Firewood and timber collection and management strategies from early medieval sites in eastern england. Initial results from the anthraco-typological analysis of oak charcoal remains

Robert Francis, Alexa Dufraisse

Journal Pre-proof

Firewood and timber collection and management strategies from early medieval sites in eastern england. Initial results from the anthraco-typological analysis of oak charcoal remains

Robert Francis, Alexa Dufraisse

PII: S1040-6182(20)30716-3

DOI: https://doi.org/10.1016/j.quaint.2020.10.070

Reference: JQI 8615

To appear in: *Quaternary International*

Received Date: 31 July 2020

Revised Date: 22 October 2020

Accepted Date: 27 October 2020

Please cite this article as: Francis, R., Dufraisse, A., Firewood and timber collection and management strategies from early medieval sites in eastern england. Initial results from the anthraco-typological analysis of oak charcoal remains, *Quaternary International* (2020), doi: https://doi.org/10.1016/j.quaint.2020.10.070.

Firewood and timber collection and management strategies from early medieval sites in eastern England. Initial results from the anthraco-typological analysis of oak charcoal remains

Robert Francis [a], Alexa Dufraisse [b]

a Department of Classics and Archaeology, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

b UMR 7209, Archeozoologie, Archeobotanique: societes, pratiques et environnements CNRS, Museum national d'Histoire naturelle, , CP56, 55 rue Buffon, 75005 Paris, France

Abstract

The study of charcoal from archaeological sites often focuses on merely the identification of taxa. However, the anthraco-typological analysis of oak charcoal offers extensive evidence about the wood diameter, growth pattern, and minimum age of the trees selected for harvest. This in turn gives valuable data on palaeoecology and woodland management. This review focuses on early stage results from oak charcoal remains from three early medieval rural sites in eastern England, dating from the 5th to the 9th century AD. Over 200 fragments of oak charcoal were selected and examined to identify the size class of the wood, the growth patterns and whether the wood was sapwood or heartwood. This has then given evidence of timber and fuel wood collection strategies and woodland management regimes. The data has provided additional evidence on the nature of the sites' features. Furthermore, the analysis has allowed comparisons to be drawn between the three contemporary sites, as well as to expand the archaeobotanical record to a more detailed understanding of the environment around these settlements. Exceptional material from the early medieval site of Flixborough has allowed a unique insight into the selection of timber and possible long-term woodland management strategies undertaken in the area during the mid 8th to 9th century AD. The results will be discussed regarding the economic and environmental context, demonstrating the value of dendro-anthracological tools in adding additional detail and a new understanding of these sites.

KEY WORDS: Wood Charcoal, Wood Diameter, Radial Growth, Sapwood/Heartwood, Dendro-anthracology

1. Introduction

Woodlands are not a static feature of the landscape. They have always been considered a commodity and exploited according to the needs of the community. Changes in the needs of the population due to various factors such as demographic pressures may cause the management strategies to change, for example from managed harvesting to the clearing of ground for arable land (Haneca et al*.,* 2009). By the early medieval period Britain is described as having lost most, if not all, of its wild wood, with most of the cultivatable land being given over to agriculture and the remaining land being heath and moorland (Rackham, 1994). Woodland usually represents managed naturally grown trees clustered in 'islands' amongst farmland. The term forest is not used in this article so as to avoid confusion with the medieval use of the term 'Forest'; a place for keeping and hunting deer (Rackham 2006: 24-27). During the early medieval period there were areas of Britain which had little or no woodland (Hooke, 2010: 120). By the end of this period the Domesday book records the county of Lincolnshire (the county in which Flixborough is situated) as only having 4% of its area covered by woodland and Northamptonshire (the county in which Dando Close and Higham Ferrers are situated) as having 8.8% of its area covered by woodland (Rackham, 1995: 54).

Palynology and anthracology are common proxies used to reconstruct woodland environments (Haneca, 2005). Evidence for the state of Britain's woodlands during the early medieval period is heavily reliant on pollen evidence. Although post Roman abandonment of managed woodlands and the reforesting of cultivated areas has often been suggested, the pollen evidence only supports this for some areas in the north west and north of England between AD 400-800 (Dark, 2000:156) and (Huntley, 2010:31). This in turn highlights the problem with relying on pollen evidence as most sites are primarily located either in the western and northern edges of Britain, or in the southeast (Gearey and Richer, 2017). The sites under analysis here are situated in the East of Britain and do not have relative pollen data.

Alternatively, anthracological analysis of assemblages can provide an assessment of the wood harvested for domestic and industrial purposes. The analysis of charcoal differs from a pollen reconstruction as it is normally a result of human interaction with the environment during the period under investigation and therefore represents the past vegetation and how the inhabitants interacted with it (Asouti and Austin, 2005). Unfortunately, the number of anthracological assessments from the early medieval period in Britain is scarce in comparison to the preceding Roman period (Smith 2002, Murphy et al., 2001 and Huntley, 2010). Assessments that include interpretations relating to the age, size, and possible woodland management strategies are particularly limited. There are however examples of evidence of wood selection recorded and interpreted by anthracologists. Robinson's (1997) analysis at Clacket Lane, Surrey, concluded that mature slow growing oak branch wood (identified by the presence of tyloses) was being selected for pottery furnaces. Another example is the Saxon pottery kiln at Michelmersh, Hampshire where Gale (2007) identifies the maturity of oak wood by assessing the presence of heartwood versus sapwood and stem diameters. Hall and Kenward (2004: 412) discuss the local woodland management around medieval York by interpreting the number of growth rings present in willow and hazel rods recovered from urban deposits. These three examples rely on the presence of round wood to identify age as well as the presence of tyloses to indicate heartwood in oak.

More recent studies have seen the adoption of anthracological approaches from continental Europe. Crew and Mighall's (2013) assessment of a medieval bloomery in Snowdonia calculates the estimated diameter of the charcoal fragments following Nelle's (2002) and Ludemann's (2008) diameter stencil method. This has allowed them to interpret the woodland management strategies at the site. Additionally, the study by Hazel et al. (2017) of charcoal from the post-medieval charcoal burning platforms at Barbon, Cumbria, uses an array of measurements based on methodology set out by Marguerie and Hunot (2007), including the number of growth rings, a qualitive assessment of the ring curvature, the presence of pith, bark, reaction wood, tyloses, degradation, radial fractures and vitrification level.

As of yet no study in Britain has used a quantitative combination approach following those set out in this article, making this initial study unique in Britain.

Oak is a preferred timber tree because of its durability and mechanical properties and can be found in the construction of castles, cathedrals as well as domestic buildings (Haneca et al., 2009). Oak also responds well to coppice and pollarding (Rackham, 1995: 8). The ubiquitous presence of oak charcoal in archaeological assemblages from the early medieval period, (Smith, 2002, Murphy et al., 2001 and Huntley, 2010) make it the ideal genus for dendro-anthracological analysis. This research represents the innovative application of dendro-anthracological tools to archaeological assemblages rich in oak charcoal. For the first time this methodology has been applied to three sites in early medieval eastern England.

The objectives of the dendro-anthracological analysis were to:

(i) identify wood collection strategies, including the tree's estimated minimum diameter and what parts of the tree were being exploited.

(ii) identify the growth rate and potential age range of the trees being harvested.

(iii) inter-site and temporal comparisons of the size, growth rate and what part of the trees were being used.

(iv) identify evidence of possible woodland management or climatic and environmental impacts on the growth of the trees.

