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Veteran Tree Management and Dendrochronology

Birklands & Bilhaugh cSAC, Nottinghamshire

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Summary

1. Sherwood Forest (Nottinghamshire) is important for its ancient oaks. Previous work showed that 35% of these are entirely dead and many others have major sections of the trunk dead. However very little is known about when the trees died and how long dead trees may survive as part of population. Dendrochronology was used to explore this question by relating cores taken from dead trees to the established East Midlands Tree-Ring Chronology that has been derived from building timbers.

2. Ninety-two trees (58 dead trees, 34 living trees) were sampled between 2000 and 2002, using standard Haglof increment borers. 102 core lengths were obtained of which 80 had measurable ring sequences. 71 of these could be linked to the East Midlands Tree Ring Chronology.

3. The highest number of rings counted from a core was 403 and more than half produced at least 100 rings. The earliest ring measured dates to 1415. Dates of death for samples were estimated at between 1914 and 2001. There is little evidence for significant variation in death rates over the century.

4. No samples were dateable for dead trees earlier than 1914 (they may occur but lack a sapwood-heartwood boundary), but heartwood within trees could be dated back to 1415 in one instance. 57 trees contained wood dating to 1815 or earlier.

5. Although based on only a small sample, the oak population appears to how a clear cohort structure, rather than continuous regeneration.

Contents

1. Introduction: aims and objectives

1.1 Recent work carried out by Watkins and Lavers (1998) has produced a database of the cohort of ancient oak trees surviving within the remnants of Sherwood Forest. The database shows that around 35% of the cohort of ancient oaks are entirely dead, and large sections of many of the live oaks are dead (Clifton 2000a; Clifton 2000b). This dead wood resource is of enormous nature conservation and historical importance (Lott 1999; Watkins 1998) yet remarkably little is known about when the trees died, how long largely dead trees may remain alive, and how long the dead wood is likely to survive before rotting away.

1.2 As most of the extant oak trees, both dead and alive, are hollow, there has formerly been little interest in carrying out dendrochronological analysis of the trees. Much of the interest in such analyses stems from the desire to provide a precise estimate of the age of the trees, and the hollowness of the great majority at Sherwood means that this objective is unattainable. Attention has concentrated on the historical analysis of medieval and early modern building timbers (Laxton *et al* 1995; Laxton 1997) rather than the analysis of oak trees. Such research enabled the East Midland Tree-Ring Chronology (Laxton and Litton 1988) to be constructed.

1.3 The authors proposed to English Nature in January 2000 a project which would use the dendrochronological approach in a very different way. Rather than using the tree ring data to estimate the age of trees, or look at fluctuations in the growth rate, the data could be used to estimate the date of death and likely longevity of the surviving ancient trees. This information is important in determining the future management of the remaining fragments of Sherwood Forest in Birklands and Bilhaugh cSAC. Factors influencing tree death will also be explored. This information provides a basis for the development of management strategies to ensure the long-term supply of old oak trees.

1.4 Our first aim was to assess the feasibility of using dendrochronology on ancient oaks. Would it be possible to gain usable dendrochronological samples from the dead wood of ancient trees? Was it possible to extract small samples using standard tree corers, or was the timber either too hard and dry, or soft and rotten, to extract a core? Second, once extracted, were the rings of what could be very slowly growing oak trees decipherable in the dendrochronology laboratory? Would it be possible to place the rings within the established East Midland Tree-Ring Chronology? Finally, would it be possible to distinguish the sapwood/heartwood boundary in the samples, and thus make an estimate of the date of death for individual trees?

1.5 The heartwood/sapwood boundary is the most important time marker in a study of this kind. The sapwood of an oak tree consists of a variable number of rings (typically 15-40) adjacent to the bark. Sap and water are transported in this zone in living trees. Oak sapwood is usually lighter in colour and invariably weaker than the inner heartwood, and tends to be more vulnerable to insect attack and mechanical weathering. It thus tends to crumble away from the heartwood of timber beams and dead portions of trees. The other major cause of wood loss is 'heart rot'. The process of heart-rotting is complex and not fully understood (Rayner and Boddy 1988) but in Sherwood it typically results in the production of a hollow cavity lined with wholly or partially rotted wood, bounded by an entire, fragmented, or multiply-breached cylinder of as yet un-rotted wood.

1.6 The Buck Gates site where the work was carried out is important because estate management records indicate that there has been relatively little active management of the ancient oak trees over the last 100 years or so, apart from the following issues:

- A plantation of oak trees was made in the south-eastern section of the site in the 1890s. The Turkey oaks planted then have now been removed. Many of the English oaks survive but is not known how many of the ancient oaks, if any, were felled when this plantation was made.
- A small plantation of pines survives in the north-west section of the site. Again it is not known whether any ancient trees were removed when this was made but one fallen ancient oak remains within the borders of this plantation.
- There are many felled oaks within the borders of the Proteus Camp. Some of these may have been removed from the Buck Gates site in the post war years. These factors all suggest that the population of ancient oaks is likely to have been reduced during the twentieth century. This is corroborated by several oak stumps which indicate that the trees were felled by saw.

1.7 The project started on 1 May 2000 and took place over two years although the second year of research was delayed for three months by foot and mouth disease restrictions. The first year interim report provided tree ring data for 18 trees, and demonstrated that it was possible to collect usable samples from standing dead trees and link these samples to the existing regional oak dendrochronological sequence.

2. Methods

2.1 The research contract specified that 90 trees would be subject to dendrochronological analysis. The use of such techniques for standing trees is novel and a two year research period was allotted to allow techniques to be developed and refined. Although many of the trees sampled were entirely dead, samples were also taken from trees which had some sections living; such trees could have as little as 5% of their surface bark area alive. The taking of samples from live sections of trees was important because it ensured sufficient linkage to the population of live trees to allow for the interpretation of sapwood data.

2.2 Permission to take samples at the site was provided by Andrew Poole Woodward for Thoresby Estates Management Ltd. All ancient oak trees in this section have been tagged with galvanised steel unique numbers. Figure 1 shows the outline of the Buck Gates Section of the Birklands and Bilhaugh cSAC (Watkins and Laver 1995) and the distribution of the 92 sampled trees. The sample is distributed across the site. The number sequence for this section runs from (7)047- (7)453. The numbers for the individual trees sampled are shown in Figure 2.

2.3. A random sample of trees was taken from the existing database of 406 ancient trees found in the Buck Gates section (Watkins and Lavers 1995). This sample was not a random sample of *all* ancient oaks on site, because most of the trees are alive, and the main focus of the study was to establish dates of death. However, knowing that living trees can be largely dead, we also wanted to take a sample of cores from living trees to investigate, for example, the length of time that a tree may continue to live after portions of it have begun to die. Thus we took a quota sample aiming for two thirds of our survey effort to be from dead trees, and one third from living trees: the actual figures were 58 (63%) of the 92 samples were from dead trees and 34 (37%) were from living trees. Within the quotas our samples of dead and living trees were random. In addition four reference samples were taken from large non-ancient oak trees.

Coring procedures

2.4 Samples were taken using standard Haglof incremental corers. Although some problems were encountered, one of our principal conclusions is that good results can be achieved using these corers. There are some practical problems however: a) some trees are so bossed that it is very difficult to take cores; b) the Haglof increment corers can jam in the tree and be very difficult to extract; c) the Haglof corer can become blocked with a piece of very hard wood which is extremely difficult to remove; d) some cores may be too dry and powdery to collect; 3) some cores may be too wet or rotten to collect.

2.5 The working method we developed was to take at least two, sometimes three, cores from each sample tree. Samples were generally taken at breast height (this is usually the most comfortable and safe height for using the corer) and in sections of trunk which were relatively smooth, free from bosses and not deeply rutted. A few samples were also taken from large branches. Wherever possible cores were taken at places where there was clear evidence from the remaining bark that the outside layer was likely to contain sapwood. In some cases (for example tree (7)099) we noted that where the sapwood was missing the surface of the remaining wood looked superficially like that of the sapwood.

2.6 We tried to obtain as long a core as possible. Where we could see into the hollow trunk, we could position the corer at a site where there was the greatest width of surviving wood. Otherwise we cored 'blind'. If only a very short sample was obtained, we took another core, but frequently only a short core was obtainable.

2.7 In practice we needed a minimum team of three people, and preferably four, to collect the samples efficiently, with two people taking samples and the others identifying sample trees and labelling and storing cores.

2.8 The sample cores were carefully lifted from the Haglof corer and placed in labelled plastic straws for safe transport to the dendrochronology laboratory at Nottingham University.

2.9 We also collected some fragments of dead wood which appeared to provide ring evidence to the centre of the tree. One fallen tree within the Buck Gates section (Tree (7)336) provided a very useful sample to the centre of the tree. Data from this tree were crucial in matching trees within the overall chronology.

