and five beech trees distributed amongst 5 different woodlands in the south central English Midlands. A further four samples were found to be unsuitable for analysis.

Interpretation of the results tend to show that while two woodlands have a few trees that are between 200 and 290 years of age (in 2020), and thus may have begun growing in the 1730s and 1740s, most trees are younger than this, with the majority (23 of the 46 dated examples) being between 75 and 125 years of age (in 2020). There is a small group of trees, seven in number, younger than this, the youngest tree estimated to be 41 years of age.

While one woodland in particular appears to contain the oldest trees, and another appears to perhaps have mostly younger trees, the age profile of the trees in the five woodlands is not noticeable different, with all five woodlands appearing to contain numbers of trees of similar ages.

The analysis undertaken has produced data which has been combined to create a modern oak tree-ring 'reference chronology' for the southern English Midlands, which will be of considerable use in the dating of other woodlands and standing buildings in this region.

In addition, data was obtained on the girth of trees in relation to their ages. From this, as indeed intimated by earlier studies in other woodlands, there also appears to be no relationship between the circumference of a tree and its age, with some large trees being younger than some smaller tress, and some smaller trees being older than larger trees.

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INTRODUCTION

The route planned for the new High Speed rail link between London and Birmingham heads north-west out of the capitol across a portion of the Chiltern Hills in the English South-Midlands. There is, along the line of the proposed route, a number of Ancient or Historic Woodlands, some of which will be impacted by the building of the line and its attendant infrastructure. However, as a result of this, either prior to or during the felling phase at the sites, it was felt that an opportunity would be presented to acquire a sample of dendrochronological data from six such woodlands.

From north to south across this area: (see maps Figs 1a–h)

Windmill Hill Spinney, Warwickshire
Glyn Davies/Fox Covert Wood, Northamptonshire
Halse Copse Farm, Northamptonshire
Fox Covert, Whitfield, Northamptonshire
Widmore Farm, Oxfordshire
Jones Hill Wood, Northamptonshire

Windmill Hill Spinney, Warwickshire;
A narrow but elongated area of north-west facing woodland, varying from approximately 50mtrs to 100 meters wide, and being approximately 600 meters long. Its elongated length follows the curving line of the hill here and flows steeply down the slope from a high point at about 120 mtrs to about 95 mtrs. A considerable number of well established ash trees, with some beech and alder, but a relatively small number of oak trees (almost all sampled). Medium density understorey of low shrubs and younger trees. Possibly dense flora, but not highly visible at time of sampling.

Glyn Davies/Fox Covert Wood, Northamptonshire;
A roughly rectangular area of woodland, approximately 200 mtrs by 600 mtrs, facing approximately south to south-west down gently sloping land from a high point at about 160 mtrs to just under 140 mtrs, the lower parts being boggy to wet. Now known as Glyn Davies wood, but originally known as Fox Covert Wood. A highly mixed woodland with a number of ash trees along with some sycamore and other types (particularly toward the wetter ground where some willow and birch trees). A number of substantial oak trees seen to this woodland, with some smaller examples as well. Medium-dense to dense understorey growth of smaller trees including hazel and some holly. Dense ground cover of flora (particularly possibly bluebells), though not in bloom at time of sampling.

Halse Copse Farm, Northamptonshire;
No survey or sampling work undertaken.

Fox Covert, Whitfield, Northamptonshire;

An elongated strip of woodland, approximately 400 mtrs in length, and varying in width from about 100 mtrs to about 40 mtrs. This woods stands of a virtually flat area of land at approximately 140 mtrs, and appears to be an isolated pocket surrounded on all sides by fields of arable crops. Within, there appears to be a dominance of ash, although there are some good-sized oak standards as well. The understorey appears to be of medium dense growth comprising some hazel, hawthorn and possibly elder. The ground flora appears to be highly mixed but includes bluebells.

Widmore Farm, Oxfordshire

A full Woodland and Botanical Survey of the Widmore Farm site has been reported on by Ruskins Tree Consultants, but in outline the woodlands of interest to this report form a linear feature following the embankment to the western side of a disused section of the Great Central Railway. It is recognised as being part of the adjacent 'Grassy Plantation' woods. The site consists of two distinct parcels of land, area 'A', to the northern end, and area 'B' further south. Area 'A' is said to be dominated predominately by sweet chestnut, with silver birch, with beech, some rowan, and some Holly.

Area B is dominated by ash and hawthorn with some field maple and oaks. The western boundary is in part marked by an earth bank with mature oaks (including a large dead oak) and mature field maples with a mature ash. This earth bank and row of trees is considered to be the original boundary between the farmland on the west and scrub, now woodland, to the east. The woodland has encroached westwards and a new ditch line has been dug further west which runs parallel to the old boundary. There are a number of mature oak trees with a mature apple tree to the south eastern corner railway boundary of the site

Jones Hill Wood, Northamptonshire;

Jones' Hill Wood is a sub-rectangular area of woodland approximately 300 mtrs long by about 100 mtrs wide. It stands to the west side of a low-domed hill, and slopes gently down from a height of about 200 mtrs to just under 100mtrs. The canopy is extensively dominated by beech, although there is some ash, and a small number of oak trees. The understorey is of medium density and is again dominated by shrub and immature beech and possibly some hazel. The flora again includes bluebell, but some primrose and violet were also seen

The dendrochronological work undertaken reported upon here forms part of a larger project on these woodlands using a range of techniques including archaeological investigation and survey, ecological studies, and a study of previous woodland management practices in order to gain a wider understanding of the place of woodlands in the landscape. It was hoped that dendrochronology could be used to date the trees within the selected woods to provide a framework for the history of the sites.

Presently, an almost complete tree-ring chronology for England is available, reaching back from the present day to the Neolithic period, though at either end of this time period the amount of data, and its geographical distribution, is somewhat limited. It was to be hoped that tree-ring data from the trees in these six woodlands living into the present day would increase the amount of 'modern' data available in both temporal and geographical terms

The development of a 'modern' tree-ring reference chronology for central England.

In addition to establishing a date for the trees and providing some information on the history of the sites, it was also felt that dendrochronology could possibly provide tree-ring data for the production of a regional oak reference chronology which would be 'anchored' to the present day (Winter 2020). It was felt that such a reference chronology could possibly extend sufficiently far back in time (ie, into the late-eighteenth century) to overlap with the later parts of the numerous, pre-existing, site chronologies created from work already undertaken on standing buildings in the region, thus forming the basis of an extended and continuous Regional Master Chronology with widespread regional application.

At the present time, something in excess of 500 individual vernacular and ecclesiastical buildings from all parts of the English Midlands have been analysed by dendrochronology, most site providing between a minimum of 8 samples and a maximum of approximately 20 samples. Some buildings have provided many more samples, with a few providing 100-plus samples. It is estimated that analysis of these samples has produced something in excess of 800 separate site chronologies (although of course, not all sites, or chronologies, have dated).

Overall, those pre-existing site chronologies which have dated cover the period AD 976–1800, though the period after about AD 1700 is represented by a very small number of samples from the area under consideration in this report, and the reference data for this later period is somewhat thin. And while it is true that, as dendrochronological fieldwork continues, and the number of site chronologies is constantly increasing, given that such work is generally directed more towards older buildings which have greater 'historic' interest, it is likely that such further work, while possibly 'filling-in' some geographical gaps in the data, will add to or consolidate the existing historic data, rather than extending the span of the chronologies further forward in time towards the present day.

The corpus of existing site chronologies, however, can only be made truly reliable by being 'fixed' to a known point, ie, the present day, by being anchored to a modern-tree-reference chronology. Currently, there are very few, if any 'modern' tree-ring reference chronologies for Midland England, and this 'anchoring' is achieved by using 'out of area' reference chronologies which, naturally, have less than local regional application.

The possible relationship between the circumference of oak trees and their age

In addition, it was hoped that this programme of tree-ring research might provide some information about the relationship between size of a tree and its age. It is commonly and popularly held that there is a general relationship between the size of a tree, particularly its girth or circumference, and its age, with 'big' trees usually thought of as being older, while smaller trees are, naturally, believed to be younger. It was hoped that this programme of research might provide some information about the relationship between size and age.

<u>SAMPLING</u>

Nottingham Tree-ring Dating Laboratory undertook sampling visits to five of these woodland sites during December 2020, with the sixth site, Glyn Davies/Fox Covert Wood, not being available for sampling until early May 2021. As a result of these visits, a total of 50 core samples was obtained from five of these woodlands (10 samples from each wood), the sixth wood (Halse Copse) containing no sizeable trees within its designated area of interest and no samples were taken.

All the woodland examined here might be described as being of medium density growth, with a number of mature oaks trees in particular, plus a mixture of both beech and ash trees. All such mature trees were widely and openly distributed amongst many smaller examples of each type, with a good degree of medium density understory. The trees selected for sampling, both oak and beech, were all of a mature size in the belief that they would provide long tree-ring growth sequences (Fig 2a–d). Such tree varied as to their position within the woodlands from middle location with much surrounding vegetation to woodland edge or boundary. The topography of the sites varied from flat, relatively boggy, ground, such as the woods at Widmore Farm, this parcel of woodland being a long but fairly narrow piece, to Jones Hill Wood covering a domed hill-top site, or set on elevated but more steeply sloping ground such as the Windmill Hill Spinney.

Cores samples were obtained from standing trees at about breast height (the usual level for sampling) using 300mm, 400mm, and 500mm hand-driven, Haglof increment corers (Fig 3a–c). Allowing for the thickness of the bark, protuberances on the trees, and the angle of coring, these can produces cores with a maximum length of up to approximately 450mm. Such cores have a diameter of 4mm (Fig 4).