2. Regional setting

Charcoal from samples not previously examined were chosen from three early medieval sites in eastern England (Fig. 1). The sites of Dando Close, and Higham Ferrers are in the county of Northamptonshire, and the site of Flixborough is in Lincolnshire, England.

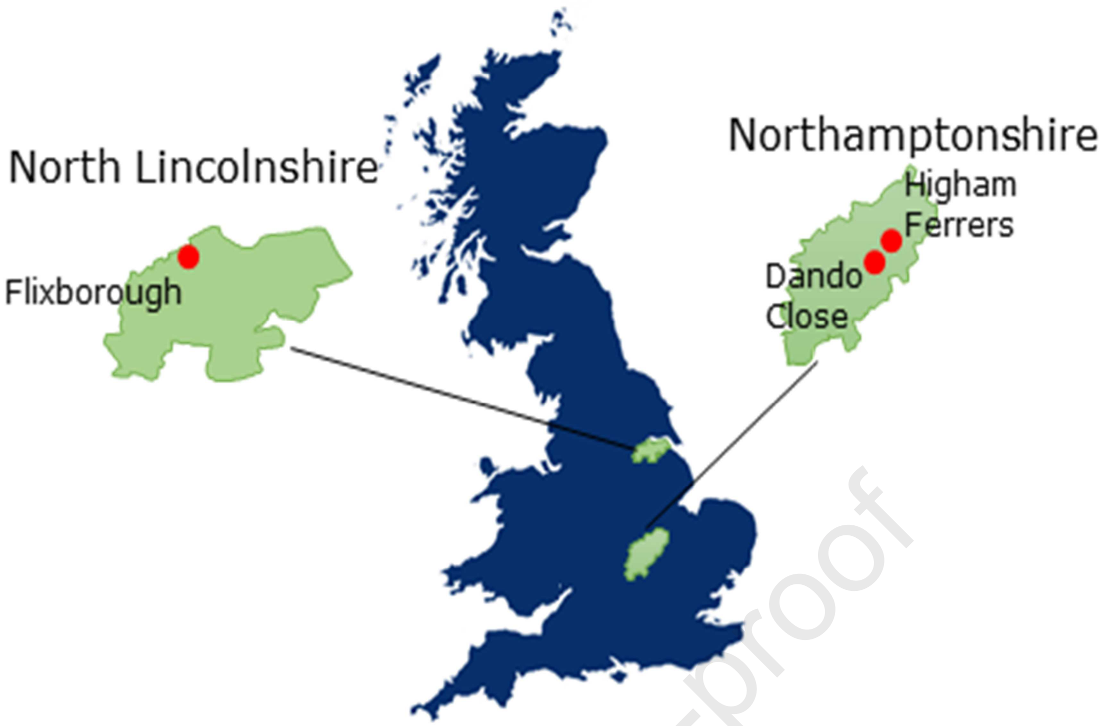


Fig. 1. Location of the three study sites.

The site of Dando Close is situated in the village of Wollaston on a ridge of limestone overlooking the alluvial plain of the Nene Valley, 5 km east of the River Nene (British Geological Survey, 2020). The area has a temperate oceanic climate with an average rainfall of between 500 and 750 mm annually. The average summer temperature is between 14.8 and 15.8 $^{\circ}$C and the average winter temperature is between 3.8 and 4.2 $^{\circ}$C. (Met Office, 2020). Approximately 5.2% of the county is covered in woodland (compared to 10% nationally). 57% of this is broadleaved and 43% is coniferous or mixed scrubland species (Northamptonshire County Council 2020). The village of Wollaston has limited woodland with 3.35 hectares of small plots of broadleaved woodlands within 2 km of the site (Forestry Commission 2020).

Heritage Network Ltd undertook the excavations at Dando Close, between 2000 and 2002. The excavation revealed an early medieval settlement with remains dating from the 5th to the 14th centuries AD (Semmelmann and Ashworth 2003: 2). The contexts sampled included, fills of post-holes, fills of an oven, fills of sunken feature buildings, and fills of hearths.

The site of Higham Ferrers is situated in the town of the same name on a ridge of limestone on the eastern bank of the River Nene. The surrounding occupation area includes alluvial plains and a Boulder Clay plateau (British Geological Survey). The area has a temperate oceanic climate with an average rainfall of between 500 and 750 mm annually. The average summer temperature is between 14.8 and 15.8 $^{\circ}$C and the average winter temperature is between 3.8 and 4.2 $^{\circ}$C. (Met Office, 2020). The town of Higham Ferrers has limited woodland with 9.72 hectares of small plots of broadleaved woodlands within 2 km of the site, most of which is situated in the nearby Nene Valley (Forestry Commission 2020).

The Oxford Archaeological Unit excavated the site between 1993 and 2003 (Hardy et al., 2007). The excavation uncovered a rural settlement with continuous occupation from the Roman to the medieval period, including a large 8th century AD enclosure and associated buildings. Sampled contexts included the fill of pits, the fill of sunken feature buildings and residues from a malting oven.

The site of Flixborough, North Lincolnshire is situated on a series of windblown sand spurs 8 km south of the Humber estuary. The site overlooks the floodplain of the River Trent (Loveluck, 2007: 3). The area has a temperate oceanic climate with an average rainfall of between 560 and 660mm annually. The average summer temperature is between 14.8 and 15.8 $^{\circ}$C and the average winter temperature is between 3.8 and 4.2 $^{\circ}$C (Met Office, 2020). Just over 4% of Lincolnshire is covered by woodland, making it one of the least wooded counties in Britain. 57.5% of this is broadleaved and 42.5% is coniferous or mixed scrubland species (Collop, 2011). The area around the village has approximately 55.21 hectares of mainly broadleaved woodland within 2 km of the site (Forestry Commission, 2020).

The excavation was conducted by Humberside Archaeology Unit between 1989 and 1991 and funded on behalf of English Heritage. The excavation uncovered the remains of an early medieval settlement, including over thirty buildings dating from the early 7th to the mid 14th centuries AD. Also uncovered were well preserved refuse deposits containing large quantities of artefacts, faunal remains and charcoal, sealed by windblown sand (Loveluck, 2007: 8). The charcoal remains from the site were exceptionally well preserved with many large fragments, some of which show carpenter tool marks (Loveluck and Darrah 2007: 57).

This study focuses on the early medieval period between the 5th and 10th centuries. (Fig. 2). Dating for the sites was based on stratigraphic, artefactual and scientific dating where possible (Hardy et al., 2007: 13, Semmelmann and Ashworth, 2003: 29), and (Loveluck, 2007: 8-30).