2.10 Once the samples had arrived at the University, they were given the Tree-ring Laboratory code SHR-M (for Sherwood, modern) and numbered, the location of the source tree and its identification number having been recorded. In some cases the sample broke into two or more pieces; each piece was given its own sample number. The sample cores were then prepared for analysis by sanding and polishing. The growth rings were measured and the growth ring sequences were compared with each other to produce a site chronology.

2.11 A number of problems arose with the cores in the laboratory. The main difficulties were a) cores with too few rings for meaningful analysis; and b) cores with compacted or distorted rings. There is only a rough correlation between the length of the core and the number of rings; ring widths vary, and so it is possible, for example, for some short cores to have many narrow rings. Short cores should not therefore be discarded as likely to contain few measurable rings.

3. Results of dendrochronological analysis

3.1 Table 1 shows data for all 92 ancient trees sampled, listed in tree number order. For six trees (52, 138, 319, 369, 422, 438) there are two sets of results, either because the sample was broken, or because two sample cores produced useful results. The total number of samples is therefore 102.

3.2 Of the 102 samples, 22 samples could not be used because the sample was either too fragmentary (13), had too few rings (5) (samples need at least 55 measurable rings in order to place them in the dendrochronological sequence (Laxton and Litton 1988)), or had compacted rings (4).

3.3 Of the 22 unusable samples, 15 were from dead trees and 7 were from living trees, (dead standing and fallen (17%); live trees (20%); 'boats' and stumps (38%)). 'Boats' are trees which consist of hollow, prone trunks with their upper portions rotted away. The boats and stumps by definition have a great proportion of their timber on the ground and are most likely to be rotten, and hence these types of tree are the most difficult from which to extract usable samples.

3.4 The sampling procedure produced 80 samples from which accurate measurements of the tree rings could take place, a success rate of 78% which is comparable with results obtained in dendrochronological work on building timbers (Robert Howard, personal communication).

3.5 The measured ring sequences were linked to the East Midland Tree-Ring Chronology (Laxton and Litton 1988) only 9 of the samples not fitting into the chronology. This very positive result demonstrated the validity and potential of the approach.

3.6 The highest number of rings counted was 489. This was from Tree 336 where a section was sawn from a fallen dead tree, one of the few that had not become hollow. Further analysis of this sample is given in Section 7. The highest number of rings measured from cored samples was 403. Three samples produced 300-399 rings, eight 200-299 rings, 36 samples 100-199 rings and 32 samples had 40-99 rings.

3.7 It was possible to estimate the number of unmeasured rings towards the centre of the core for three of the trees, but these rings have not been included in the full analysis. In 11 cases there were rings towards the outer edge of the sample which it was not possible to measure, but for which a usable estimate could be made. These data have been included in the analysis shown in Figure 3.

4. Analysis of longevity and date of death of sample trees

4.1 In Figure 3 the 71 samples from cross-matched and dated trees at Buck Gates are placed in order of the last known or estimated dated ring. So, for example, the top sample's latest growth ring is 1650, while the bottom sample's last growth ring is 2001. Column A shows the position of the first measured ring on each sample in relation to the earliest measured ring of any sample. The earliest measured ring is given the position 000, which is ascribed to the year 1415, taken from Tree 336. Column B shows the date of the first measured ring from each sample. Column C shows the total number of measured rings from each sample. The dates in relative years and calendar years are given at the bottom of the Figure.

4.2 The boundary between heartwood and sapwood is also indicated on Figure 3. Where sapwood was measurable to the bark, the total number of sapwood growth rings is given, followed by the letter 'C' for 'Complete'. Twelve samples had complete sapwood; the number of sapwood rings ranged from 20 to 37, with a mean of 28 growth rings. In six cases it was possible to make an estimate of unmeasured rings which were difficult to measure precisely. These growth rings are indicated separately on the diagram.

4.3 Twenty-seven of the first 28 samples on the diagram have no identifiable heartwood-sapwood boundary. This makes the identification of the date of death of the sample difficult. The top six samples have a last growth ring of before 1815. These samples have probably lost many of their outer growth rings, and we can exclude them from further discussion. One tree (56) has 35 sapwood rings, and the last dated ring is 1836. This is problematic, however, as the tree is still alive and the sample was taken through the bark. This tree must therefore have been misdated by the dendrochronological method, the only instance we have of a clearly misdated sample. The remaining 21 top samples have latest growth rings ranging from 1831 to 1907. None has a heartwood-sapwood boundary, but taking the average number of sapwood rings as 28, they should have a minimum number of 28 years added to their last date. This changes the range of dates of death for these 21 samples to 1859 to 1935. We feel, that only a few heartwood rings have been eroded, and so this range of dates *could* be fairly accurate. However, as we do not know how many heartwood rings may have been eroded, the addition of the mean number of sapwood rings has not been indicated in Figure 3.

4.4 The bottom 43 trees in the diagram all have a heartwood-sapwood boundary. With these, the addition of the mean sapwood growth ring figure (28) when no sapwood is present provides a useful indication of the likely date of death of the *sample*. Taking this modification into account, the samples have dates of death ranging from 1914 to 2001.

4.5 When grouped into 20 year periods, there is an indication that a relatively low number of samples have a date of death for the period 1961-1980. This is indicated by the kink in Figure 3 between trees 316 and 118. However, compared to the period before and after, this may not be a significant difference.

Last growth ring	-1920	21-40	41-60	61-80	81-97	Alive
No of samples	3	8	10	3	7	12

4.6 It may just reflect natural variation in death rates. Higher death rates in the middle years of the twentieth century might be due to felling associated with wartime activity such as tank manoeuvres. Another reason frequently given for death of oak trees is air pollution, but these figures do not strongly support the idea of a 'catastrophic' impact of air pollution on the trees mid-century.

5. Defining date of death

5.1 Table 2 shows the status of the trees from which the samples were taken. All the living trees (34) were standing. Of the 58 dead trees, 23 (40%) were standing; 10 (17%) were fallen 'whole' trees; 13 (22%) were 'boats', that is trees which consisted of hollow, prone trunks with their upper portions rotted away; and 8 (14%) were tree stumps.

5.2 Although 37% of the samples were taken from living trees, the sample may not have been taken through the bark of the living section of the tree. While wherever possible cores were taken at places where there was clear evidence from the remaining bark that the outside layer was likely to contain sapwood in four cases samples had to be taken from sections where no bark remained. The usual reason was that the surviving bark was heavily bossed and burred, making any sample taken through the bark unusable.

5.3 Taking samples through the bark of living trees did not necessarily result in a sample which included tree rings up to the date of sampling, because the bark sometimes covered dead sections of the tree trunk. We found no simple method in the field of identifying beforehand whether we had obtained a core from a live or dead section of the tree when coring through bark and 10 samples fall into this category.

5.4 Only three of the samples from the top group of 28 samples with no heartwood-sapwood boundary come from a tree which is alive. One of these (56) appears to be dated wrongly (see 4.3). The other two (423 and 342) have last growth rings of 1831 and 1907. For the 30 samples where accurate dates of death have been assigned (Tree 302 down to Tree 304 on Figure 3) 17 (57%) are from dead trees and 13 (43%) from live trees.

5.5 While it is possible to estimate the date of death of the *section of tree* from which individual samples are taken, it is not possible to provide a clear estimate of the date of death of the *trees* themselves. This is because different sections of the tree will cease growing at different times.

6. Survival of dead wood

6.1 We have accurate date of death data from 17 of the cores from dead trees (Table 2). These data can be used to give the earliest estimate of the date of death of the trees concerned. It may be that other sections of the tree outlived the section from which these cores were taken. Of these 17 trees, 10 are now standing dead trees, five are fallen (four of which can be classed as boats) and two are stumps. The dates of death for the 10 standing trees range from 1914-1994 (with an average of 1952); the dates of death for the five fallen trees and two stumps range from 1920-1983 (with an average of 1944).

6.2 These data indicate that samples from dateable dead trees are likely to be less than 100 years old. We do not have a precise date of death for any sample earlier than 1914 (Tree 302) because samples older than this had no surviving heartwood-sapwood boundary.

6.3 General field observations suggest that the dead wood in standing trees (both dead and alive) is likely to survive longer than 'boats' and stumps which have a high proportion of their surface area touching the ground and which are likely therefore to be wetter than standing trees. This is backed up by the information given in Section 3.3 on the relative difficulty in obtaining usable samples from stumps and boats.