Each sample obtained was given a site reference code based on the source woodland name, the samples from each site then being numbered 01–10. An especial attempt was made to obtain samples from oak trees in particular, these generally believed to be a longer-lived tree type. In addition, oak trees are understood be more regular in their annual growth, recording one, and *only* one, new growth ring each year (unlike some species where individual trees sometimes appear to present 'false' growth rings some years, where growth appear to start, then halts, before starting again for the same year). The annual growth rings on oak trees are also generally clearer and more distinct than on some other types of tree where the division between one year's growth and the next is sometimes difficult to determine.

In most of the woodlands, Widmore Farm, Windmill Hill Spinney, Glyn Davies Wood/Fox Covert Wood, the number oak trees actually present was perhaps surprisingly small, these woods, although having a mixture of species, often tended to be dominated by beech. In most of the woodlands examined, virtually every available oak tree was sampled. In one woodland, however, Jones Hill Wood, there were very few oaks within the designated area of impact, in which case 5 beech trees were substituted, these being the most common type available. An attempt was also made to obtain samples from different sized trees, with some trees of particularly large girth being sampled, along with those of a smaller size. Details of the 50 samples thus obtained will be found in Tables 1a–e.

The Nottingham Tree-ring Dating Laboratory would like to take this opportunity to thank a number of people for their help with this programme of tree-ring analysis. Firstly we would like to thank Mark Collard, Graham Cruse, and Steven Thorpe of Network Archaeology acting for Fusion, the firm coordinating the enabling works on the route of the line. We must also thank a number of site coordinators who assisted at each site at the time of sampling. Finally, we would like to thank various unknown members of HS2 staff at the various sampling sites who were always very helpful and cooperative.

AN OUTLINE OF TREE-RING DATING

Tree-ring dating relies on a few simple, but quite fundamental, principles. Firstly, as is commonly known, trees (particularly oak trees) grow by adding one, and *only* one, growth-ring to their circumference each, and every, year. Each new annual growth-ring is added to the outside of the previous year's growth just below the bark. The width of this annual growth-ring is largely, though not exclusively, determined by the weather conditions during the growth period (roughly March–September). In general, good weather conditions produce wider rings and poor weather conditions produce narrower rings. Thus, over the lifetime of a tree, the annual growth-rings display a climatically influenced pattern. Furthermore, and importantly, all trees growing in the same area at the same time will be influenced by the same growing conditions and the annual growth-rings of all of them will respond in a similar, though not identical, way (Fig 5).

The regularity of annual growth seen in oak trees is very rarely found in trees of other species, some trees, such as elm, appearing to be particularly erratic, with closely adjacent trees quite often showing quite unrelated relative growth patterns. Such phenomenon has up to now limited, and in some cases precluded, the application of dendrochronological dating to other types of wood. There has, for example, been some success in the dating of pine, but attempts to date other woods, including beech and chestnut, along with elm, have proved very disappointing.

Secondly, because the weather over any number of consecutive years is unique, so too is the growth-ring pattern of the tree. The pattern of a short period of growth, 20, 30, or even 40 consecutive years, might conceivably be repeated two or even three times in the last one thousand years. A short pattern might also be repeated at different time periods in different parts of the country because of differences in regional micro-climates. It is less likely, however, that such problems would occur with the pattern of a longer period of growth, that is, anything in excess of 54 years or so. In essence, a short period of growth, anything less than 54 rings, is not reliable, and the longer the period of time under comparison the better.

Tree-ring dating relies on obtaining the growth pattern of trees from sample timbers or living trees of unknown date by measuring the width of the annual growth-rings of a sample taken from the beam or tree. This is done to a tolerance of 1/100 of a millimeter. The growth patterns of these samples of unknown date are then compared with a series of 'reference chronologies', the date of each ring of which is known. When the growth-ring sequence of a sample 'cross-matches' repeatedly at the same date span against a series of different relevant reference chronologies the sample can be said to be dated. The degree of cross-matching, that is the measure of similarity between sample and the reference chronology, is denoted by a '*t*-value' (a statistical calculation indicating the degree of similarity or matching); the higher the *t*-value the greater the similarity or the closer the match. The greater the similarity the greater is the probability that the patterns of samples and references have been produced by growing under the same conditions at the same time. The statistically accepted fully reliable minimum *t*-value is 3.5.

However, rather than attempt to date each sample individually it is usual to first compare all the samples from a single site, be it a single building or an individual woodland, with one another, and attempt to cross-match each one with all the others from the same building or woodland. When samples from the same phase do cross-match with each other they are combined at their matching positions to form what is known as a 'site chronology'. As with any set of data, this has the effect of reducing the anomalies of any one individual (brought about in the case of tree-rings by some non-climatic influence) and enhances the overall climatic signal. As stated above, it is the climate that gives the growth pattern its distinctive pattern. The greater the number of samples in a site chronology, the greater is the climatic signal of the group and the weaker is the non-climatic input of any one individual.

Furthermore, combining samples in this way to make a site chronology usually has the effect of increasing the time-span that is under comparison. As also mentioned above, the longer the period of growth under consideration, the greater the certainty of the cross-match. Any site chronology with less than about 55 rings is generally too short for reliable dating.

Having obtained a date for the site chronology as a whole, the date spans of the constituent individual samples can then be found. From this the first and last growth-ring dates of living trees may be calculated, or the cutting dates of felled trees used for building timbers may be determined. Where a sample, such as one from a living tree, retains complete sapwood, that is, it has the last or outermost ring produced by the tree, the last measured ring date is the latest growth date of the tree, or, where a tree has been felled, its felling date.

Where the sapwood is not complete it is necessary to estimate the likely felling date of the tree. Such an estimate can be made with a high degree of reliability because oak trees generally have between 15 to 40 sapwood rings. For example, if a sample with, say, 12 sapwood rings has a last extant sapwood ring date of 1400 (and therefore a heartwood/sapwood boundary ring date of 1388), it is 95% certain that the tree represented was felled sometime between 1403 (1400+3 sapwood rings (12+3=15)) and 1428 (1400+28 sapwood rings (12+28=40)).

ANALYSIS

As outlined in the notes above on tree-ring dating, the basis of dendrochronology is in obtaining cross-matches between samples of unknown date with reference chronologies of known date. The significance, or reliability, of any cross-match is indicated by the level of *'t',* the higher the t-value, the greater the degree of similarity (usually the result of trees growing at the same time in the same place), and thus the greater the reliability.

All 50 samples obtained from the five woodlands were prepared by sanding and polishing. It was seen at this point that four oak samples, FOX-C10 (Fox Covert Wood), JHW-A10 (Jones Hill Wood), and WID-F09 and WID-F10 (Widmore Farm), had distorted, compressed, or decayed rings, and their annual widths could not be measured. Such samples were rejected from this programme of analysis.

The annual growth-ring width sequences of the remaining 46 oak and beech samples were, however measured twice, once as an 'A' sequence, and once as a 'B' sequence. There are thus 92 data sets, two for each of the 46 samples. The two data sets of the ring-width measurements for each individual sample were firstly compared with each other, ie, the data of sequence FOX-C08a were compared with the data of sequence FOX-C08b, sequence JHW-A05 with sequence JHW-A05b, and so on. This process acts firstly as a method of obtaining extra data, and secondly as double-check of the ring-width measurements of each sample, in that any errors in measuring are likely to be spotted (it might be possible to make a mistake once in a reading, but this unlikely to occur twice). This process also provides information, in the form of *t*-values, on the levels, or degrees, of cross-matching within each individual sample. This information is given in Table 2.

As described in the notes above, the extant combined A and B data of the two types of timber sampled here, the 41 oak and the 5 beech, were then compared with all the other samples of the same type, ie, oak with oak, and beech with beech. By this process, the extant data of all 41 oak samples could be formed into a single cross-matching group. These 41 oak data sets were then combined at their relative off-set positions to form a 'site chronology', *HS2CHRON1,* this having an overall extant length of 253 rings. This site chronology was then satisfactorily dated by repeated and consistent comparison with a number of relevant reference chronologies for oak as having a first ring date of 1768 and a last ring date of 2020, the evidence for this dating being given in the t-values of Table 3.

In addition to the oak samples, two of the beech samples, JHW-A01 and JHW-A02, were also seen to cross-match with each other. The data of these two samples were similarly combined to form *HS2CHRON2,* a site chronology with a combined overall length of 160 extant rings. There is currently, however, no beech reference chronology against which this site chronology can be compared and the two samples must, therefore remain undated by dendrochronology. However, given that the coring date, and thus the most recent growth ring date, 2020, of the samples is known, the first growth ring dates of the samples can also be calculated.

<u>RESULTS</u>

Dating of the trees

Thus, with the creation of a combined oak site sequence, *HS2CHRON1*, having a last ring date of 2020, it is now becomes possible to determine the date-span of the extant rings in each individual oak sample, and, by allowing for any possible un-cored rings towards the centre of the tree, the trees likely life-span may be calculated.

Naturally, where a dated oak core sample contains both the centre of the tree (that is, its first growth ring) and its outermost, or most recent, growth ring, the life-span of the tree is clearly available. Sample FOX-C06 for example contains 109 growth rings, including the outermost or most recent ring, and the centre, or first growth ring, of the tree. Given that its outermost ring is dated to 2020, the centre ring, ie, its first growth ring, must have been laid down in 1912.

On a number of other samples, although the exact centre ring of the tree is not included on the extant core sample, the inner-most extant ring on a core is close, and sometimes very close, to the centre, the approach to near the centre being clear, or the corer having missed the centre by a few rings. In such cases, FOX-C04, FOX-C05, or WIN-H09 for example, with only a few rings to the centre estimated to have been missed, it is possible, given that the last growth ring date of the tree is known, to closely estimate when such a tree would have started growing.