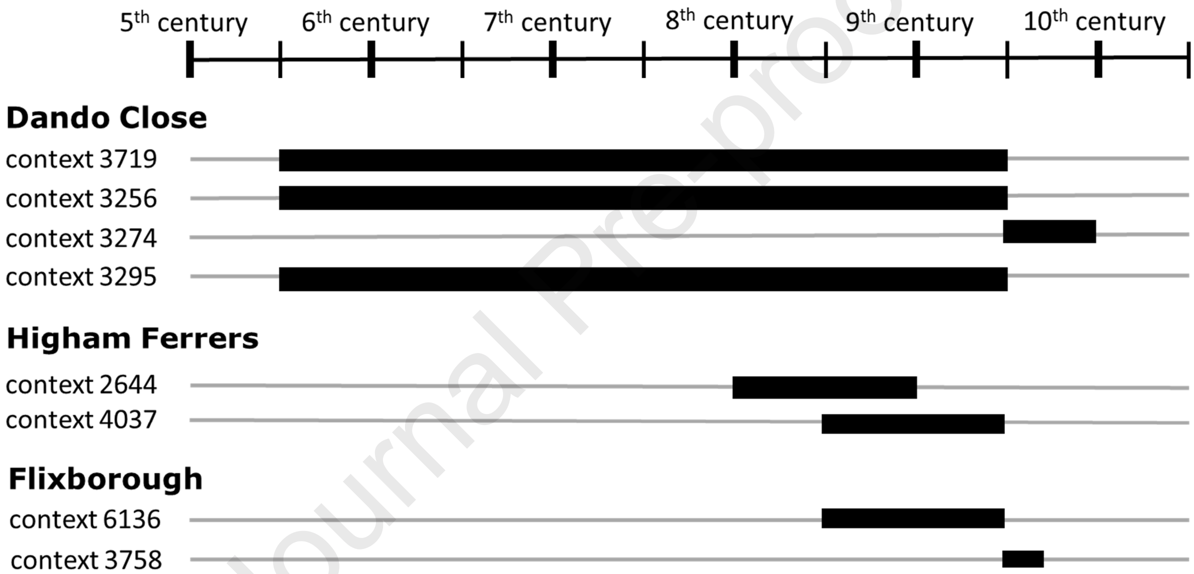


Fig. 2. Chronology for the samples analysed.

3. Material and methods

3.1. Material

Sample selection was based on three criteria. Firstly, the date of the samples were selected to be similar across the three sites. This would allow comparisons to be drawn between the sites. Secondly, samples were selected from contexts of interest, such as domestic refuse deposits and specialised structures, like that of the malting oven at Higham Ferrers. This criteria allowed short and long term deposits to be sampled, with long term deposits likely to give information on the diversity of the vegetation and short term deposits more likely to represent specific composition of the last firing event (Chabal et al., 1999: 61). Finally, samples with an abundance of large oak fragments were selected. This would optimise the chances of enough suitable fragments being available for dendro-anthracological assessment.

3.1.1. Dando Close

A bulk sampling strategy was adopted for the site whereby all dateable features were sampled. As a result, 714 bulk samples were taken for analysis. The bulk samples were sent to Environmental Archaeology Consultancy to be processed using a Siraf flotation tank fitted with a 0.5 mm sieve to collect the light fraction and a 1 mm mesh to collect the heavy residue. Once the flots were dry the heavy residue was refloated to create a second light fraction allowing for the recovery of additional charred material that could have been potentially still trapped in the sediment.

Environmental Archaeology Consultancy loaned 41 unanalysed light fraction samples for the author's PhD research project. Of these, four samples were selected for this dendro-anthracology study.

The sample from context 3295 (mid 5th to mid 9th century AD) comes from the fill of a post hole from a sunken feature building.

The sample from context 3256 (mid 5th to mid 9th century AD) comes from a post hole not associated with any buildings containing a large amount of charcoal consisting nearly exclusively of oak.

The sample from context 3719 (mid 5th to mid 9th century AD) comes from a hearth containing a large amount of oak charcoal.

The sample from context 3274 (mid 9th to 10th century AD) comes from the fill of a post-hole believed to be from a burnt down grain store due to the large amount of grain found in the post holes. It was postulated that the grain relates to a single burning incident (Rackham, 2003).

3.1.2. Higham Ferrers

Oxford Archaeology undertook the environmental sample processing at Higham Ferrers. Bulk samples were taken at the discretion of the excavator and in consultation with the archaeobotanist. Occupation material, as well as context deemed of interest were sampled. 94 samples in total were collected. 42 samples were processed by Siraf flotation using a 0.25 mm sieve to collect the light fraction and a 1 mm mesh to collect the heavy residue. The Oxford

Archaeological Unit loaned five unanalysed charcoal samples from the published site of Higham Ferrers, two of which were selected for this study.

The sample from context 2644 (early to late 8th century AD) comes from the fill of a post-pipe located in a dwelling. The material is believed to be domestic in origin or from grain processing.

The sample from context 4037 (late 8th to early 9th century AD) comes from the bottom of a flue in a stone built malting oven. The botanical remains were rich in barley, a proportion of which showed signs of sprouting (Moffett, 2007).

3.1.3. Flixborough

Humberside Archaeology Unit undertook the environmental sampling at Flixborough. 560 samples and sub-samples from 386 contexts were taken. Due to the exceptional preservation of the charcoal in the refuse deposits, it was collected on site as spot finds to avoid mechanical damage (Hall, 2000). The North Lincolnshire Museum archive loaned nine samples of hand-collected charcoal from excavated contexts of which two were selected for this study.

The sample from context 6136 (mid 8th to early 9th century AD) and the sample from context 3758 (mid 9th century AD) both come from large waste dumps in a shallow valley. The contents of which are believed to be the result of rebuilding or the demolition of structures on the site.

3.2. Methods

3.2.1. Anthracology method

The anthracological analysis of the charcoal followed Chabal et al. (1999: 66-67) recommendations, that to recover the full range of taxa in an assemblage it is necessary to establish a fragment/taxa curve until a plateau is reached.

For each sample a minimum of 100 fragments were analysed. The charcoal was graded into >4 mm and 2-4 mm fractions and all fragments were then analysed. Fragments were fractured following standard methods of preparation (Leney and Casteel, 1975). The fragments were fractured so as the transverse section could be observed using a low power stereomicroscope at x10-40 magnification, allowing the growth rings to be examined and counted. The fragments were then fractured in all three sections (transverse, tangential longitudinal and radial longitudinal) and observed using an epi-illuminating microscope at magnifications of x100-500, so as the key features could be recorded. The anatomy of the fragment was then compared with published sources (Hather, 2000; Schweingruber, 1982) and with the modern charcoal sample from a reference collection available at the Department of Classics and Archaeology of the University of Nottingham. Identification to genus level was usually possible, however trees and shrubs belonging to the apple subfamily (Maloideae) including hawthorn (*Crataegus*), apple (*Malus*), pear (*Pyrus*) and mountain ash/service (*Sorbus*) are notoriously difficult to identify to genus and therefore were labelled as Maloideae. It is often difficult to distinguish between willow (*Salix* sp.) from popular (*Populus* sp.) based on their wood anatomy. The distinguishing feature used here are the predominance of heterogeneous rays visible in the radial section of willow. Popular has a predominance of homogeneous rays. Where the rays were not visible or there was not a predominance of either heterogeneous or homogeneous rays the label of popular/willow was given to the fragment (Hather 2000: 111). Oak fragments were identified as *Quercus* dec. (deciduous oak) as anatomically the two species of common deciduous oak pedunculate (*Quercus robur* L.) and sessile oak (*Quercus petraea* (Matt.) Liebl.) cannot be differentiated based on their wood anatomy. Charcoal fragments of oak that had a 2 mm or greater transverse cross section and at least one entire growth ring including both boundaries were separated for further dendro-anthracological analysis.

3.2.2. Dendro-anthracological method

Oak provides clearly identifiable anatomy, such as growth rings and ligneous rays which facilitate measurements as well as the ability to identify the lignification process where heartwood is created. Fragments of oak charcoal were observed using a Nikon AZ100 multizoom microscope with magnification factors of x4 to x500 and NIS Element image analysis software based at the UMR 7209 (MNHN/CNRS, Paris) according to the protocol defined by Dufraisse et al. (2018a).