6.4 The great majority of the ancient oaks are hollow. Only one of the trees (336) clearly had rings to the centre of the trunk. We could not see into the hollow centre of all the trees, but the Haglof coring indicated clearly, by 'giving', that most were hollow or at least internally delaminated. The inner dates shown in Figure 3 are also important, however, because they indicate how long we might expect the dead wood to survive within the trees. The oldest piece of wood found was produced in the year 1415. Thirty-one (43%) of the trees contain wood accurately dated to 1765 or earlier; 57 (80%) of the trees contain timber dated back to 1815 or earlier. This emphasises the great importance of the dead wood resource in ancient trees.

6.5 The number of surviving growth rings in trees which have no identifiable heartwood-sapwood boundary (Figure 3) is significantly lower than for trees with a clear boundary. Those samples with no heartwood-sapwood boundary ($n=22$) have a mean number of 119 growth rings; those with a heartwood-sapwood boundary ($n=39$) have a mean of 181 (statistically significant difference, Mann-Whitney $U=199$, $p<0.01$).

6.6 Our observations suggests that remnant cylinders continue to rot away predominantly from the inside towards the outer heartwood, though erosion of exposed outer rings may also occur. The following sequence of senescence is probably typical for the ancient oaks of Sherwood:

i. Heart rot attacks the tree's core, leaving it hollow (for modes of initiation and mechanisms of heart rot, see Rayner and Boddy, 1988, Ch. 10). When the rate of heart rot exceeds the rate at which new wood is added to the growing margin, the total amount of wood present in the trunk begins to decline.

ii. Sections of trees die at different times. Some sections of trunk may be entirely dead, with no actively growing cambium, while other sections of trunk are still alive with active growth.

iii. When a section of the trunk dies, its bark and sapwood disintegrate relatively quickly, leaving the youngest layer of heartwood exposed.

iv. While there may be some erosion of this outer layer of heartwood once the overlying bark and sapwood have disappeared, heart rot eliminating material from the interior of the tree is likely to be by far the most important cause of wood loss from the trunk.

v. Eventually the whole tree dies, most of its branches, bark and sapwood disappear, and a whole or partial cylinder of heartwood remains.

vi. The trunk continues to rot from the inside towards the outer layer of heartwood. If lower sections of the trunk rot faster than upper sections, the trunk eventually falls; if the reverse happens, the standing trunk above ground gradually decays until only a stump remains.

7. Generational history of oak trees at Buck Gates

7.1 A fallen oak (336), solid almost to its centre, was found in the southern part of the Buck Gates area. This is in the area that was planted with oaks in the late nineteenth century (Figure 2). Two wedges were cut from different parts of the trunk using a chainsaw (a continuous section could not be cut because of the presence of zones of burring and contorted rings). The sections were mounted and sanded, and the rings counted, measured and correlated with the East Midlands Tree Ring Chronology (Figure 4). Slice 1 spans the dates 1415-1634, while slice 2 spans 1492-1903 (Figure 4c). Ring widths in the portion of overlap (1492-1634) are markedly different because of differential growth rates within the tree(Figure 4c) but strongly correlated ($r=0.7$, $p<0.01$).

7.2 We estimate that 15-20 heartwood rings from the centre of the tree and 15-40 sapwood rings from the outer margin are missing. Thus, this oak was probably at breast height in c. 1400 and died between the first and second world wars, aged around 530. This accords well with previous estimates of the ages of ancient oaks in Sherwood Forest based on ring counts of fallen trees (Clifton 2000).

7.3 The pattern of growth of tree 336 is shown in Figure 4 a and b. Rings declined in width linearly over the first century of the tree's life (calculated from slice 1; Figure 4 a), before stabilising at an average of 1.12mm per year (calculated from slice 2; Figure 4 b). The estimated yearly increase in diameter and girth of this oak between 1492 and 1903 is thus 2.2mm and 7mm respectively, considerably lower than estimates for trees growing in open situations (Mitchell, 1996). Growth varied considerably from year to year after establishment, but there is no long-term trend of increase or decrease (slope and intercept of the fitted line in Figure 4 b are within one regression standard error of the expected values of 0.0 and 112mm/100 respectively). This evidence of relatively constant growth over the long term may be useful in reconstructing the history of Sherwood's oak generations.

7.4 Figure 5 shows preliminary results of an independent study currently underway in the Buck Gates area of Sherwood Forest. Only two small areas have been surveyed to date, but our familiarity with as yet unsurveyed areas of the site suggest that tentative conclusions can be drawn from the data already at hand.

7.5 The frequency of oaks in different size classes (diameter at breast height) in a study area in the south-east of the site is shown in Figure 5 a, while Figure 5 b shows the same for oaks from an area in the north-west. The south-eastern area is dominated by plantation oaks with a modal DBH of 45cm, known from historical records to have been established in the late nineteenth century. Ring counts from recently felled Turkey oaks in the area confirm this dating (ages of 111, 110, 110, 110, 108, 106, 104 were obtained). The few young oaks in the area are currently caged in wire mesh or wooden frames for protection. Trees with diameters between 90cm and 140cm are extremely rare. The ancient cohort of oaks, typically with diameters between 140cm and 190cm, is relatively poorly represented in this area.

7.6 In contrast, the north-western study area is dominated by both very old and very young oaks, with few of intermediate size and age (Figure 5 b). The difference in recent rates of regeneration at the two sites may be due to the inhibitory effect of the now closed-canopy plantation oaks in the south-east of the Buck Gates site, a cohort that is absent in the north-west.

7.7 A tentative historical timeline for the Buck Gates woodland can be constructed from the results of our dendrochronological and survey work (Figure 5 c). Three points are shown on top of the line: the present; c.1890, corresponding to the modal diameter of the plantation oaks in the south-eastern study area; and tree 336, which we estimate to have germinated around 1400. The diameter of 336 is difficult to estimate as the tree is prone, heavily burred and lacking sapwood or bark. Our best estimate of its current DBH is 145cm. Adding 15cm to this figure to allow for bark and sapwood yields an estimated diameter at death of 160cm (Figure 5 c).

7.8 Assuming that the ancient oaks increase in diameter at a regular rate over the long term as suggested by the analysis illustrated in Figure 4 b, the elapsed period between the origination of tree 336 and the establishment of the plantation cohort of the 1890s may tentatively be divided into regular intervals (Figure 5 c). This reconstruction suggests that regeneration of oaks in those areas of Buck Gates not subject to late Victorian replanting was extremely rare for at least 250 years between c.1650 and the early part of the twentieth century (Figure 5b and c). This may be due to heavy grazing during those years.

8. Management implications of results

8.1 This research confirms the great importance of the dead wood resource of the ancient oaks at Buck Gates. Almost all trees, both dead and living, are hollow, and the great majority contain dead wood originating before 1815 (Section 6). Every effort should be made to maintain all dead wood, whether in the form of stumps, fallen trees or standing trees.

8.2 Most of the ancient living trees have a very small canopy. Our results show that these trees can live on in this state for many years (Sections 4, 5 and 6). Every effort should be made to manage the area to maximise the survival of the living trees. The removal of conifers immediately surrounding the ancient trees appears to have a beneficial effect. This policy should continue and be extended over the whole of the SSSI.

8.3 The potential effect of birch trees overshadowing ancient living oaks should be considered. In some cases it may be advisable to remove overshadowing birch when these appear to be adversely affecting the live oaks.

8.4 Care should be taken that management operations, such as bracken rolling, do not cause damage to dead wood found in stumps and smaller remnants of trees. Such stumps, such as trees 411 and 418 can provide useful dendrochronological samples and provide dead wood habitat (Section 3.3).

8.4 Preliminary survey work indicates that there are three main generations of oak trees present at the Buck Gates site (Section 7). The first is 500+ years old and consists of the ancient oaks; the second is of 1880-1900; the third is of recent post 1950 growth. The second generation is mainly to be found in the SE part of the site. Observations suggest that oaks intermediate in age between the ancient cohort and the plantation generation are present in as yet unsurveyed areas, but these are few in number and would probably not show up as a distinct cohort in a diagram such as Figure 5a.

8.5 The recent growth is natural regeneration which has been allowed by the former lack of grazing. The recent reintroduction of grazing is resulting in some damage to this very important new generation and care should be taken to protect the young oaks (Section 7).

8.6 The analysis of the ancient trees provides no clear evidence that any particular factor is causing the death of trees. Most of the ancient trees appear to be dying "naturally" at a slow rate. Analysis of the date of death of *samples* (not necessarily trees) shows that an average of about six samples was dying in each twenty-year period (Section 4.5). Many of the second generation of trees, on the other hand, appear to have died fairly recently, and the condition of these trees should be assessed with some urgency. Preliminary work by the authors on the dieback of second generation oaks is already underway, funded by the University of Nottingham.