There are some cases, however, where the core sample does not include the centre or first growth ring of the tree, and a larger part of the inner rings are missing. In some trees the inner portion, nearer the centre, is decayed and the earlier part of the sample breaks up as it is cored or as the core is extracted as on GLY-D07 or WIN-H03 for example. In some cases the inner portion of the tree has simply rotted away and the tree would appear to have a void at its centre, as with sample WID-F01 for example.

In such cases it is necessary to make an estimation of the likely number of annual growth rings the missing or lost portion of the core might have contained. This is usually done by taking the circumference of the tree at breast height (the height of core sampling), and calculating from this the radius of the trunk (the distance from the centre of the tree to its outer edge). By deducting the length of the extant core obtained from the radius measurement, the length of the missing portion of core may be determined.

One possibility is to now make a simple count of the number of rings found in the equivalent, inner-most, length of the extant core (where the rate of growth is most likely to be similar to that in the missing portion), and to add this number to the number of rings in the extant core. This calculation is, however, based on the assumption that the trunk of the tree is perfectly circular, which it frequently is not, and that the centre/first growth ring of the tree is in the middle of the tree. Again, with many trees having growth biased in one direction or another (brought about by such features as ground slope and/or competition from other trees) this again is not always the case.

A second method is to calculate the average width of the rings over the whole length of the extant core, and divide the length of the missing portion by this number, this again giving the likely number of rings that the missing portion of core contained. This however, assumes that the growth of the tree is roughly constant over its whole life time, and that there are no long periods of suppressed growth (where the rings are very narrow and add little to the girth of the tree), or rapid growth (where the rings are very wide). The greater the length of missing core, the greater is the likely inaccuracy of the method.

As an example, let us take sample FOX-C03. The circumference of the tree is 1970mm. Dividing this by '*pi*' (3.14) we obtain a figure of 627mm for its diameter (the distance, through the centre, from one side to the other). Dividing 627 by 2, we obtain a radius of 313mm (the distance from the outside of the tree to its centre). The extant core actually obtained from this tree is 235mm long, this meaning that there are 78mm of core missing to the centre. There are 89 rings in the extant 235mm length of core, the average width of each extant ring thus being just about 2.6mm. Dividing 2.6mm into the 78mm of missing core suggests that it might have contained 30 rings. Adding these 30 rings to the 89 rings on the extant core, gives the tree a life of 119 years (this then being rounded up to 120 years). Knowing that the most recent growth ring on the tree is dated to 2020, the centre ring of the tree, ie, when it began to grow, must be dated to 1901. A visual aid to this calculation is given in Figure 6.

This information is given for every sample in each woodland in Tables 1a–e beginning with the dendrochronological sample code, the tree number where available, followed by the circumference and radius of each tree. The length of the extant core is then given, followed by the length of any un-cored portion towards the centre ring of the tree. The number of rings on the extant core is then shown, followed the average width of these rings. Having used these data, the likely number of rings on the missing core portion is given. This is added to the number of rings on the extant core, the total number of rings the tree thus had, ie, its age in 2020, is then listed, along with the date of the life-span dates of the tree.

Although it has not been possible to date the five beech trees by dendrochronology (there being as yet no beech tree reference chronology available against which any site chronology can be compared), an assumption is made about the life-span dates of these trees on the basis of their last growth rings being dated to 2020. Given the known number of rings on each beech sample, and allowing as with the oak samples for any possible missing rings towards the centre of the tree, the likely first growth ring date of the beech trees may also be estimated.

The relative position and calculated date-span of each of the 41 oak samples is shown firstly grouped by source woodland in Figure 7, and then as an overall group in Figure 8. In both cases, the assumed date-spans of the beech trees is also shown.

INTERPRETATION

Dating the trees

The representation of the calculated life-spans of the trees in the two bar diagrams, Figures 7 and 8, perhaps provides a 'graphic' into the possible dating history of the various woodlands. Perhaps the most notable feature of the trees is possibly that none of them is perhaps quite as old as might have been imagined, particularly as the source woodlands are usually described as being 'ancient'. That said, it must of course be remembered that the trees presently seen are only the latest populations of the woodlands, these present trees perhaps being the latest surviving members of ancestral generations.

The oldest tree found in this programme of work appears to be represented by sample WID-F04, from Widmore Farm, which, estimated to have started growing in 1731, has a calculated age of 290 years, followed by WID-F03, estimated to have started growing in 1746, and being 275 years of age in 2020. There are two other trees, WID-F01 and JHW-A04, which also have 200 or more rings. As may then be seen in the bar diagram of Figure 7, the ages of the trees then gradually drop away towards one or two very young examples, with WIN-H05 and WIN-H09 having 50 rings or less. Remembering that almost all available oak trees in each woodland was sampled, there appears to be no distinct 'step' pattern or sudden changes to the ages of the trees, there appears to be no evidence of sudden woodland regeneration, or, perhaps just as importantly, no evidence of the sudden loss of particularly old trees.

A second observation that might be worth noting is that, although Widmore Farm does have a few aged trees, and that one or two other woods do have quite old trees, all five woodlands appear to have a similar tree-age profile. As may perhaps be seen in Figure 8, where the trees are sorted into their source woodlands, there is no woodland that appears to have only very old trees, or to have only very young trees, although Windmill Hill Spinney could be a contender for this title, and Glyn Davies/Fox Covert wood also has some young examples.

Table 5 attempts to tabulate the number of trees by age group in 25-year intervals. It will be seen that overall, while there is a small number of young trees, and a smaller number of older trees, the majority of trees, half of those sampled, are, in 2020, between 76 and 125 years of age.

The possible relationship between the circumference of oak trees and their age

It is popularly believed that trees, particularly oak trees, with a large girth are older than those with a small girth, and that any tree with a circumference of more than 4 metres is likely to be 'ancient', possibly having stood since the time of Doomsday. As part of this programme of research the opportunity was taken to see if there was any general relationship between the size of the trees, as measured by their girth or circumference at breast height (CBH - the usual core height), and the age of the tree as indicated by the number of growth rings.

The information obtained for each tree is given in Tables 1a–e, this showing the circumference of the trunk, its radius, the length of the extant core, the number of rings missing from the core sample to centre of the tree, and the likely age and growth start date of the tree. The relevant information, ordered by tree size and then tree age, is then given in tables 4a and 4b respectively.

These tables clearly show that in general, size is not very closely related to age. The largest tree, WID-F08, has a circumference of 4000mm, and has 120 rings, while the oldest tree, WID-F04, with 290 rings, has a circumference of 3050mm, almost a metre less. In another example, WID-F01, with a circumference of 2200mm, has 235 rings, while WID-F02, with a larger circumference of 2300mm has fewer rings, with only 105. It may also be observed that while tree WIN-H02, with a circumference of 1000mm, has 61 ring, WID-F08, with a circumference four times larger at 4000mm, has only just under twice as many rings, 120. Of the 46 sampled trees, 21 have girths of between 1000–2000mm, 16 have girths of 2001 – 3000mm, and 9 have girths of 3001mm+. It would thus appear that girth is not a good indicator of tree age.

<u>CONCLUSION</u>

Interpretation of the results tend to show that while two woodlands have a few trees that are between 200 and 290 years of age (in 2020), and thus may have begun growing in the 1730s and 1740s, most trees are younger than this, with the majority (23 of the 46 dated examples) being between 75 and 125 years of age (in 2020). There is a small group of trees, seven in number, younger than this, the youngest tree estimated to be 41 years of age.

While one woodland in particular appears to contain the oldest trees, and another appears to perhaps have mostly younger trees, the age profile of the trees in the five woodlands is not noticeable different, with all five woodlands appearing to contain numbers of trees of similar ages.

The analysis undertaken has produced data which has been combined to create a modern oak tree-ring 'reference chronology' for the southern English Midlands, which will be of considerable use in the dating of other woodlands and standing buildings in this region.

In addition, data was obtained on the girth of trees in relation to their ages. From this, as indeed intimated by earlier studies in other woodlands, there also appears to be no relationship between the circumference of a tree and its age, with some large trees being younger than some smaller tress, and some smaller trees being older than larger trees.

Bibliography

Arnold, A J and Howard, R E, 2012 unpubl Tree-ring Analysis of Living Trees from Hutton in the Forest, Penrith, Cumbria – Nottingham Tree-ring Dating Laboratory unpubl computer file *HIFMSQ01*

Arnold, A J, Howard, R E, and Tyers, C, 2018 Tattershall Castle, Sleaford Road, Tattershall, Lincolnshire; Tree-ring Analysis of Oak Timbers of the Moat Bridges 2, 3, and 4 – Historic England Res Dep Rep**, 52/2018**

Arnold, A J, and Howard, R E, forthcoming A master tree-ring chronology for Kent and south-east England – Nottingham Tree-Ring Dating Laboratory

Baillie, M G L, and Pilcher, J R, 1982 unpubl A Master Tree-ring Chronology for England, unpubl computer file *MGB-EOI,* Queens Univ, Belfast

Howard, R E, Laxton, R R, and Litton, C D, 2000, Tree-ring Analysis of Timbers from the buildings and Living Trees at Stoneleigh Abbey, Stoneleigh, Warwickshire, Anc Mon Lab Rep, **80/2000**

Howard, R E, Laxton, R R, and Litton, C D, 2002 unpubl, Analysis of Samples from Living Trees in Gloucestershire – Nottingham Tree-ring Dating Laboratory unpubl computer file *GLOMSQ01*

Howard, R E, Laxton, R R, and Litton, C D, 2003 Tree-ring Analysis of Timbers from Combermere Abbey, Whitchurch, Cheshire*,* Anc Mon Lab Rep, **83/2003**