At its core, dendro-anthracology aims by means of several different tools to identify where in the tree the fragment of charcoal originated in respect of the centre of the stem, thus allowing the growth rate and the diameter of wood harvested to be calculated (Dufraisse et al., 2018a). Firstly, the fragment is assessed as to whether it shows the presence of sapwood or heartwood, this is achieved by calculating the ratio of tyloses filled vessels versus empty vessels. Up to 50 vessels spread over 3-4 rings are counted. If over 85% of the vessels have tyloses, the fragment is considered to be heartwood. Those fragments where less than 65% of the vessels have tyloses are recorded as sapwood. This measurement estimates the minimum age range of the wood, as heartwood generally forms in oak wood after 20 to 25 years (Dufraisse et al. 2018b). Secondly, the pith estimation tool. This calculates an estimated minimum radius for the charcoal fragment being studied. This is done by measuring the radius of the fragment from the outermost complete growth ring using a trigonometric tool to measure the angle and the distance between two ligneous rays (Dufraisse et al., 2020). The measurement is repeated five times and the average is calculated after removing the two extreme values. The radius value then gives a projected diameter (radius x2) and is grouped in diameter classes according to Dufraisse et al*.* (2018a) 0-2 cm, 2-4 cm, 4-7 cm, 7-10 cm 10-20 cm, and >20 cm. Finally, the growth rings of each fragment are measured to the nearest 0.01 mm and the average calculated for the fragment. A threshold of 1.5 mm is used to differentiate narrow from wide rings. Additionally, the growth pattern of fragments with multiple rings was recorded. The measured width for the growth ring has a correction of an additional 20% applied to compensate for the shrinkage effect while being transformed from wood to charcoal. This is based on experimental work carried out by Paradis-Grenouillet and Dufraisse (2018) where oak wood underwent carbonization (heating without oxygen as described by Braadbaart and Poole (2008)) and the reduction in size was measured. The combination of these parameters makes it possible to arrange each fragment into 8 anthraco-groups (Fig. 3). The first division separates the fragments into less or greater than 7 cm diameter and relates to the limit between branches and trunks in deciduous oak woodlands. The next division combines specific threshold values between sapwood and heartwood and narrow and large rings (Dufraisse et al., 2018a).

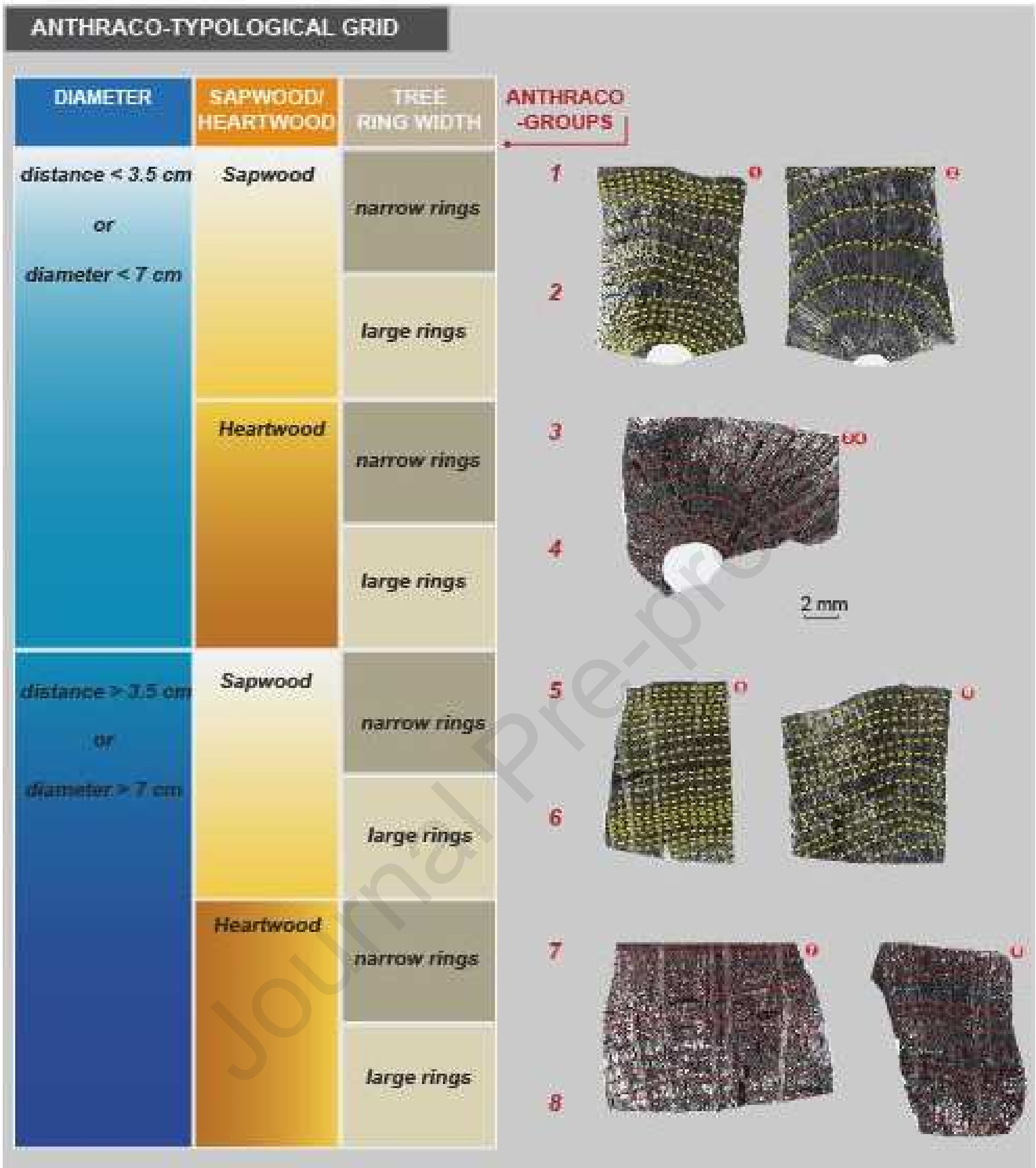


Fig. 3. Anthraco-typological grid, from Dufraisse et al., 2018a

4. Results

4.1. Anthracological results

Eight samples from the three research sites were analysed (Fig. 4). 1160 fragments were identified. The presence of eight taxa were recorded, those of oak (*Quercus* dec.), ash (*Fraxinus* excelsior), hazel (*Corylus avellana*), field maple (*Acer campestre*), birch (*Betula* sp.), alder (*Alnus glutinosa*), willow (*Salix* sp.) popular/willow (*Populus/Salix* sp.) and Maloideae. All the samples contained a majority of oak fragments ranging from 60% to 100% with the next most abundant taxa being hazel and ash. These findings are comparable with the diversity of species already identified from Higham Ferrers (Thompson and Francis, 2007), Flixborough (Hall, 2000) and from the samples analysed by the author from Dando Close (Francis, unpublished).