9. Future research

We have identified a number of potential research projects linked to this research:

9.1 Sample dendrochronology and measurement survey of ancient oaks in Birklands and the rest of the SSSI to examine cohorts and management implications. Observations suggest that the age structure of the oak population may vary substantially from place to place across the SSSI.

9.2 Dendrochronological analysis of a larger sample of trees with intact heartwood, similar to 336 (we have already identified a number of these and hope to take sections in the near future).

9.3 Work on the condition of trees and of field level species using nineteenth and early twentieth century photographs. These can be used, for example, to assess changes in extent of bracken, and changes in the condition of individual trees.

9.4 Monitoring of the new cohort of young oaks, particularly in relation to the reintroduction of grazing.

9.5 Analysis of the likely age of a sample of hollow trees using cored ring widths and sample lengths in conjunction with detailed measurements of interior spaces of trees.

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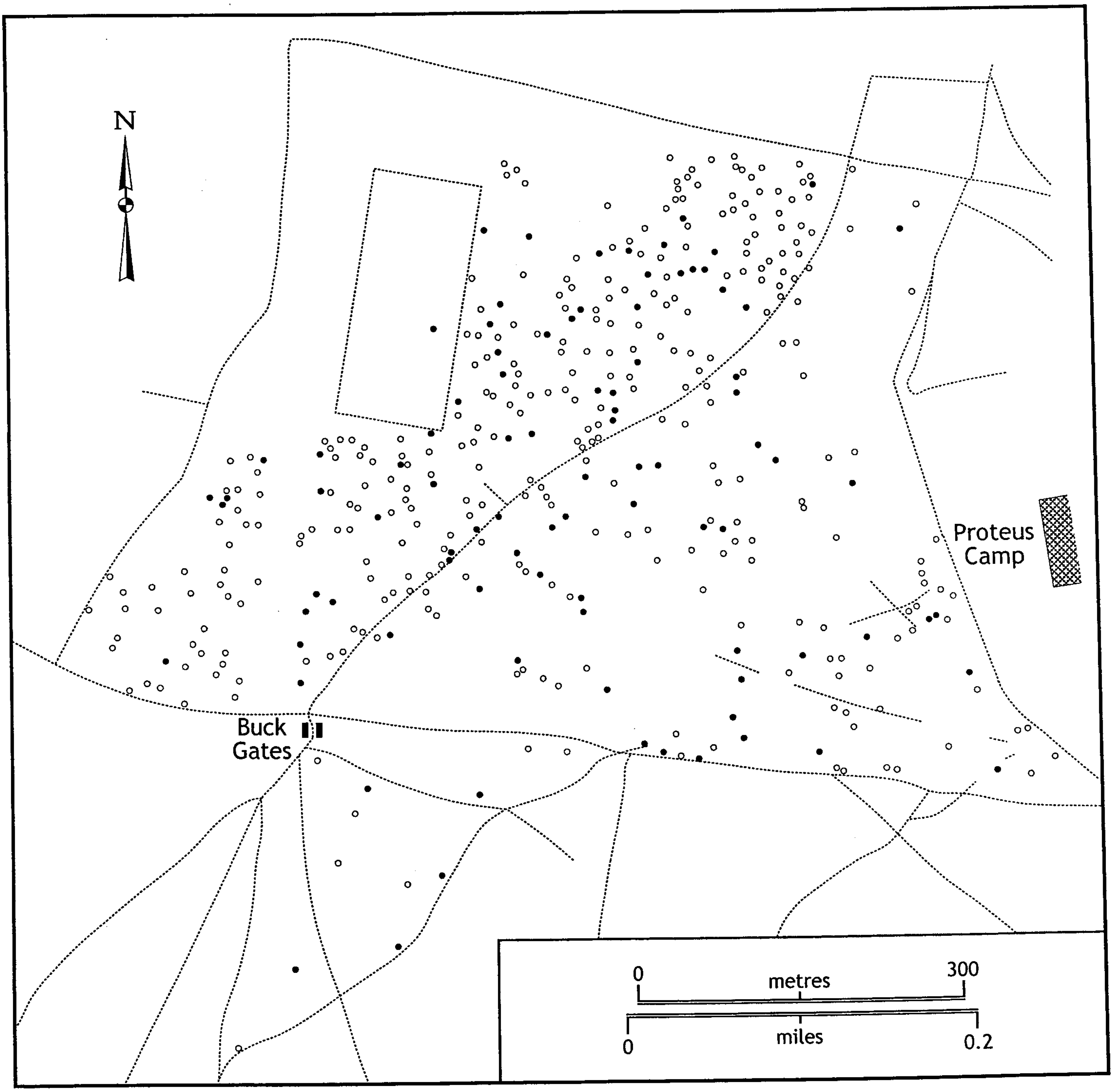


Figure 1 Distribution of all ancient oaks at Buck Gates, sample trees shown by full circles