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, Monograph Series, **III**

Pilcher, J R, and Baillie, M G L, 1980 Eight Modern Oak Chronologies from England and Scotland, Tree Ring Bulletin, **40**, 45–58

TABLES

In the following tables, Table 1a–e, the dendrochronological sample code is given, along with (where available) the tree number. The circumference of the tree at chest height (the distance all the way round) is then give, followed by the radius (the distance from the outside of the tree to its centre). Then the length of the extant core actually obtained from the tree is given, followed by the difference between the length of the core obtained and the radius (the innermost portion of the tree usually being the missing portion). The number of measured rings extant on the core is then given, followed by the average width of these rings (the length of the extant core divided by the number of rings it contains). This average ring width is then divided into the missing portion of core to give the likely number of rings missing to the centre of the tree. This number is then added to the extant rings on the core to indicate the total number of rings the tree is likely to have had, ie, its age in 2020 (usually rounded up to the nearest five). Given that the last ring on the trees all date to 2020, the date at which the trees began to grown may be calculated. In four cases, WID-F09, or JHW-A10, the growth rings of the cores were distorted and/or compressed, and no data could be obtained (represented by -----)

As an example, let us take sample FOX-C03. The circumference of the tree is 1970mm. Dividing this by pi (3.14) we obtain a figure of 627mm for its diameter (the distance, through the centre, from one side to the other). Dividing 627 by 2, we obtain a radius of 313mm (the distance from the outside of the tree to its centre). The extant core actually obtained from this tree is 235mm long, this meaning that there are 78mm of core missing to the centre. There are 89 rings in the extant 235mm core, the average width of each extant ring thus being just about 2.6mm. Dividing 2.6mm into the 78mm of missing core suggests that it might have contained 30 rings. Adding these 30 rings to the 89 rings on the extant core, gives the tree a life of 119 years (this then being rounded up to 120 years). Knowing that the most recent growth ring on the tree is dated to 2020, the centre ring of the tree, ie, when it began to grow, must be dated to 1901.

Table 1a; Details of tree-ring samples from Fox Covert										
Sample	**Tree number**	**Circumf** *mm*	**Radius** *mm*	**Core length** *mm*	**Missing Core** ***mm***	**Extant rings**	**Av ring width** *mm*	**Rings to centre**	**Tree age**	**Life span**
FOX-C01	1010	1730	275	275	00	145	1.9	<5	150	1871 -2020
FOX-C02	------	2430	387	280	107	76	3.7	00	76	1945-2020
FOX-C03	------	1970	313	235	78	89	2.6	30	120	1901-2020
FOX-C04	------	2000	318	310	08	89	3.5	<5	95	1926-2020
FOX-C05	------	1850	295	235	60	93	2.5	<5	100	1921-2020
FOX-C06	------	2140	340	335	05	109	3.1	00	109	1912-2020
FOX-C07	Nr 0573	2580	410	325	85	101	3.2	<5	106	1915-2020
FOX-C08	6788	1920	305	285	20	145	2.0	<10	155	1866-2020
FOX-C09	Adj 0573	2030	323	160	163	105	1.5	<10	115	1906-2020
FOX-C10	8108	2130	339	235	104	Distorted	Distorted	------	------	------

Table 1b; Details of tree-ring samples from Glyn Davies/Fox Covert Wood										
Sample	**Tree number**	**Circumf** *mm*	**Radius** *mm*	**Core length** *mm*	**Missing Core** ***mm***	**Extant rings**	**Av ring width** *mm*	**Rings to centre**	**Tree age**	**Life span**
GLY-D01	0796	2300	360	320	40	125	2.56	15	140	1881-2020
GLY-D02	2467	1550	250	225	25	60	3.75	7	70	1951-2020
GLY-D03	2991	1720	275	240	35	103	2.33	15	120	1901-2020
GLY-D04	3765	2600	410	330	80	45	7.33	10	55	1966-2020
GLY-D05	7567	2420	390	310	80	97	3.20	**< 5**	125	1896-2020
GLY-D06	8859	2200	350	320	30	85	3.76	8	95	1926-2020
GLY-D07	8860	3000	480	355	125	90	3.94	32	125	1896-2020
GLY-D08	9944	2340	370	325	45	120	2.71	17	140	1881-2020
GLY-D09	9945	3040	480	335	145	100	3.35	43	145	1876-2020
GLY-D10	9946	2220	350	300	50	110	2.72	18	130	1891-2020

Table 1c; Details of tree-ring samples from Jones Hill Wood										
Sample	**Tree number**	**Circumf** *mm*	**Radius** *mm*	**Core length** *mm*	**Missing Core** ***mm***	**Extant rings**	**Av ring width** *mm*	**Rings to centre**	**Tree age**	**Life span**
*JHW-A01	74	1980	315	240	75	160	1.5	<5	165	1856-2020
*JHW-A02	Adj 100	1590	253	200	53	113	1.8	29	145	1876-2020
JHW-A03	------	3140	500	500	00	136	3.7	00	136	1885-2020
*JHW-A04	69	1590	253	240	13	189	1.3	10	200	1821-2020
*JHW-A05	100	1500	238	230	08	93	2.5	3	95	1926-2020
*JHW-A06	108	2250	358	300	58	95	3.2	18	115	1906-2020
JHW-A07	------	1640	261	255	07	89	2.9	2	90	1931-2020
JHW-A08	------	1630	260	255	05	116	2.2	2	120	1901-2020
JHW-A09	------	1790	285	280	05	95	3.0	<5	105	1916-2020
JHW-A10	------	1550	250	235	15	Distorted	Distorted	------	------	------

* = Beech trees

Table 1d; Details of tree-ring samples from Widmore Farm										
Sample	**Tree number**	**Circumf** *mm*	**Radius** *mm*	**Core length** *mm*	**Missing Core** ***mm***	**Extant rings**	**Av ring width** *mm*	**Rings to centre**	**Tree age**	**Life span**
WID-F01	9026	2200	350	125	225	84	1.5	150	235	1786-2020
WID-F02	7169	2300	366	330	36	92	3.6	10 est	105	1916-2020
WID-F03	3956	3130	498	335	163	251	1.3	20 est	275	1746-2020
WID-F04	7127	3050	485	345	140	205	1.7	82	290	1731-2020
WID-F05	1392	2250	358	315	43	88	3.6	<5	93	1928-2020
WID-F06	7103	2030	323	310	13	93	3.3	00	93	1928-2020
WID-F07	7151	3200	510	510	00	111	4.6	<5	116	1905-2020
WID-F08	6109	4000	637	200	437	111	1.8	10 est	120	1901-2020
WID-F09	1393	1500	239	230	09	Distorted	Distorted	------	------	------
WID-F10	6119	3150	501	220	280	Distorted	Distorted	------	------	------

Table 1e; Details of tree-ring samples from Windmill Hill										
Sample	**Tree number**	**Circumf** *mm*	**Radius** *mm*	**Core length** *mm*	**Missing Core *mm***	**Extant rings**	**Av ring width** *mm*	**Rings to centre**	**Tree age**	**Life span**
WIN-H01	------	1080	172	135	37	80	1.6	<5	85	1936-2020
WIN-H02	------	1000	159	115	44	61	1.9	00	61	1960-2020
WIN-H03	------	3150	501	245	256	121	2.0	<50	170	1851-2020
WIN-H04	------	3000	477	460	17	178	2.6	00	178	1843-2020
WIN-H05	0035	1270	202	202	00	41	4.9	00	41	1980-2020
WIN-H06	0075	1000	159	130	29	69	1.9	00	69	1952-2020
WIN-H07	0112	1320	210	205	05	51	4.0	<5	55	1966-2020
WIN-H08	0001	1940	309	205	104	90	2.3	00	90	1931-2020
WIN-H09	------	1670	266	260	06	44	6.0	<5	50	1971-2020
WIN-H10	------	1000	159	155	04	51	3.0	00	51	1970-2020