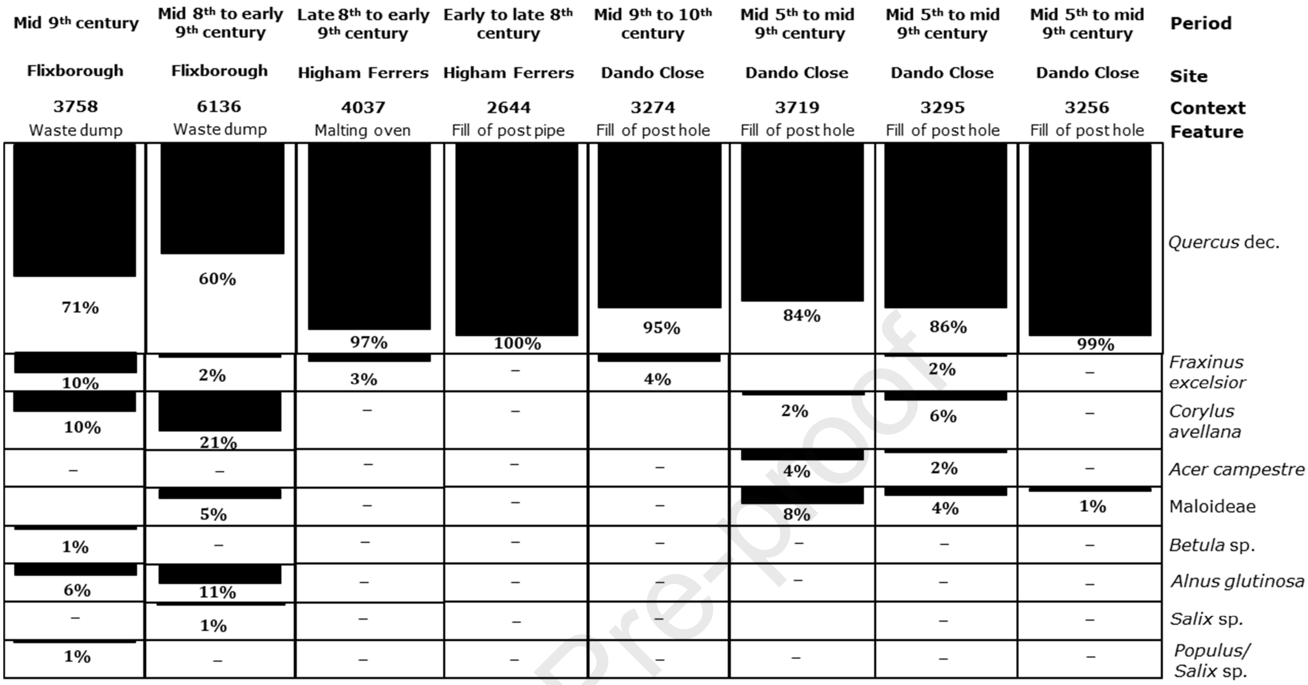


Fig. 4. Anthracological results from the sites of Dando Close, Higham Ferrers and Flixborough

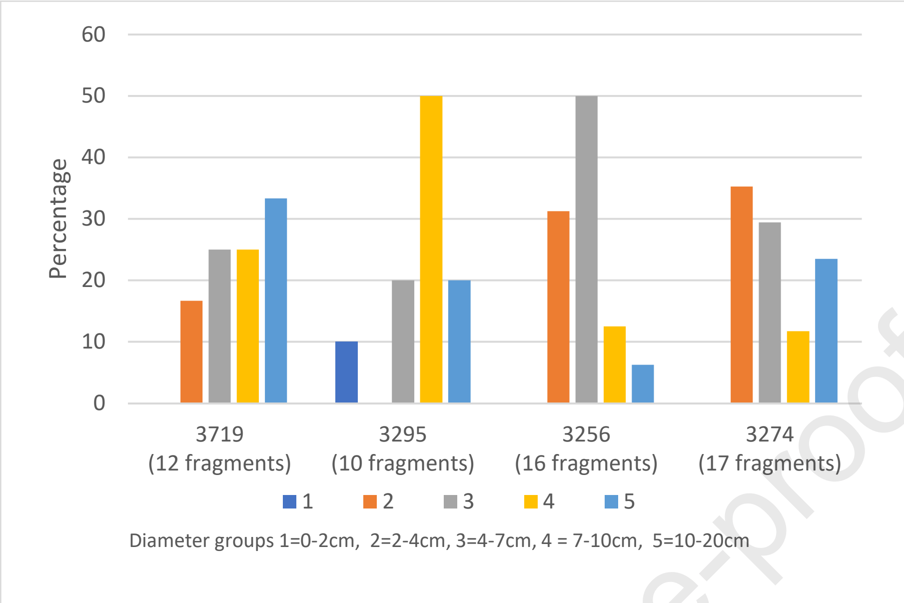
4.2. Dendro-anthracological results

Following the methodology highlighted above, 283 fragments of oak charcoal were analysed. 1370 annual growth rings were measured, with an average of nearly 5 rings per fragment, although exceptional fragments from the Flixborough site had up to 39 rings present. The wood's estimated diameter, sapwood/heartwood and annual growth rate will first be described. Following this the combination of these results will be detailed in terms of anthraco-groups.

4.2.1. Dando Close

4.2.1.1. Wood diameter

The diameter range at Dando Close varies between 0-2 cm and 10-20 cm with the highest number of fragments (32.7%) belonging to class 4-7 cm followed by classes 2-4 and 7-10 cm. The least represented class is 0-2 cm. The distribution of wood diameter is not the same from one context to another. Thus, the fragments of between 4-7 cm are the main class in context 3256, while those between 7-10 cm dominate context 3295. Fragments of between 2-4 cm are highest in context 3274 and those between 10-20 cm are highest in context 3719 (Fig. 5 & 6).