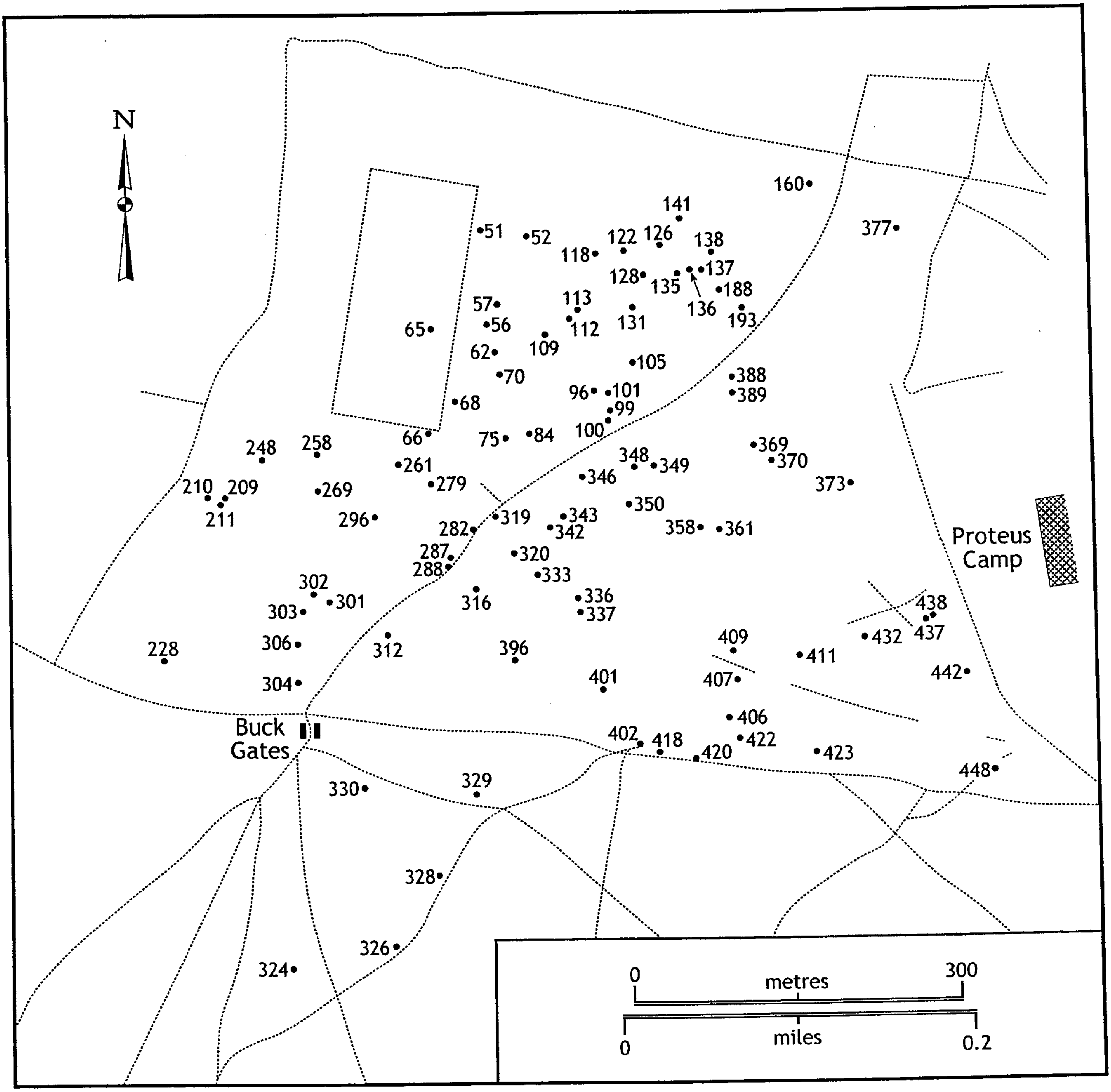


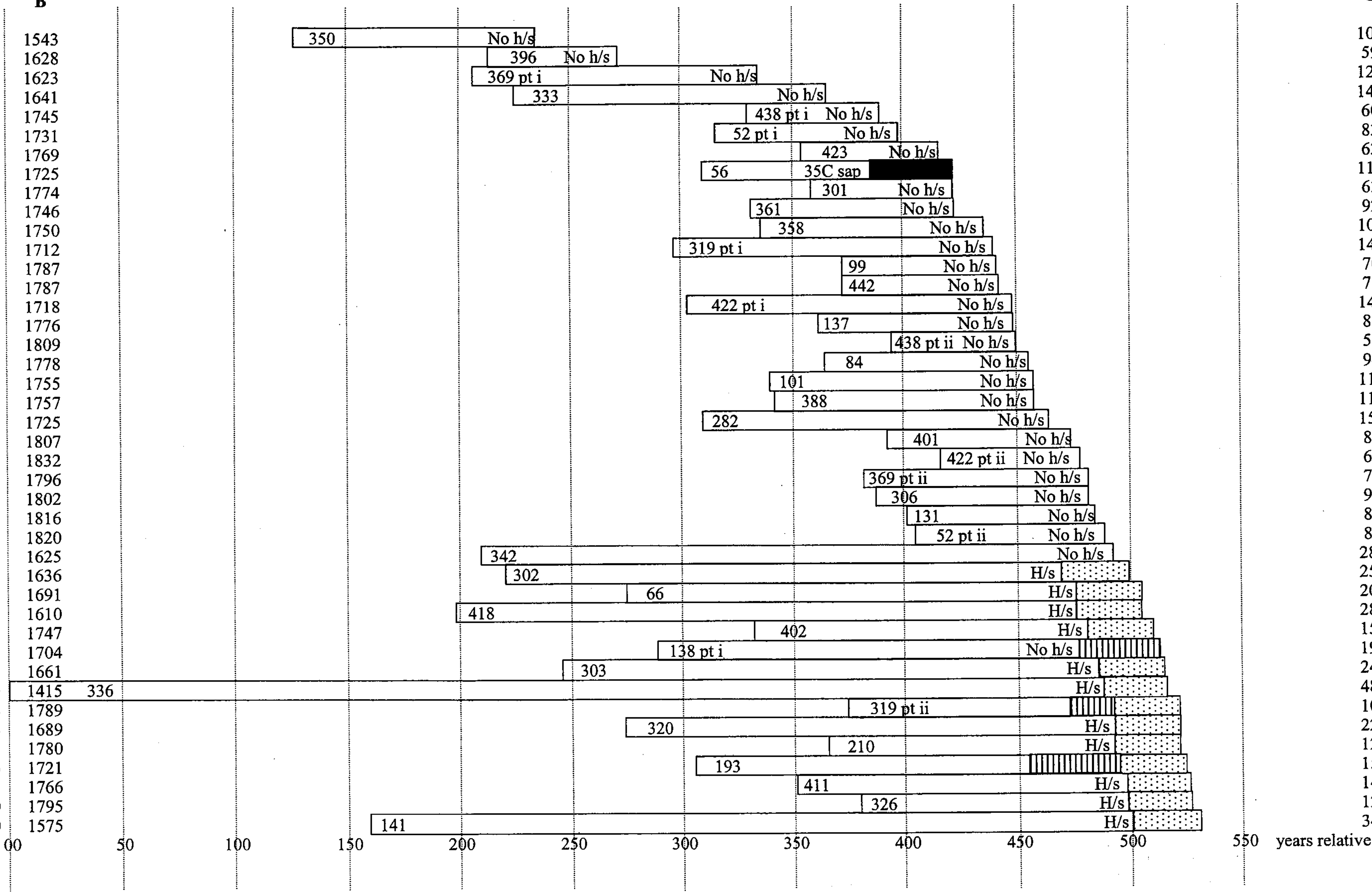
Figure 2 Distribution of sampled trees with their numbers

Figure 3. Bar diagram of cross-matched and dated samples from Buck Gates ancient oaks

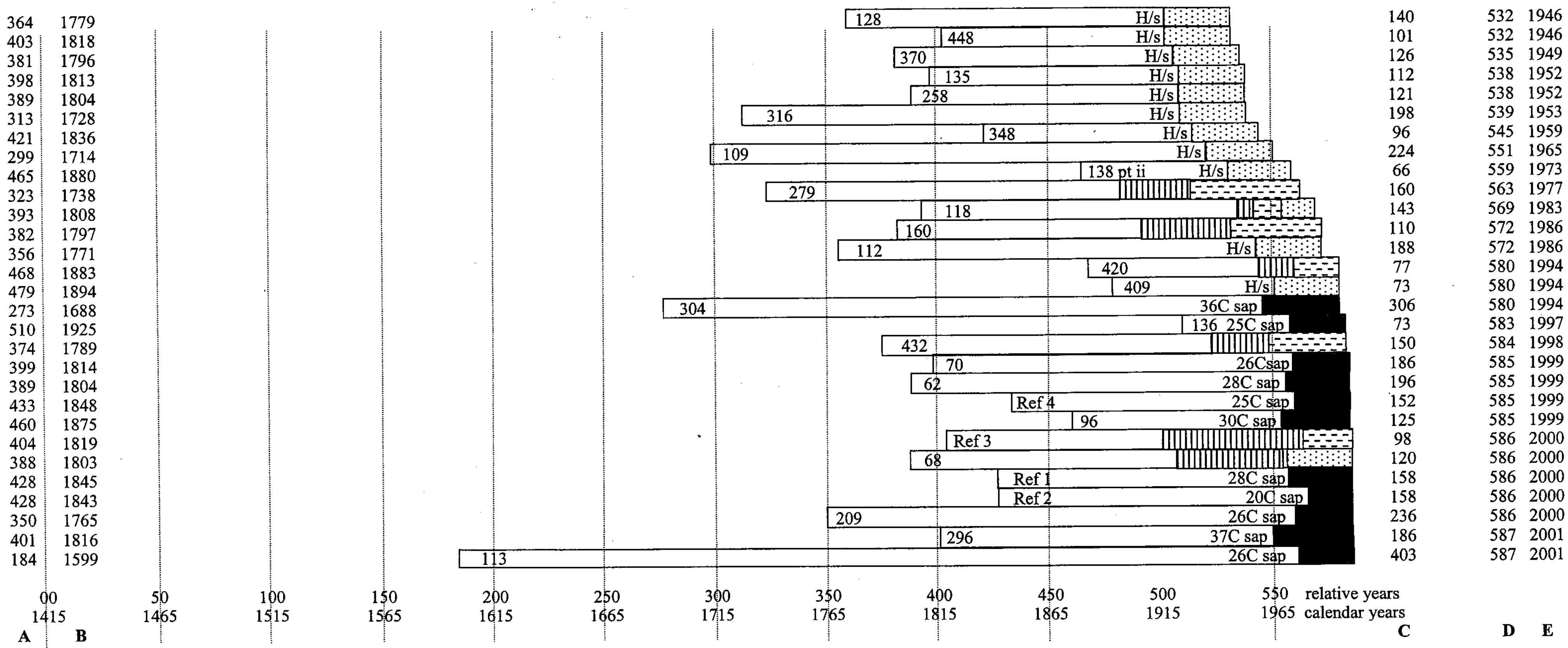
A This is the position of the first measured ring on the sample in relation to the earliest measured ring of any sample, 000, 1415, on sample 336.
B Date of first measured ring
C Number of *measured rings* on sample
D This is the position of the actual or estimated last growth ring of the tree where sapwood exists or is estimated, position relative to the earliest ring of all the samples, 000 1415 on sample 336. Where there is no sapwood or a heartwood/sapwood (H/s) boundary is not present, this is the relative position of the last measured ring date on the sample.
E Where sapwood exists, or is estimated, this is the date of the actual or estimated last growth-ring of the tree, ie, the death date. Otherwise, where sapwood, or the heartwood/sapwood (H/s) boundary, is not present, this is the date of the last measured ring on the sample.