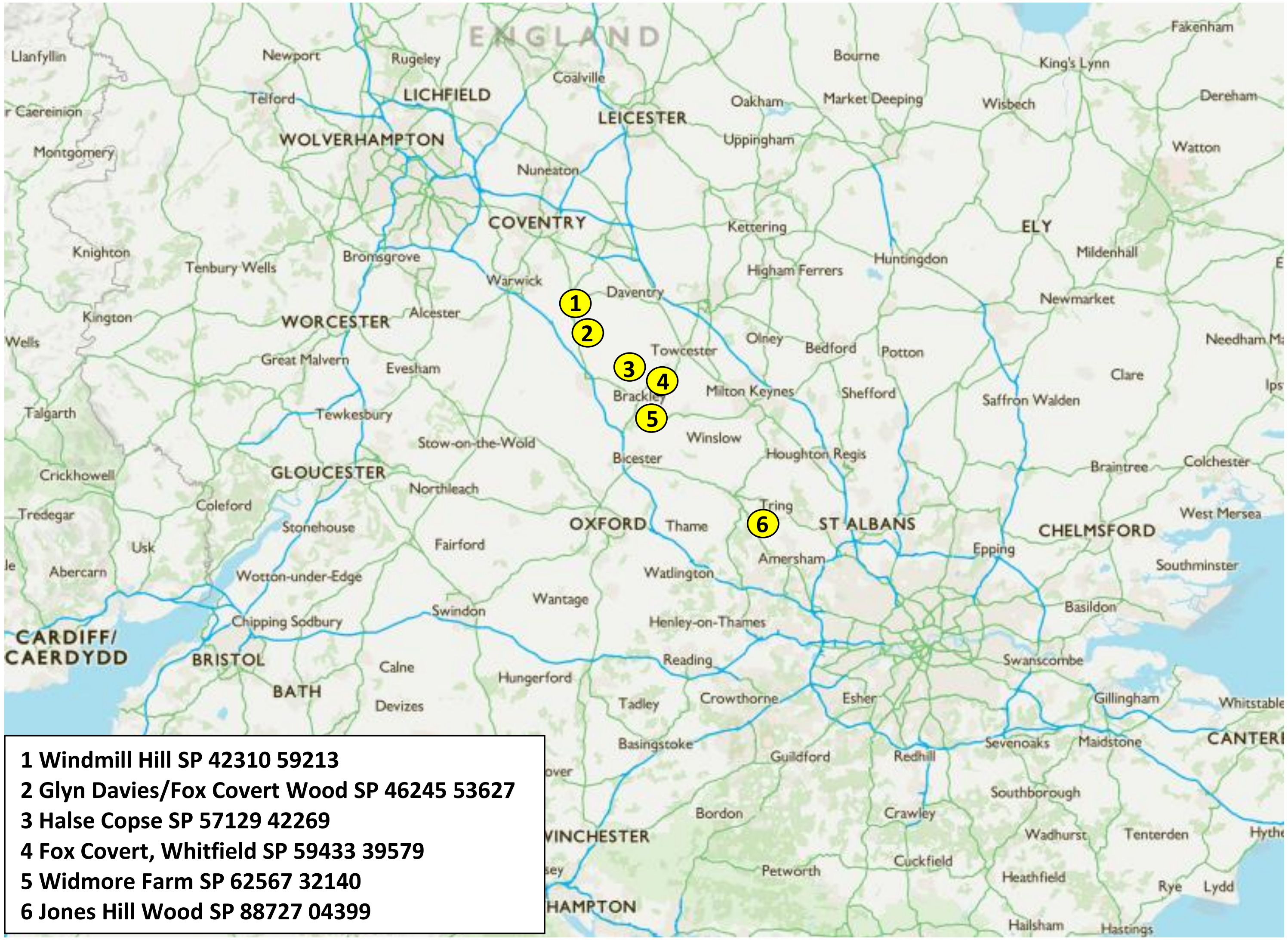


Figure 1a: Map to show general location of the woodland sites

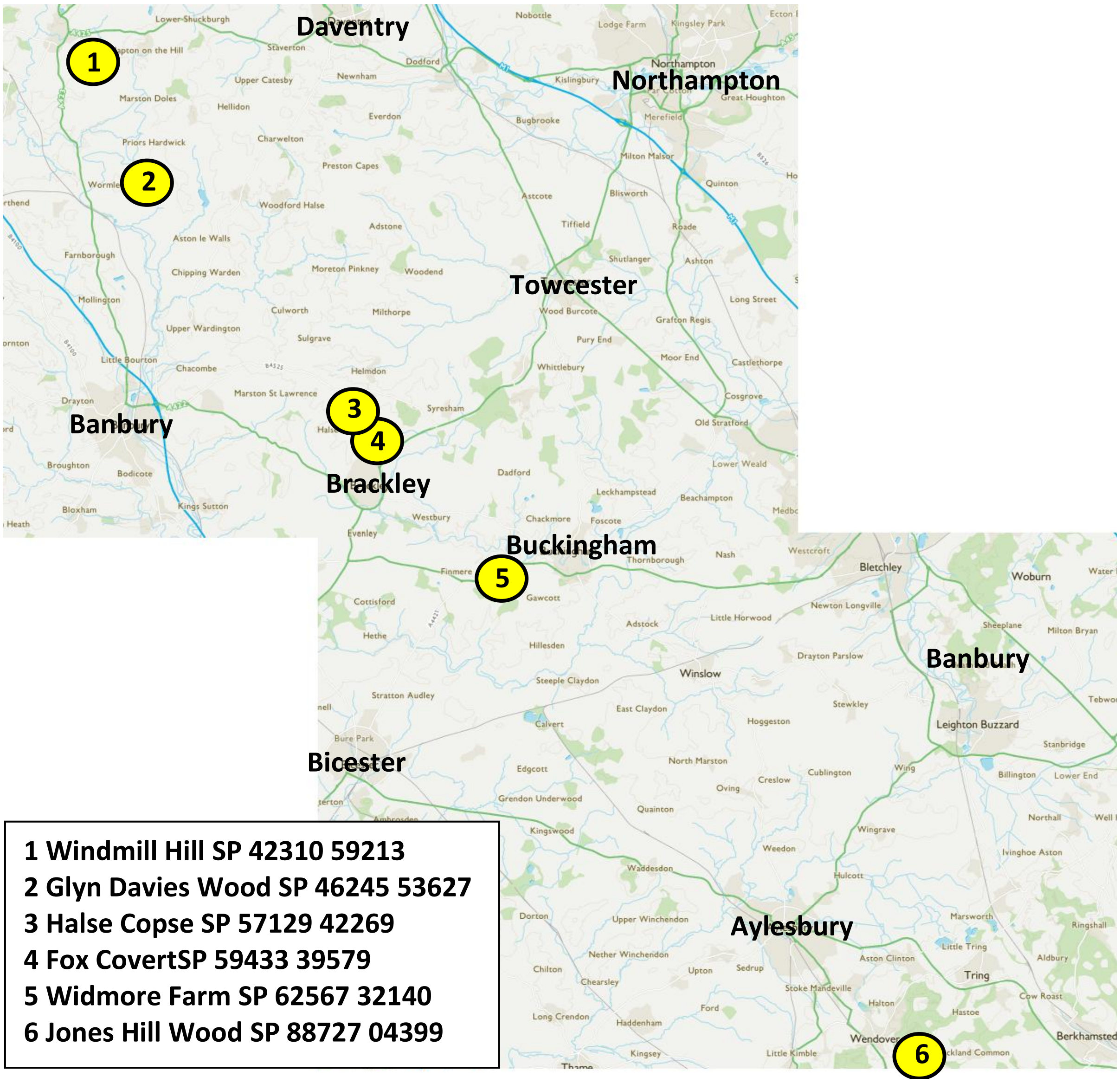


Figure 1b: Map to show more specific location of the woodland sites

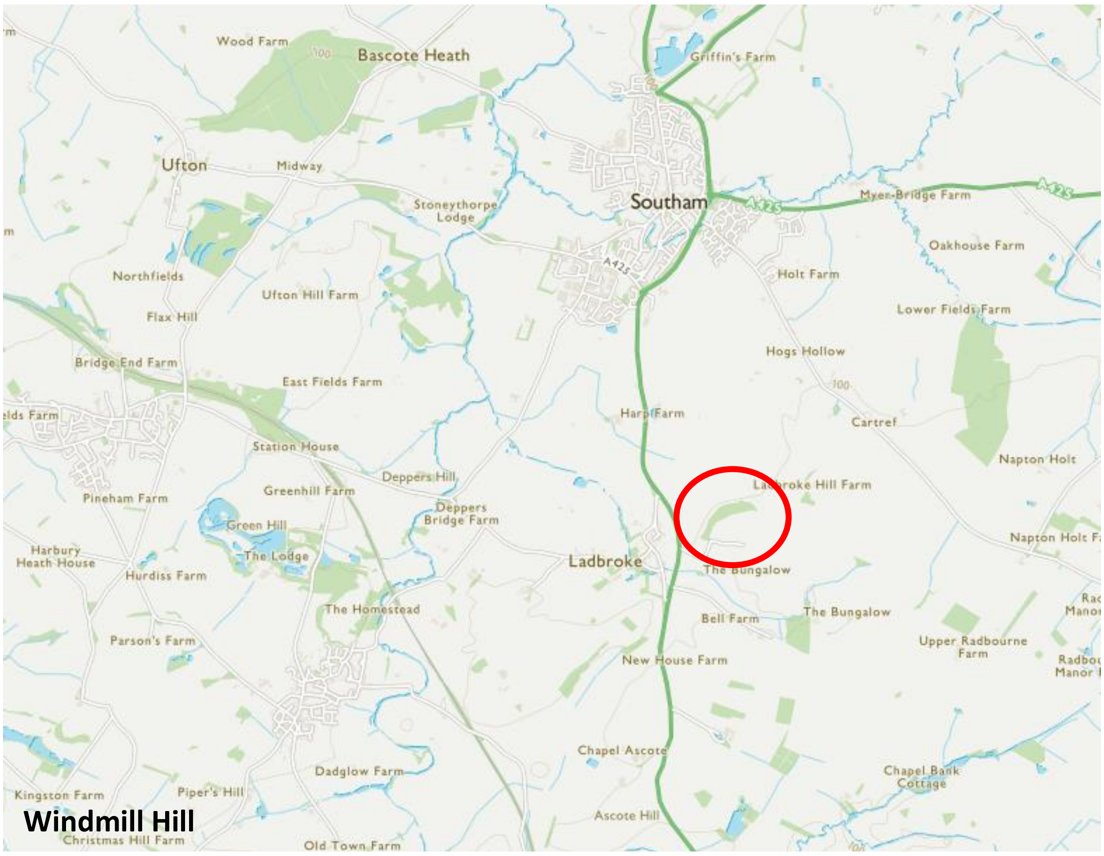
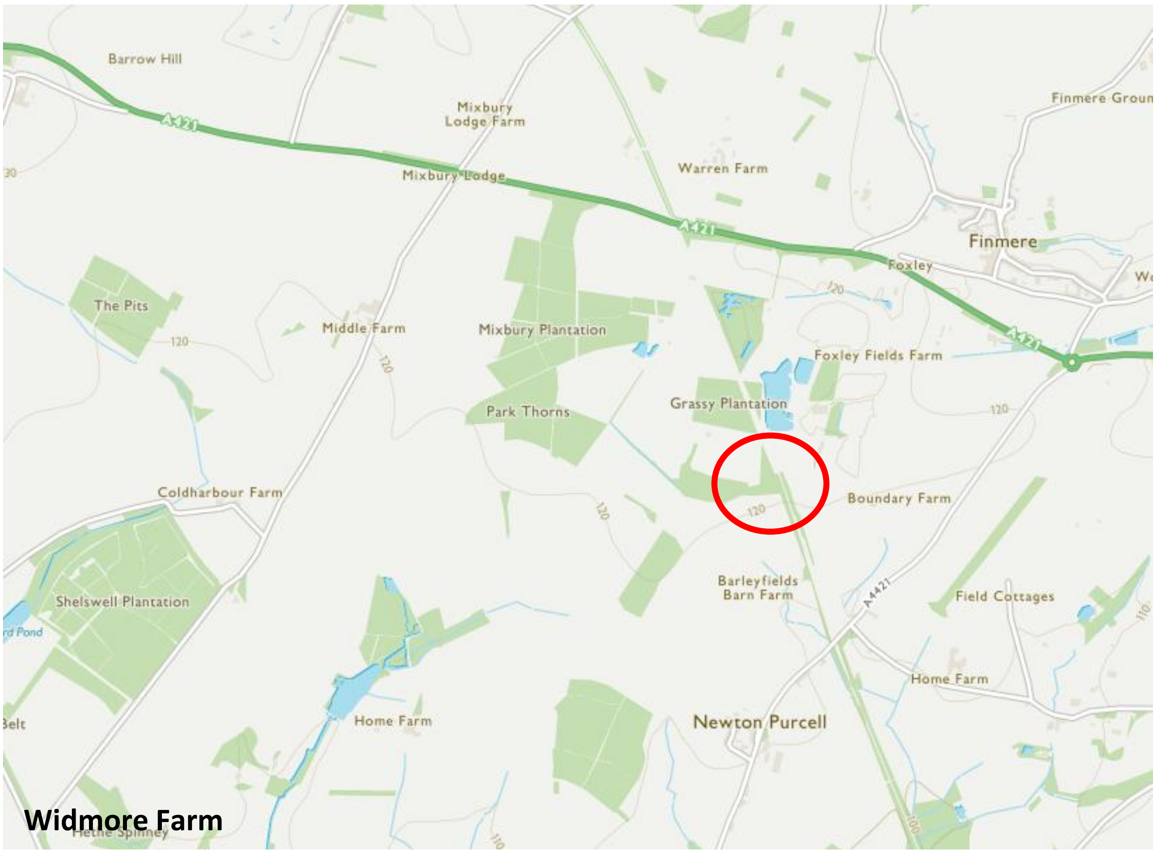