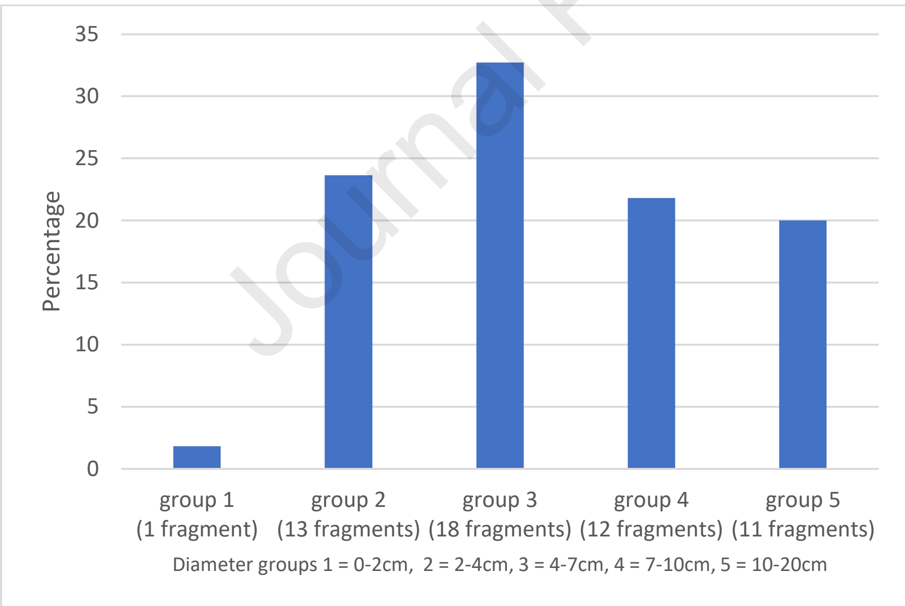


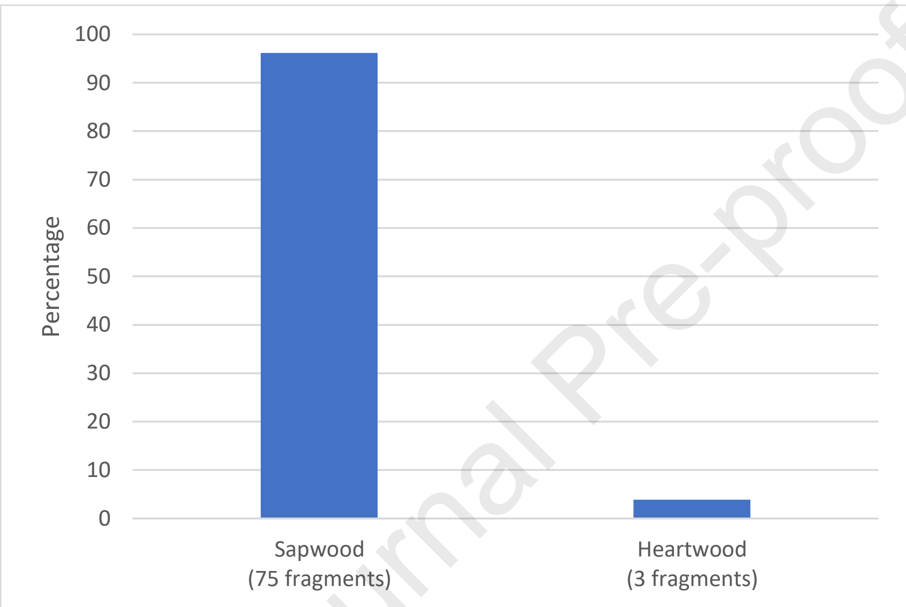
Fig.5. Charcoal fragments in percentages by context and diameter group.
Fig. 6. Charcoal fragments in percentages for the site overall by diameter group.

4.2.1.2. Sapwood vs Heartwood

96% of the fragments in the assemblage were identified as sapwood (Fig. 7). The assemblage contained only three fragments of heartwood, although these do not appear in the anthraco-typological analysis as they did not provide a pith estimation value. The three fragments of heartwood present are found in context 3719, 3295 and 3256.

4.2.1.3. Annual growth

The annual growth range for the site is between 0.77 mm and 3.85 mm with an average of 2.04 mm. The sample from context 3719 has a significantly higher average annual growth of 2.5 mm compared to that of the samples from context 3295 with 1.66 mm, context 3256 with 2 mm, and context 3274 with 1.93 mm (Fig 8.).



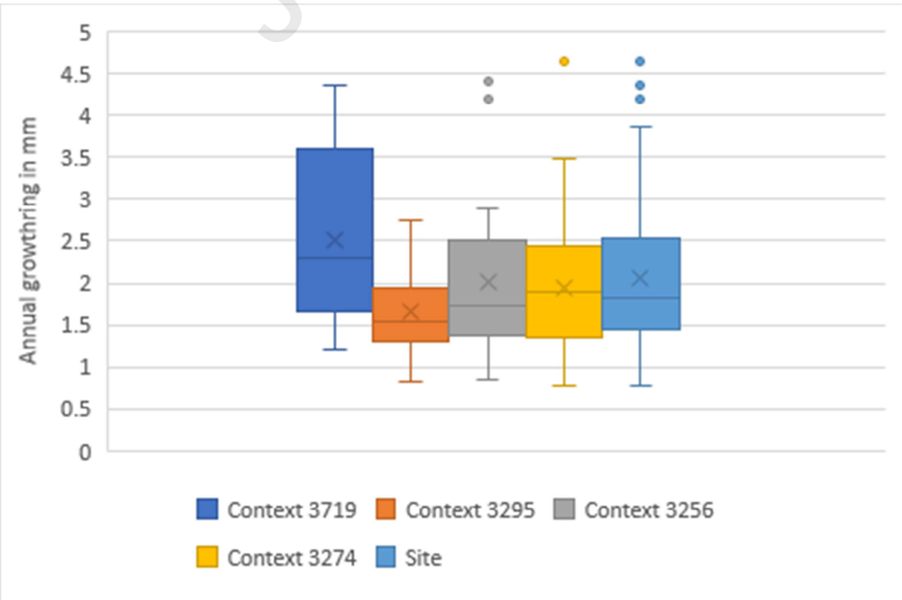


Fig. 7. Distribution of charcoal fragments by sapwood and heartwood.
Fig. 8. Annual growth ring range by context and for the site.

4.2.1. 4. Anthraco-typological analysis

The charcoal was sorted between eight anthraco-groups according to the results of the dendro-anthracological tool measurements (Fig.9.).

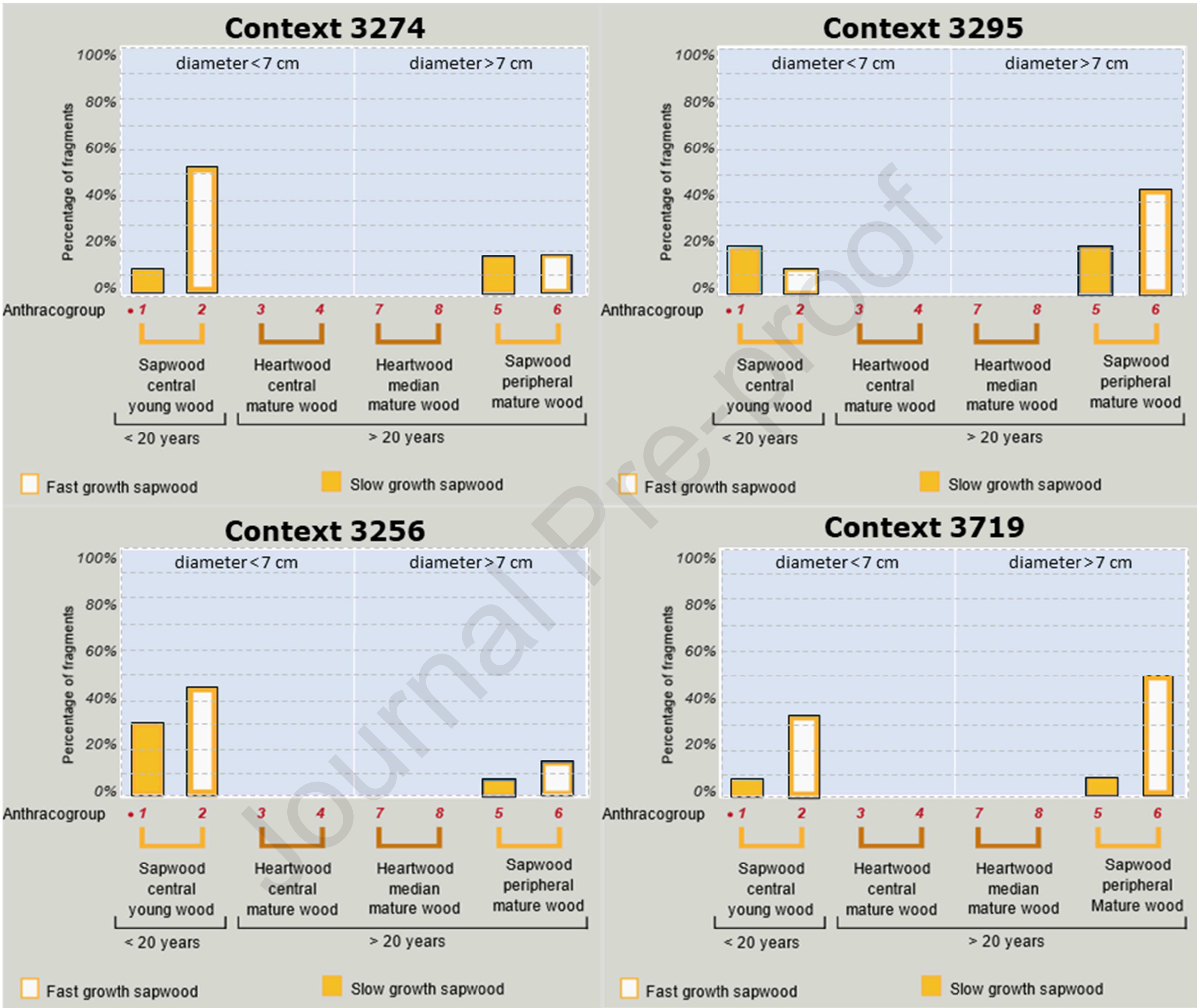


Fig. 9. Dendro-anthracological key for the oak from Dando Close sorted into anthraco-groups