= Measured heartwood rings
= Measured sapwood rings. C indicates that the sapwood is complete to the bark
= Estimated unmeasured sapwood rings where sapwood exists but where the rings are difficult to measure precisely
= Given sapwood element (using average figure of 28 rings), where there is no sapwood remaining, but the heartwood/sapwood boundary is present on the sample
= Estimated unmeasured heartwood rings

Bar diagram of cross-matched and dated samples, Buck Gates ancient oaks
25 4 02



A	B	C	D	E
128	1543	108	236	1650
213	1628	59	272	1686
208	1623	129	337	1751
226	1641	141	367	1781
330	1745	60	390	1804
316	1731	83	399	1813
354	1769	63	417	1831
310	1725	112	422	1836
359	1774	63	422	1836
331	1746	92	423	1837
335	1750	103	438	1852
297	1712	144	441	1855
372	1787	70	442	1856
372	1787	71	443	1857
303	1718	146	449	1863
361	1776	88	449	1863
394	1809	56	450	1864
363	1778	94	457	1871
340	1755	119	459	1873
342	1757	117	459	1873
310	1725	156	466	1880
392	1807	83	475	1889
417	1832	62	479	1893
381	1796	72	483	1897
387	1802	96	483	1897
401	1816	84	485	1899
405	1820	84	489	1903
210	1625	283	493	1907
221	1636	251	500	1914
276	1691	202	506	1920
195	1610	283	506	1920
332	1747	150	510	1924
289	1704	190	514	1928
246	1661	241	515	1929
000	1415	489	517	1931
374	1789	100	522	1936
274	1689	220	522	1936
365	1780	129	522	1936
306	1721	151	525	1939
351	1766	148	527	1941
380	1795	120	528	1942
160	1575	343	531	1945



364 1779 128 H/s 140 532 1946
403 1818 448 H/s 101 532 1946
381 1796 370 H/s 126 535 1949
398 1813 135 H/s 112 538 1952
389 1804 258 H/s 121 538 1952
313 1728 316 H/s 198 539 1953
421 1836 348 H/s 96 545 1959
299 1714 109 H/s 224 551 1965
465 1880 138 pt ii H/s 66 559 1973
323 1738 279 160 563 1977
393 1808 118 143 569 1983
382 1797 160 110 572 1986
356 1771 112 H/s 188 572 1986
468 1883 420 77 580 1994
479 1894 409 H/s 73 580 1994
273 1688 304 36C sap 306 580 1994
510 1925 136 25C sap 73 583 1997
374 1789 432 150 584 1998
399 1814 70 26Csap 186 585 1999
389 1804 62 28C sap 196 585 1999
433 1848 Ref 4 25C sap 152 585 1999
460 1875 96 30C sap 125 585 1999
404 1819 Ref 3 98 586 2000
388 1803 68 120 586 2000
428 1845 Ref 1 28C sap 158 586 2000
428 1843 Ref 2 20C sap 158 586 2000
350 1765 209 26C sap 236 586 2000
401 1816 296 37C sap 186 587 2001
184 1599 113 26C sap 403 587 2001
00 50 100 150 200 250 300 350 400 450 500 550 relative years
1415 1465 1515 1565 1615 1665 1715 1765 1815 1865 1915 1965 calendar years
A B C D E

Ring widths, tree 336 (two slices)