Figure 1c/d: Maps to show more detailed location of the woodland sites

Figure 1e/f: Maps to show more detailed location of the woodland sites



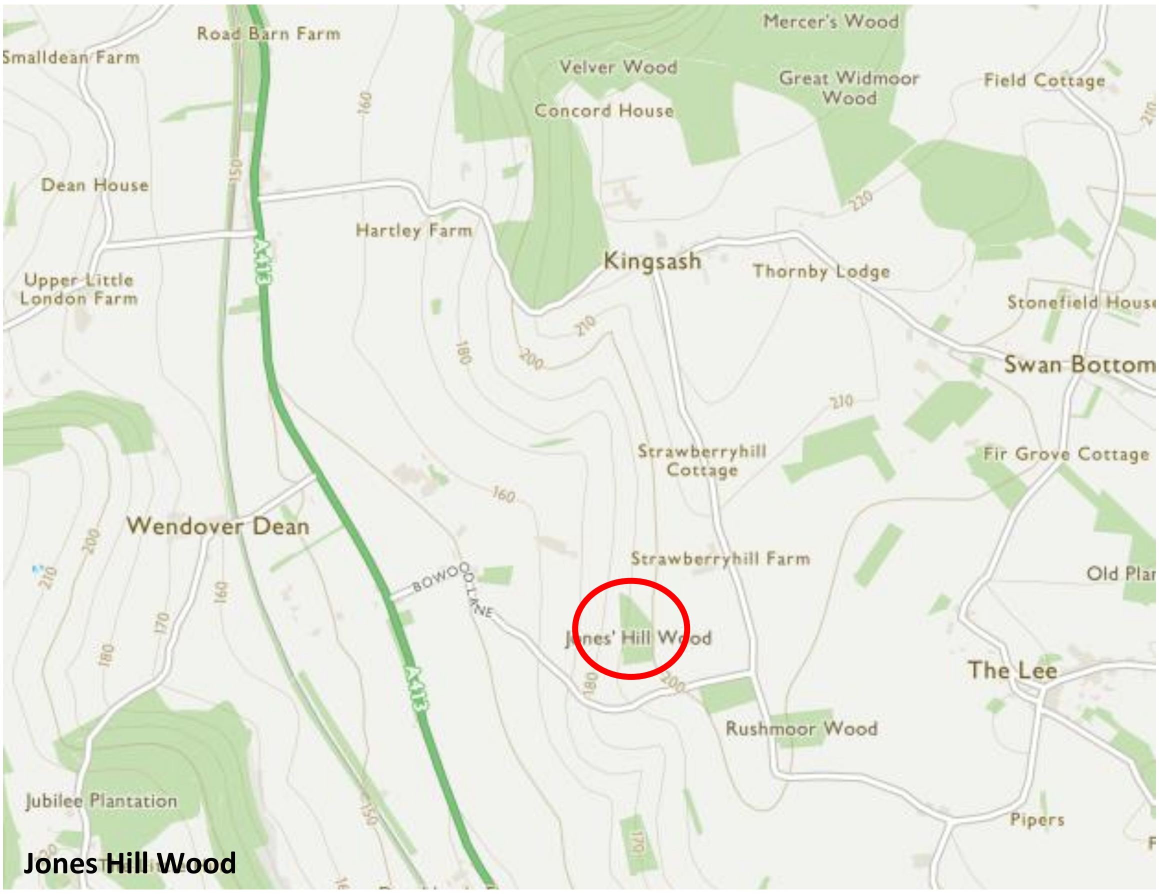


Figure 1g/h: Maps to show more detailed location of the woodland sites

Figure 2a/b: Windmill hill (top), Glyn Davies (bottom)

Figure 2c/d: Fox Covert, Whitfield (top), Glyn Davies/Fox Covert (bottom)

Figure 3a/b: Haglof Corer (top), with coring in progress (bottom)

Figure 3c: Extraction of core sample from the corer

Figure 4: Representative examples of the cores. The cores vary in length from approximately 350mm up to approximately 450mm and have a diameter of 4mm. Each sample is given a unique Dendrochronological identifier code, eg, ‘FOX-C10’.

Table 2: Table showing the levels of cross-matching between the 'A' and 'B' readings of each individual sample

Sample	T-value
Fox Covert Wood	
FOX-C01	20.3
FOX-C02	47.0
FOX-C03	33.9
FOX-C04	22.6
FOX-C05	31.6
FOX-C06	19.3
FOX-C07	37.2
FOX-C08	43.3
FOX-C09	27.3
FOX-C10	Distorted
Glyn Davies/Fox Covert	
GLY-D01	30.4
GLY-D02	39.7
GLY-D03	20.4
GLY-D04	31.2
GLY-D05	28.4
GLY-D06	31.6
GLY-D07	27.6
GLY-D08	52.4
GLY-D09	30.2
GLY-D10	26.3
Jones Hill Wood	
JHW-A01	19.4
JHW-A02	26.1
JHW-A03	30.8
JHW-A04	44.1
JHW-A05	51.4
JHW-A06	58.6
JHW-A07	27.8
JHW-A08	27.8
JHW-A09	24.5
JHW-A10	Distorted

Sample	T-value
Widmore Farm	
WID-F01	38.4
WID-F02	45.9
WID-F03	30.0
WID-F04	38.2
WID-F05	27.7
WID-F06	27.9
WID-F07	38.3
WID-F08	20.9
WID-F09	Distorted
WID-F10	Distorted
Windmill Hill Spinney	
WIN-H01	25.1
WIN-H02	17.7
WIN-H03	32.9
WIN-H04	48.7
WIN-H05	33.2
WIN-H06	17.9
WIN-H07	44.7
WIN-H08	15.7
WIN-H09	21.7
WIN-H10	23.6

It will be seen that the highest value is obtained between JHW-A06a/b with a value of t=58.6, the lowest is between WIN-H08a/b with a value of t=15.7

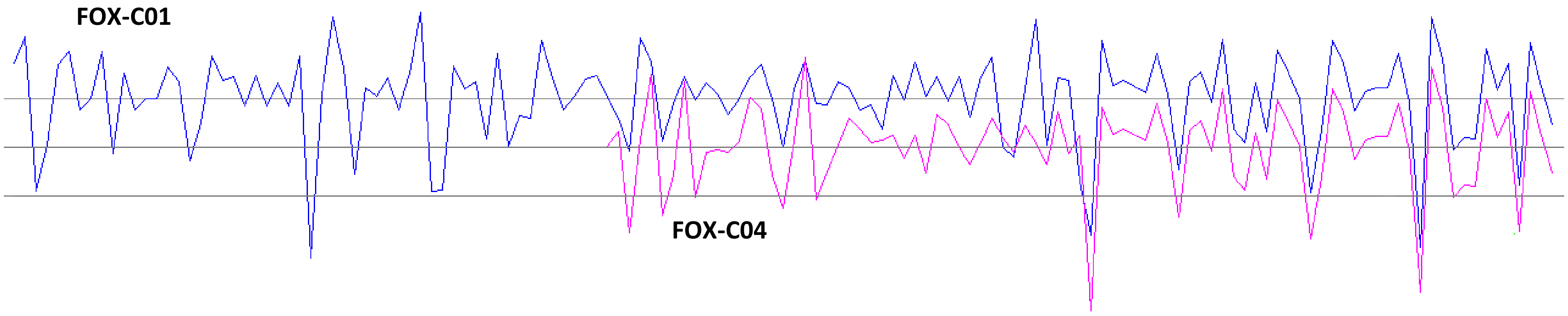


Figure 5: Graphic representation of the cross-matching of two samples, FOX-C04 (blue) and FOX-C04 (red). It can be seen that when cross-matched at the correct off-set positions, as here, the variations in width of the annual growth rings of these two samples (where their growth rings overlap with each other) correspond with a high degree of similarity. As the annual rings widths of one sample increase (represented by peaks in the graph), or decrease (represented by troughs), so too do the annual ring widths of the second sample. This similarity in growth pattern is a result of the two trees represented having grown in the same area *at the same time,* and the greater the degree of similarity, the higher the cross-matching '*t*-value'. The growth ring pattern of samples from two trees grown at different times should never cross-match at any position