There are very few differences noticeable between the contexts analysed (SM1). The combination of these three parameters indicates that at a site-wide level, there is exploitation of fast growing sapwood from young and mature trees (anthraco-groups 2 and 6) representing 68.6% of the assemblage. Group 2's average diameter for the site was 3.92 cm, its maximum diameter was 6.84 cm and its average annual growth rate was 2.28 mm. Group 6's average diameter was 10.29 cm and maximum diameter was 17.35 cm and its average annual growth rate was 2.19 mm. Fragments from group 2 represent young wood of less than 20 years old. The fragments from group 6 represent sapwood from trunks over 20 years old, however the heartwood that would be expected to show in groups 3, 4, 7 and 8 are not present in the assemblage.

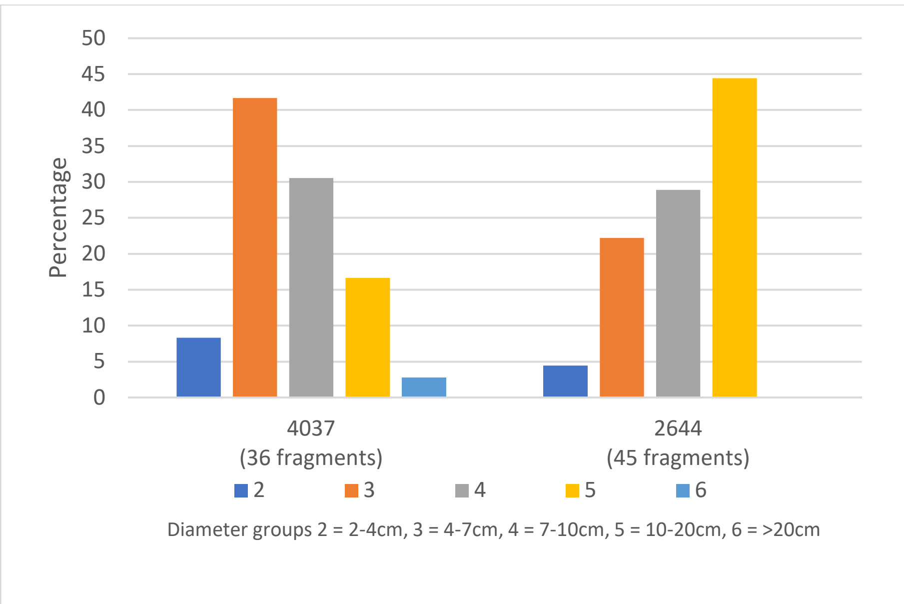
There is also the exploitation of slow growing sapwood close to the pith (anthraco-group 1). This potentially corresponds to branch wood representing 17.64% of the sampled fragments with an average growth of 1.25 mm a year. The average diameter for anthraco-group 1 was 5.29 cm and its maximum was 6.77 cm.

The smallest amount of fragments belong to anthraco-group 5 (13.72%). This is slow growing sapwood from the periphery of mature wood. Group 5's average diameter was 12.05 cm and maximum diameter was 18.71 cm and its average annual growth rate of 1.17 mm.

4.2.2. Higham Ferrers

4.2.2.1. Wood diameter

The diameter range at Higham Ferrers varies between 2-4 cm and >20 cm with the highest number of fragments (32%) belonging to the diameter class 10-20 cm followed by classes 4-7 cm and 7-10 cm. The least represented class is >20 cm. The distribution of diameter classes is not the same from one context to the other. The class 4-7 cm dominates in context 4037, while the class 10-20 cm dominates in context 2644 (Fig. 10 & 11).



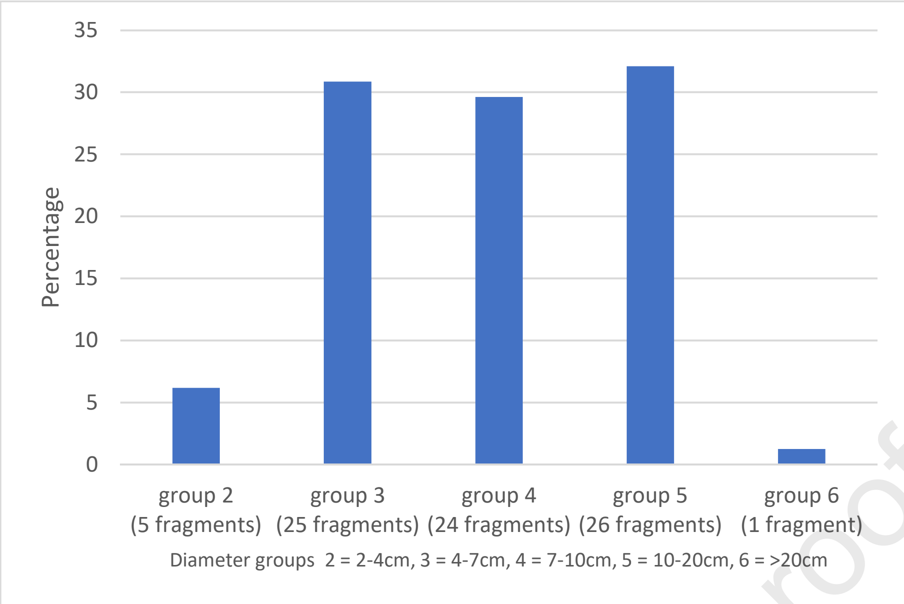


Fig. 10. Charcoal fragments in percentages by context and diameter group.

Fig. 11. Charcoal fragments in percentages for the site by diameter group.