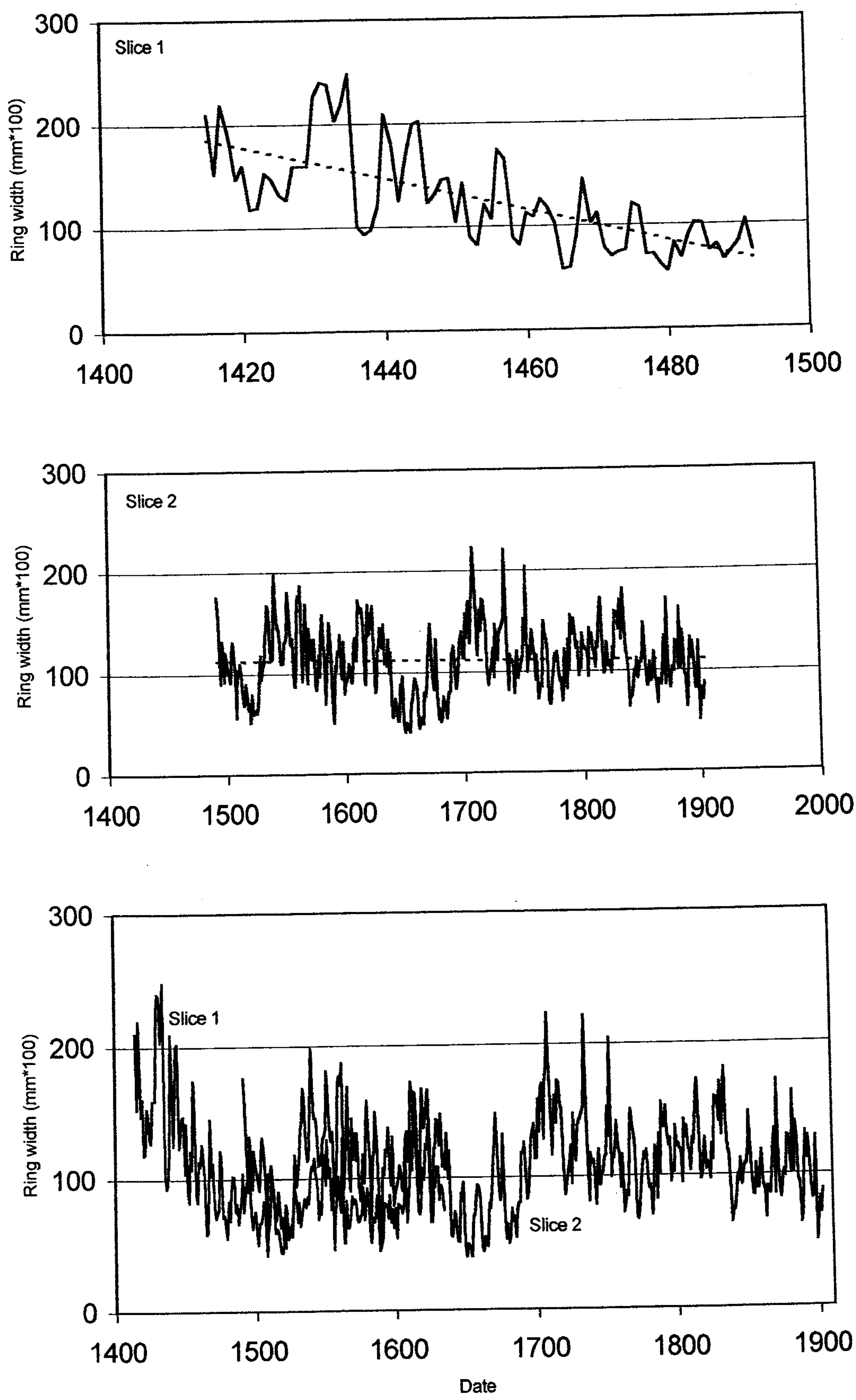


Figure 4

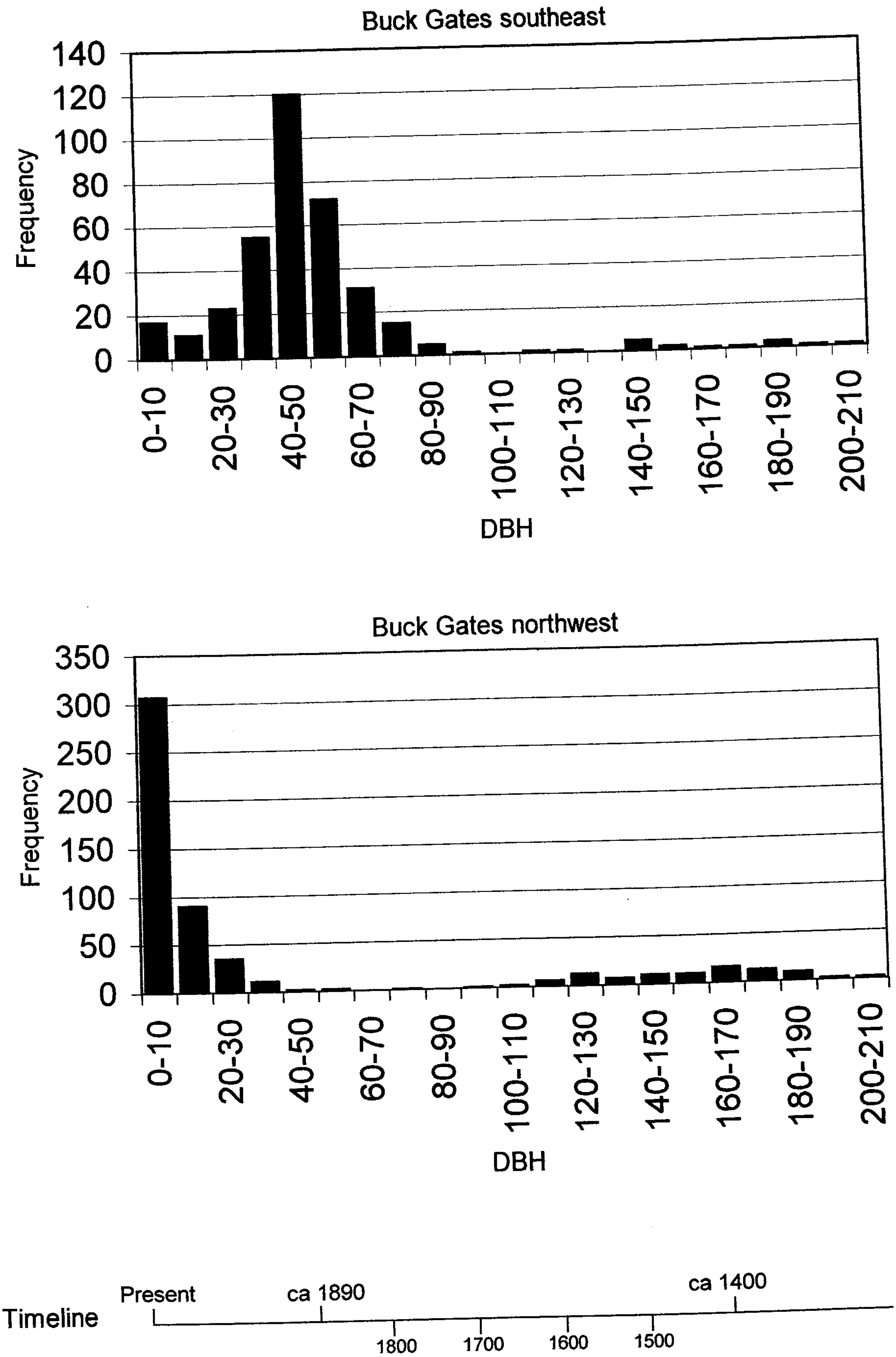

Buck Gates southeast
Frequency
0
20
40
60
80
100
120
140
0-10
20-30
40-50
60-70
80-90
100-110
120-130
140-150
160-170
180-190
200-210
DBH
Buck Gates northwest
Frequency
0
50
100
150
200
250
300
350
0-10
20-30
40-50
60-70
80-90
100-110
120-130
140-150
160-170
180-190
200-210
DBH
Timeline
Present
ca 1890
ca 1400
1800
1700
1600
1500

Figure 5

Sherwood Veteran Tree samples

Table 1

All samples showing number of measured heartwood and sapwood rings, estimated number of unmeasured heartwood and sapwood rings, plus actual or estimated last growth date of tree, ie death date

Tree No.	Estimated unmeasured central rings	*Relative start position	First measured ring date	Number of measured rings	*Relative end position	Last measured ring date	Estimated unmeasured outer rings	Sapwood rings	Estimated last growth date
Ref 1	00	428	1845	158	586	2000	00	28	2000
Ref 2	00	428	1843	158	586	2000	00	20	2000
Ref 3	00	404	1819	98	502	1916	84	20	2000
Ref 4	00	433	1848	152	585	1999	00	25	1999
51	00	---	---	90	---	undated	00	---	----
52 (pt 1)	00	316	1731	83	399	1813	00	---	----
52 (pt 2)	00	405	1820	84	489	1903	00	---	----
56	00	310	1725	112	422	1836	00	35	1836
57	Short core, too few rings		---	---	---	---	---	---	----
62	00	389	1804	196	585	1999	00	28	1999
65	Fragmentary sample		---	---	---	---	---	---	----
66	00	276	1691	202	478	1892	00	H/s	1920
68	00	388	1803	120	508	1922	60	H/s	2000
70	00	399	1814	186	585	1999	00	26	1999
75	Short core, too few rings		---	---	---	---	---	---	----
84	00	363	1778	94	457	1871	00	---	----
96	60 - 80	460	1875	125	585	1999	00	30	1999
99	00	372	1787	70	442	1856	00	---	----
100	00	---	---	67	---	undated	00	---	----
101	00	340	1755	119	459	1873	00	---	----

105	00	---	---	60	---	undated	40-50	30	----
109	00	299	1714	224	523	1937	00	H/s	1965
112	00	356	1771	188	544	1958	00	H/s	1986
113	00	184	1599	403	587	2001	00	26	2001
118	00	393	1808	143	536	1950	20	15	1983
122	Compacted rings		---	---	---	---	---	---	----
126	Compacted rings		---	---	---	---	---	---	----
128	00	364	1779	140	504	1918	00	H/s	1946
131	00	401	1816	84	485	1899	00	No h/s	----
135	00	398	1813	112	510	1924	00	H/s	1952
136	00	510	1925	73	583	1997	00	25	1997
137	00	361	1776	88	449	1863	00	No h/s	----
138 (pt 1)	00	289	1704	190	479	1893	30	No h/s	----
138 (pt 2)	00	465	1880	66	531	1945	00	H/s	1973
141	00	160	1575	343	503	1917	00	H/s	1945
160	00	382	1797	110	492	1906	80	40	1986
188	00	---	---	47	---	undated	00	---	----
193	00	306	1721	151	457	1871	40	H/s	1939
209	00	350	1765	236	586	2000	00	26	2000
210	20	365	1780	129	494	1908	00	H/s	1936
211	Fragmentary core		---	---	---	---	---	---	----
228	Fragmentary core		---	---	---	---	---	---	----
248	00	---	---	48	---	undated	00	---	----
258	00	389	1804	121	510	1924	00	H/s	1952
261	Fragmentary core		---	---	---	---	---	---	----
269	Short core, too few rings		---	---	---	---	00	---	----
279	00	323	1738	160	483	1897	80	50	1977
282	00	310	1725	156	466	1880	00	No h/s	----
287	Fragmentary core		---	---	---	---	---	---	----
288	Compacted rings		---	---	---	---	---	---	----
296	00	401	1816	186	587	2001	00	37	2001
301	00	359	1774	63	422	1836	00	No h/s	----

301	00	359	1774	63	422	1836	00	No h/s	----
302	00	221	1636	251	472	1886	00	H/s	1914
303	00	246	1661	241	487	1901	00	H/s	1929
304	00	273	1688	306	580	1994	00	36	1994
306	20	387	1802	96	483	1897	00	No h/s	----
312	Too few rings		---	---	---	---	---	---	----
316	00	313	1728	198	511	1925	00	H/s	1953
319 (pt 1)	00	297	1712	144	441	1855	00	No h/s	----
319 (pt 2)	10	374	1789	100	474	1888	20	H/s	1936
320	10	274	1689	220	494	1908	00	H/s	1936
324	Too few rings		---	---	---	---	---	---	----
326	00	380	1795	120	500	1914	00	H/s	1942
328	Fragmentary sample		---	---	---	---	---	---	----
329	Fragmentary sample		---	---	---	---	---	---	----
330	Fragmentary sample		---	---	---	---	---	---	----
333	00	226	1641	141	367	1781	00	No h/s	----
336	00	00	1415	489	489	1903	00	H/s	1931
337	Fragmentary core		---	---	---	---	---	---	----
342	00	210	1625	283	493	1907	00	No h/s	----
343	Compacted rings		---	---	---	---	---	---	----
346	Fragmentary sample		---	---	---	---	---	---	----
348	00	421	1836	96	517	1931	00	H/s	1959
349	00	---	---	40	---	undated	00	---	----
350	00	128	1543	108	236	1650	00	No h/s	----
358	00	335	1750	103	438	1852	00	No h/s	----
361	00	331	1746	92	423	1837	00	No h/s	----
369 (pt 1)	00	208	1623	129	337	1751	00	No h/s	----
369 (pt 2)	00	381	1796	72	483	1897	00	No h/s	----
370	00	381	1796	126	507	1921	00	H/s	1949
373	00	---	---	66	---	undated	00	---	----
377	00	---	---	43	---	undated	00	---	----
388	00	342	1757	117	459	1873	00	No h/s	----

389	00	---	---	48	---	undated	00	---	----
396	00	213	1628	59	272	1686	00	No h/s	----
401	00	392	1807	83	475	1889	00	No h/s	----
402	00	332	1747	150	482	1896	00	H/s	1924
406	Fragmentary sample		---	---	---	---	---	---	----
407	Fragmentary sample		---	---	---	---	---	---	----
409	00	479	1894	73	552	1966	00	H/s	1994
411	00	351	1766	148	499	1913	00	H/s	1941
418	00	195	1610	283	478	1892	00	H/s	1920
420	00	468	1883	77	545	1959	35	20	1994
422 (pt 1)	00	303	1718	146	449	1863	00	No h/s	----
422 (pt 2)	00	417	1832	62	479	1893	00	No h/s	----
423	00	354	1769	63	417	1831	inestimable	No h/s	----
432	50	374	1789	150	524	1938	60	35	1998
437	Fragmentary sample		---	---	---	---	---	---	----
438 (pt 1)	00	330	1745	60	390	1804	00	No h/s	----
438 (pt 2)	00	394	1809	56	450	1864	00	No h/s	----
442	00	372	1787	71	443	1857	00	No h/s	----
448	00	403	1818	101	504	1918	00	H/s	1946

*** Relative to earliest ring, relative 00, 1415, on sample 336**

1. This is the position of the first measured ring on the sample in relation to the earliest measured ring of all the sample, 000, 1415, on sample 336.
2. Date of first measured ring
3. Number of *measured rings* in sample
4. This is the position of the estimated or actual last growth ring of the tree where sapwood exists or is estimated, position relative to the earliest ring of all the samples, 000 1415 on sample 336. Where there is no sapwood or the heartwood/sapwood (H/s) boundary is not present, this is the relative position of the last measured ring date on the sample.
5. Where sapwood exists, or is estimated, this is the date of the actual or estimated last growth-ring of the tree, ie, the death date. Otherwise, where sapwood or the heartwood/sapwood (H/s) boundary is not present this is the date of the last measured ring on the sample.