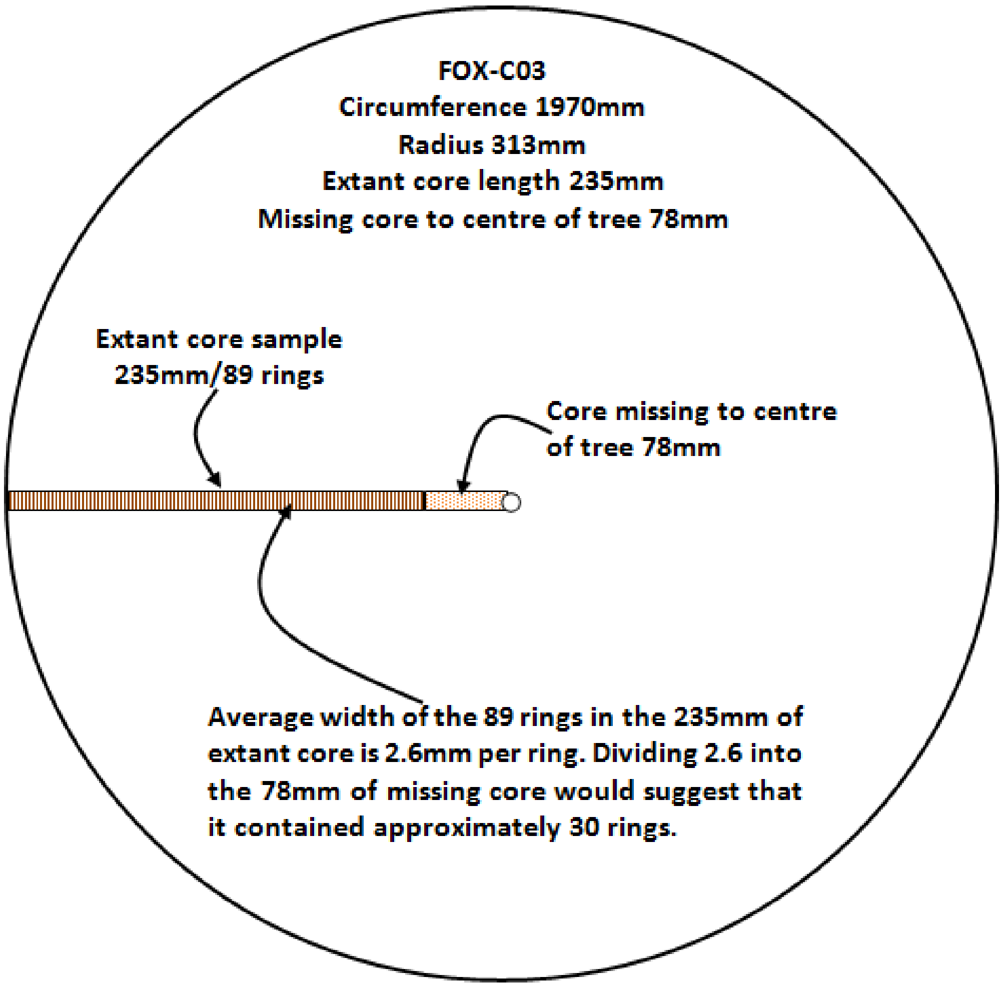


Figure 6; Method of estimating approximate number of growth rings on un-cored portion of a tree towards its centre ring

In this example, the circumference of the tree is 1970mm giving the tree a radius of 313mm (1970÷*pi* (3.14) ÷2). The extant core sample contains 89 rings and is 235mm long, this meaning that there are 78mm of core un-obtained to the centre of the tree. It would be possible to calculate the likely age of the tree by two methods. The first is illustrated above, where the average width of the extant rings (here 2.6mm) is extrapolated into the length of missing core (this determined by finding the radius of the tree and deducting the extant core length from it), to determine how many rings are missing to the centre of the tree. Adding this number to the number of rings on the extant core gives the age of the tree. If the extrapolation is correct, this would suggest that tree FOX-C03s was approximately 120 years of age in 2020, and probably began growing in 1901.

An alternative method would be to make a simple count of the number of rings found in the equivalent, innermost, length of core where the rate of growth is most likely to be similar to that in the missing portion, in the case of sample FOX-C03, the innermost 78mm of the extant core contains 23 rings. These 23 could then be added to the 89, on the extant core, suggesting (if the extrapolation is correct) that tree FOX-C03s was approximately 112 years of age in 2020, and probably began growing in 1909.

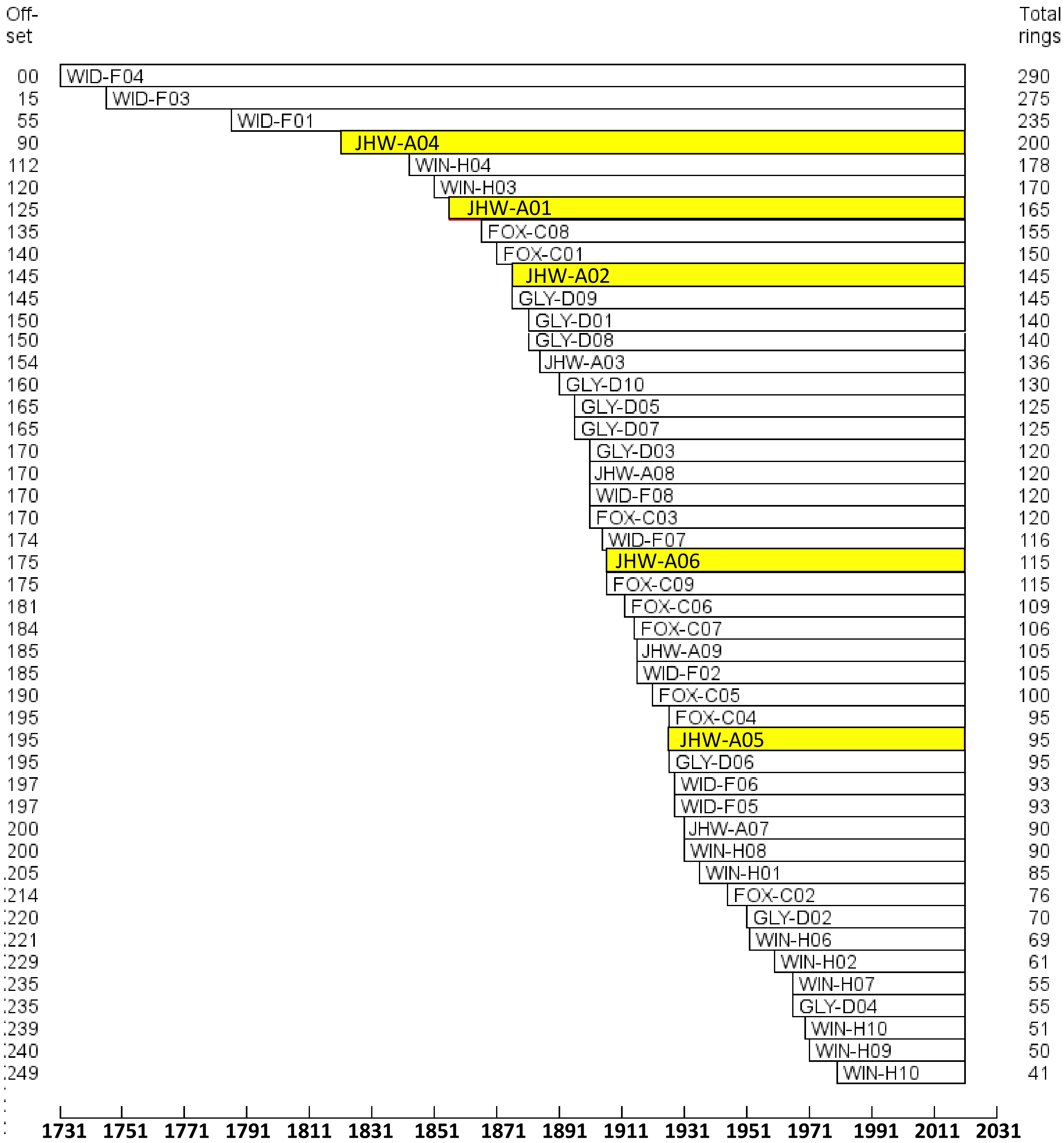
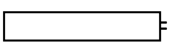


Figure 7: This bar diagram illustrates the calculated life-span of each sample in first growth ring date order (the span of the extant rings on the sample, plus the estimated number of rings missing from the un-cored portion of the tree towards its centre being included). Although undated by dendrochronology, the estimated date span of the beech trees is also shown.