Table 2 Tree status and dendrochronological results

Tree no.	Status	Form[1]	Branch order[2]	Core position[3]	First ring date	Last ring date	Estimated last growth date	Notes
Ref1	Alive	Standing	T	Bark	1845	2000	2000	Non-ancient tree
Ref2	Alive	Standing	T	Bark	1843	2000	2000	Non-ancient tree
Ref3	Alive	Standing	T	Bark	1819	1916	2000	Non-ancient tree
Ref4	Alive	Standing	T	Bark	1848	1999	1999	Non-ancient tree
51	Dead	Standing	0	Heartwood			No estimate	Does not date
52	Dead	Standing	2	Heartwood	1731	1903	No estimate	No heart/sap boundary
56	Alive	Standing	T	Bark	1725	1836	1836	
57	Alive	Standing	T	Bark			No estimate	Short core
62	Alive	Standing	T	Bark	1804	1999	1999	
65	Dead	Fallen whole	0	Heartwood			No estimate	Fragmented core
66	Alive	Standing	T	Heartwood	1691	1892	1920	
68	Alive	Standing	T	Bark	1803	1922	2000	
70	Alive	Standing	T	Bark	1814	1999	1999	
75	Alive	Standing	T	Bark			No estimate	Short core
84	Dead	Standing	1	Bark	1778	1871	No estimate	No heart/sap boundary
96	Alive	Standing	T	Bark	1875	1999	1999	
99	Dead	Standing	2	Heartwood	1787	1856	No estimate	No heart/sap boundary
100	Alive	Standing	T	Bark			No estimate	Does not date
101	Dead	Fallen whole	1	Heartwood	1755	1873	No estimate	No heart/sap boundary
105	Alive	Standing	T	Bark			No estimate	Does not date
109	Dead	Fallen boat	3	Heartwood	1714	1937	1965	
112	Dead	Standing	2	Heartwood	1771	1958	1986	
113	Alive	Standing	T	Bark	1599	2001	2001	
118	Dead	Fallen boat	2	Heartwood	1808	1950	1983	
122	Dead	Standing	2	Bark			No estimate	Compacted rings
126	Alive	Standing	T	Bark			No estimate	Compacted rings
128	Alive	Standing	T	Bark	1779	1918	1946	
131	Dead	Fallen whole	2	Heartwood	1816	1899	No estimate	No heart/sap boundary
135	Alive	Standing	T	Bark	1813	1924	1952	
136	Alive	Standing	T	Bark	1925	1997	1997	
137	Dead	Fallen boat	1	Heartwood	1776	1863	No estimate	No heart/sap boundary
138	Alive	Standing	T	Bark	1704	1945	1973	
141	Dead	Standing	2	Bark	1575	1917	1945	
160	Alive	Standing	T	Bark	1797	1906	1986	
188	Alive	Standing	T	Bark			No estimate	Does not date
193	Alive	Standing	T	Heartwood	1721	1871	1939	
209	Alive	Standing	T	Bark	1765	2000	2000	
210	Dead	Standing	1	Heartwood	1780	1908	1936	
211	Alive	Standing	T	Bark			No estimate	Fragmented core
228	Alive	Standing	T	Bark			No estimate	Fragmented core
248	Dead	Standing	3	Heartwood			No estimate	Does not date
258	Dead	Standing	2	Heartwood	1804	1924	1952	
261	Dead	Fallen boat	0	Heartwood			No estimate	Fragmented core
269	Dead	Standing	2	Heartwood			No estimate	Short core
279	Alive	Standing	T	Bark	1738	1897	1977	
282	Dead	Standing	2	Heartwood	1725	1880	No estimate	No heart/sap boundary
287	Dead	Fallen boat	0	Heartwood			No estimate	Fragmented core
288	Alive	Standing	T	Bark			No estimate	Compacted rings
296	Alive	Standing	T	Bark	1816	2001	2001	
301	Dead	Fallen boat	0	Heartwood	1774	1836	No estimate	No heart/sap boundary
302	Dead	Standing	1	Heartwood	1636	1886	1914	

303	Alive	Standing	T	Bark	1661	1901	1929	
304	Alive	Standing	T	Bark	1688	1994	1994	
306	Dead	Standing	2	Heartwood	1802	1897	No estimate	No heart/sap boundary
312	Dead	Standing	1	Heartwood			No estimate	Short core
316	Dead	Standing	5	Bark	1728	1925	1953	
319	Dead	Standing	2	Bark	1712	1888	1936	
320	Alive	Standing	T	Bark	1689	1908	1936	
324	Alive	Standing	T	Heartwood			No estimate	Short core
326	Alive	Standing	T	Heartwood	1795	1914	1942	
328	Dead	Stump	0	Heartwood			No estimate	Fragmented core
329	Dead	Stump	1	Heartwood			No estimate	Fragmented core
330	Dead	Fallen boat	0	Heartwood			No estimate	Fragmented core
333	Dead	Standing	1	Heartwood	1641	1781	No estimate	No heart/sap boundary
336	Dead	Fallen whole	0	Heartwood	1415	1903	1931	
337	Dead	Standing	0	Heartwood			No estimate	Fragmented core
342	Alive	Standing	T	Bark	1625	1907	No estimate	No heart/sap boundary
343	Dead	Fallen whole	2	Heartwood			No estimate	Compacted rings
346	Dead	Standing	2	Heartwood			No estimate	Fragmented core
348	Dead	Standing	2	Heartwood	1836	1931	1959	
349	Dead	Fallen whole	1	Heartwood			No estimate	Does not date
350	Dead	Stump	0	Heartwood	1543	1650	No estimate	No heart/sap boundary
358	Dead	Fallen boat	1	Heartwood	1750	1852	No estimate	No heart/sap boundary
361	Dead	Fallen whole	2	Heartwood	1746	1837	No estimate	No heart/sap boundary
369	Dead	Standing	1	Heartwood	1623	1897	No estimate	No heart/sap boundary
370	Dead	Standing	3	Bark	1796	1921	1949	
373	Dead	Standing	2	Heartwood			No estimate	Does not date
377	Dead	Stump	0	Heartwood			No estimate	Does not date
388	Dead	Fallen boat	0	Heartwood	1757	1873	No estimate	No heart/sap boundary
389	Dead	Stump	0	Heartwood			No estimate	Does not date
396	Dead	Fallen whole	1	Heartwood	1628	1686	No estimate	No heart/sap boundary
401	Dead	Fallen whole	0	Heartwood	1807	1889	No estimate	No heart/sap boundary
402	Dead	Fallen boat	1	Heartwood	1747	1896	1924	
406	Dead	Stump	0	Heartwood			No estimate	Fragmented core
407	Dead	Fallen boat	1	Heartwood			No estimate	Fragmented core
409	Dead	Standing	2	Bark	1894	1966	1994	
411	Dead	Stump	0	Heartwood	1766	1913	1941	
418	Dead	Stump	0	Heartwood	1610	1892	1920	
420	Alive	Standing	T	Bark	1883	1959	1994	
422	Dead	Fallen whole	0	Heartwood	1718	1893	No estimate	No heart/sap boundary
423	Alive	Standing	T	Bark	1769	1831	No estimate	No heart/sap boundary
432	Alive	Standing	T	Bark	1789	1938	1998	
437	Dead	Fallen boat	0	Heartwood			No estimate	Fragmented core
438	Dead	Standing	0	Heartwood	1745	1864	No estimate	No heart/sap boundary
442	Dead	Standing	1	Heartwood	1787	1857	No estimate	No heart/sap boundary
448	Dead	Fallen boat	0	Heartwood	1818	1918	1946	

[1]'Fallen boat', as opposed to 'fallen whole', indicates a hollow, prone trunk with its upper portion rotted away.
[2]T=twigs present; 1=first order branches only present; 2=first and second-order branches present; etc.
[3]Whether core was taken through bark or straight into heartwood.

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