White bars  = oak trees; shaded bars  elm trees

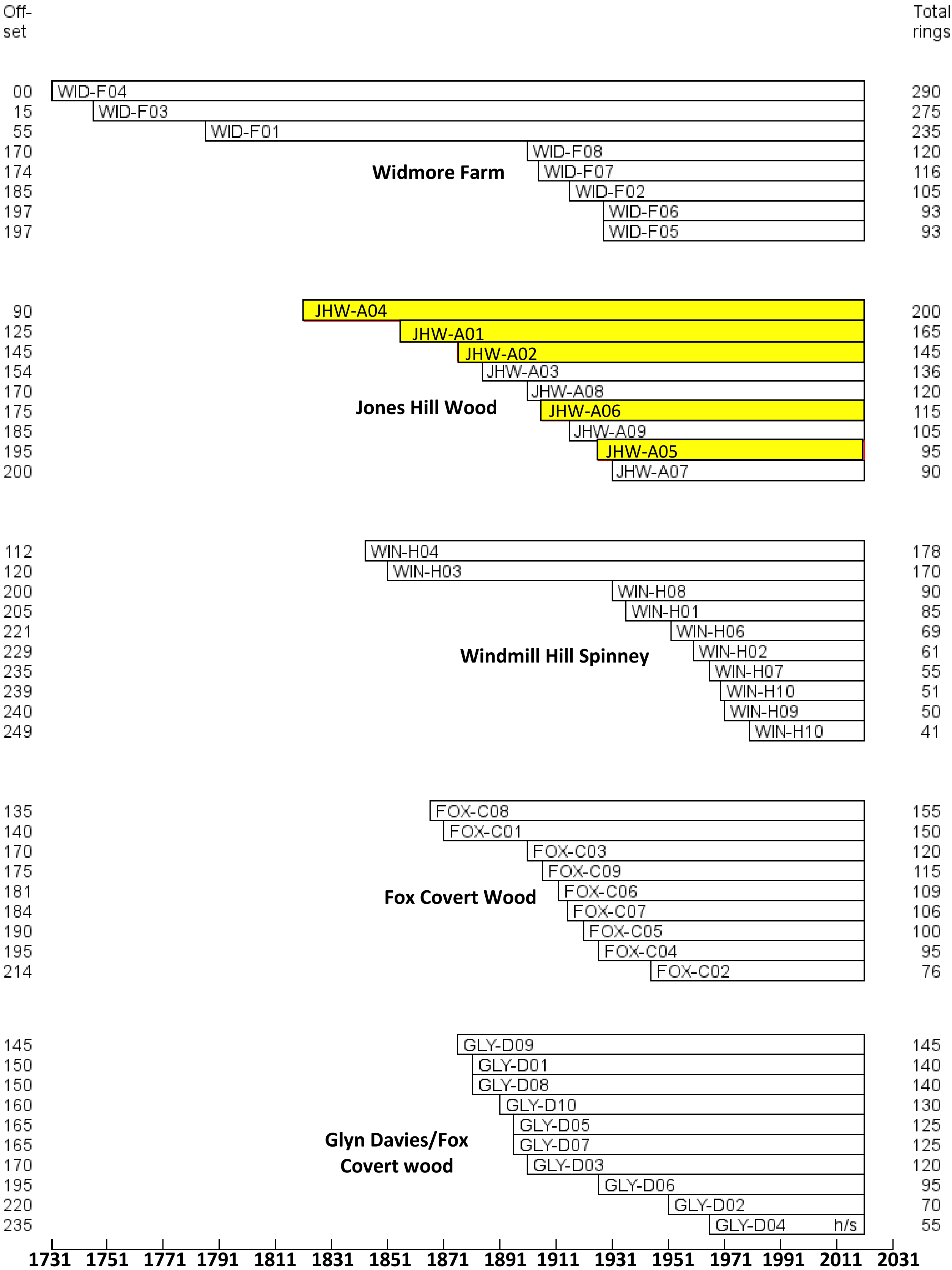


Figure 8: This bar diagram again illustrates the calculated life-span of the oak trees within each wood

White bars = oak trees; shaded bars = elm trees

Table 3: Results of the cross-matching of site chronology *HS2CHRON1* and relevant reference chronologies when the first ring date is 1768 and the last ring date is 2020		
Chronology	*t*-value	Reference
Bradgate Park, Newtown Linford Leicestershire (living trees)	9.4	(Laxton and Litton 1988)
Tattershall Castle, Tattershall, Lincolnshire	9.2	(Arnold *et al* 2018)
Stoneleigh Abbey, Stoneleigh, Warwickshire (living trees)	8.6	(Howard *et al* 2000)
Otmoor Chronology (living trees)	8.6	(Pilcher and Baillie1980)
England Master Chronology	8.1	(Baillie and Pilcher 1982 unpubl)
East Midlands Master Chronology	7.8	(Laxton and Litton 1988)
Hutton in the Forest, Penrith, Cumbria (living trees)	7.1	(Arnold and Howard 2012 unpubl)
Kent Modern Master Chronology (living trees)	6.7	(Arnold and Howard forthcoming)
Combermere Abbey, Whitchurch, Cheshire (living trees)	6.2	(Howard *et al* 2003)
Gloucestershire Modern Chronology (living trees)	6.2	(Howard *et al* 2002 unpubl)

Site chronology *HS2CHRON1* is a composite of the extant data of all 41 cross-matching oak samples. This site chronology is an 'average' of the trees' growth, where the overall climatic signal of the ring growth of the combined data is enhanced, and the possible erratic variations of any one individual sample is reduced. This 'average' site chronology is then compared to the full corpus of available reference patterns for oak covering all parts of Britain. As can be seen here, *HS2CHRON1* matches only when its 253 rings span the years 1768–2020.

It may be noticeable from Table 3 that there are possibly only two modern oak reference chronologies for central England pertinent to the HS2 sites reported on here, that for Stoneleigh Abbey (just to the south of Coventry in Warwickshire), and possible that for Bradgate Park, just to the north of Leicester, although the Otmoor Chronology is known to contain about 15 samples from trees just north of Oxford. It will be seen however, that other reference chronologies are made up of samples from living trees from as far away as Cumbria, Kent, and Lincolnshire. Indeed, so poorly is the modern period represented that in reality some of the reference chronologies listed in Table 3 are not truly independent of each other, with some of them sharing data from other chronologies, ie the East Midlands Master Chronology and the England Master Chronology. To this extent, the new data accumulated in this programme of analysis makes a valuable contribution in both temporal and geographical terms.

Table 4a: Table of all samples listed by circumference of the trunk at coring height

Sample	Circumf *mm*	Tree age
WID-F08	4000	120
WID-F07	3200	116
WIN-H03	3150	170
JHW-A03	3140	136
WID-F03	3130	275
WID-F04	3050	290
GLY-D09	3040	145
GLY-D07	3000	125
WIN-H04	3000	178
GLY-D04	2600	55
FOX-C07	2580	106
FOX-C02	2430	76
GLY-D05	2420	125
GLY-D08	2340	140
GLY-D01	2300	140
WID-F02	2300	105
JHW-A06	2250	115
WID-F05	2250	93
GLY-D10	2220	130
GLY-D06	2200	95
WID-F01	2200	235
FOX-C06	2140	109
FOX-C09	2030	115
WID-F06	2030	93
FOX-C04	2000	95
JHW-A01	1980	165
FOX-C03	1970	120
WIN-H08	1940	90
FOX-C08	1920	155
FOX-C05	1850	100
JHW-A09	1790	105
FOX-C01	1730	150
GLY-D03	1720	120
WIN-H09	1670	50
JHW-A07	1640	90
JHW-A08	1630	120
JHW-A02	1590	145
JHW-A04	1590	200
GLY-D02	1550	70
JHW-A05	1500	95
WIN-H07	1320	55
WIN-H05	1270	41
WIN-H01	1080	85
WIN-H02	1000	61
WIN-H06	1000	69
WIN-H10	1000	51

Table 4b: Table of samples listed by age of the tree in 2020

Sample	Circumf *mm*	Tree age
WID-F04	3050	290
WID-F03	3130	275
WID-F01	2200	235
JHW-A04	1590	200
WIN-H04	3000	178
WIN-H03	3150	170
JHW-A01	1980	165
FOX-C08	1920	155
FOX-C01	1730	150
GLY-D09	3040	145
JHW-A02	1590	145
GLY-D08	2340	140
GLY-D01	2300	140
JHW-A03	3140	136
GLY-D10	2220	130
GLY-D07	3000	125
GLY-D05	2420	125
WID-F08	4000	120
FOX-C03	1970	120
GLY-D03	1720	120
JHW-A08	1630	120
WID-F07	3200	116
JHW-A06	2250	115
FOX-C09	2030	115
FOX-C06	2140	109
FOX-C07	2580	106
WID-F02	2300	105
JHW-A09	1790	105
FOX-C05	1850	100
GLY-D06	2200	95
JHW-A05	1500	95
FOX-C04	2000	95
WID-F05	2250	93
WID-F06	2030	93
JHW-A07	1640	90
WIN-H08	1940	90
WIN-H01	1080	85
FOX-C02	2430	76
GLY-D02	1550	70
WIN-H06	1000	69
WIN-H02	1000	61
GLY-D04	2600	55
WIN-H07	1320	55
WIN-H10	1000	51
WIN-H09	1670	50
WIN-H05	1270	41

Table 5; Number of trees by age group	
Rings	**Trees**
0–25	**0**
26–50	**2**
51–75	**6**
76–100	**10**
101–125	**13**
126–150	**7**
151–175	**3**
176–200	**2**
201–225	**0**
226–250	**1**
251–275	**1**
276–300	**1**