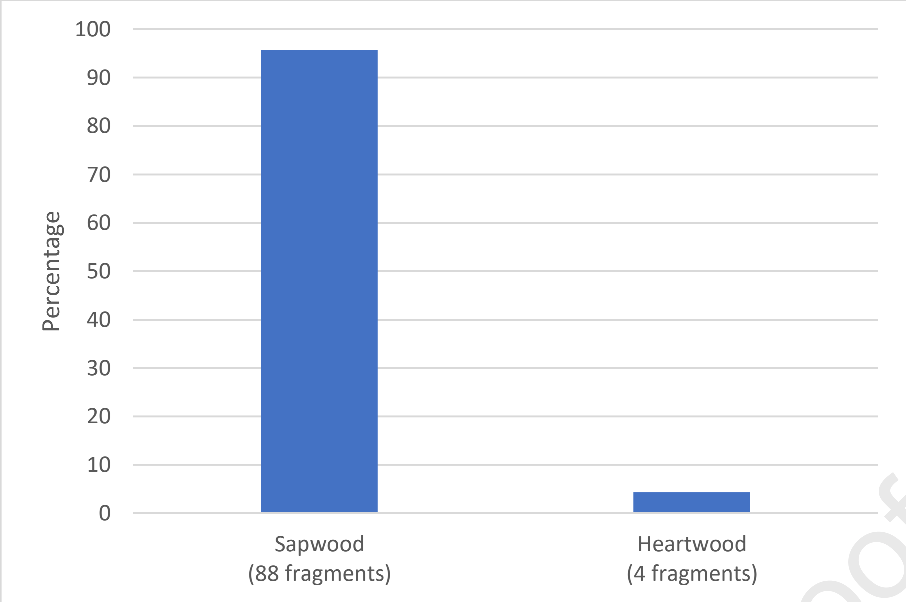
4.2.2.2. Sapwood vs Heartwood

Sapwood dominates the assemblage with 95.65% of the fragments (Fig. 12). The small amount of heartwood comes exclusively from the malting oven context 4037.

4.2.2.3. Annual growth

The growth range for the site is between 0.81 mm and 4.1 mm (excluding the outliers) with an average of 2.21 mm. The sample from context 2644 has a significantly higher average annual growth rate of 2.65 mm with a range from 1.29 mm to 4.99 mm and outliers reaching 6.52 mm (Fig. 13). In contrast the sample from the malting oven context 4037 has a lower growth range of 0.81 mm to 3.75 mm with an average annual growth of 1.76 mm.

Journal Pre-proof



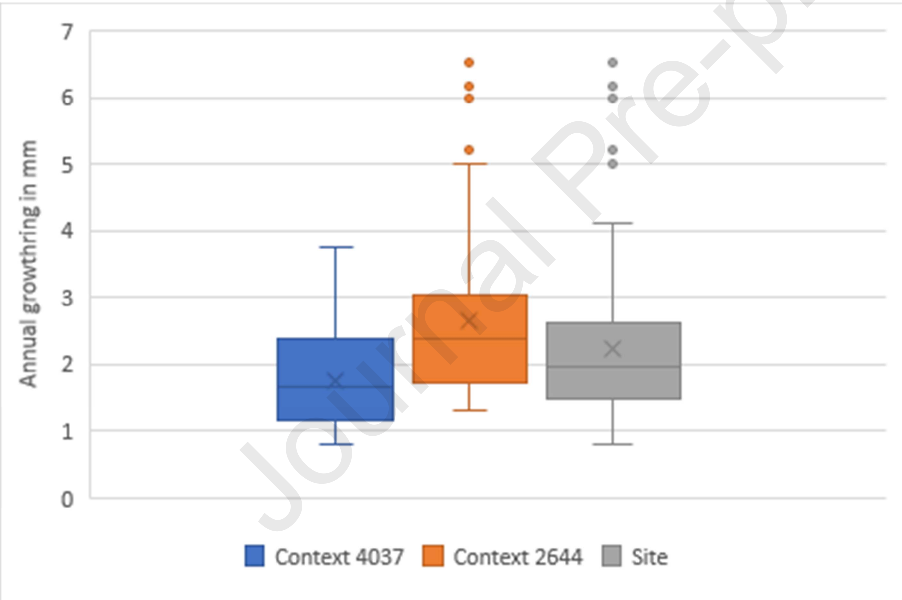


Fig. 12. Distribution of charcoal fragments by sapwood and heartwood.
Fig. 13. Annual growth ring range by context and overall, for the site.

4.2.2.4. Anthraco-typological analysis

The combination of these three parameters indicates at a site-wide level the exploitation of fast-growing sapwood (anthraco-groups 2 and 6) and slow growing sapwood (anthraco-group 5) representing 88.15% of the assemblage (Fig. 14). The average diameter of fragments from anthraco-group 2 is 4.93 cm. The maximum diameter is 6.27 cm and the average growth rate is 2.69 mm. The average diameter of fragments from anthraco-groups 6 is 10.74 cm, the maximum diameter is 17.85 cm and the average growth rate is 2.59 mm. The average diameter of fragments from anthraco-group 5 is 10.64 cm, the maximum diameter is 15.23 cm and the average growth rate is 1.21 mm (SM. 2). This data suggest on one hand the exploitation of young tree trunks less than 20 years old (anthraco-group 2) and on the other hand the exploitation of older trunks over 20 years old (anthraco-group 5 and 6) but whose heartwood is under represented with only a few fragments present in anthraco-groups 4 and 8 of context 4037. The sample from context 2644 (the fill of a post pipe) is dominated by wood that is fast growing sapwood, the majority of which is from anthraco-group 6. The sample from context 4037 (the malting oven) in contrast has a more even spread over groups 1,2,5 and 6 suggesting the use of slow and fast growing young and mature sapwood. Fragments belonging to Anthraco-group 1 are only found in context 4037 and account for 22.58% of the sample. The average diameter is 5.72 cm , the maximum diameter is 6.72 cm and the average annual growth is 1.17 mm. Context 4037 also contains a very small number of fragments from anthraco-group 4 and 8 which represent fast growing heartwood. The diameter of the fragment from anthraco-group 4 is 3.45 cm and its growth rate is 1.68 mm. The diameter of the fragment from anthraco-group 8 is 13.33 cm and its growth rate is 3.76 mm.

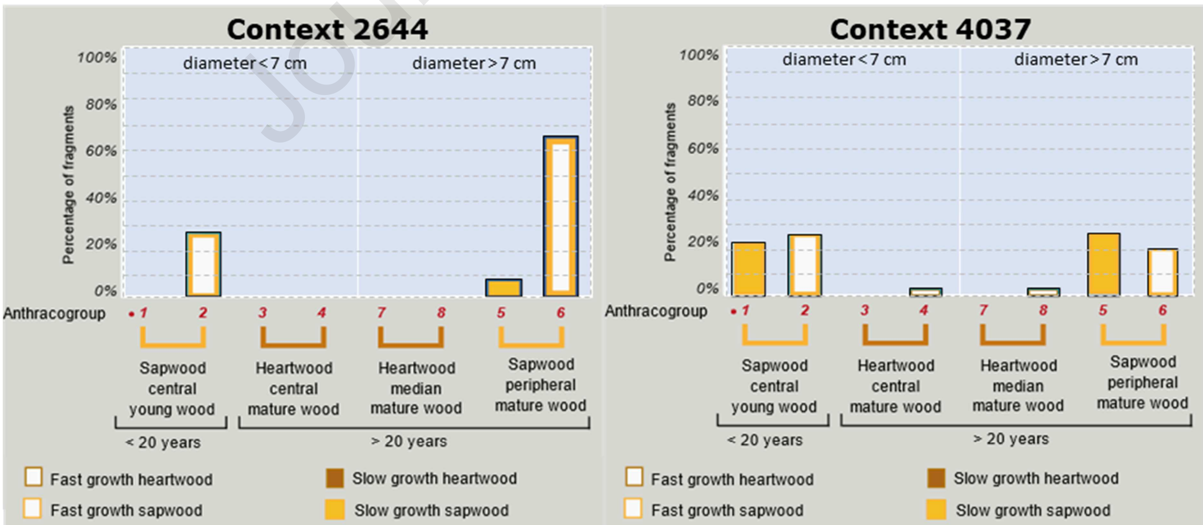
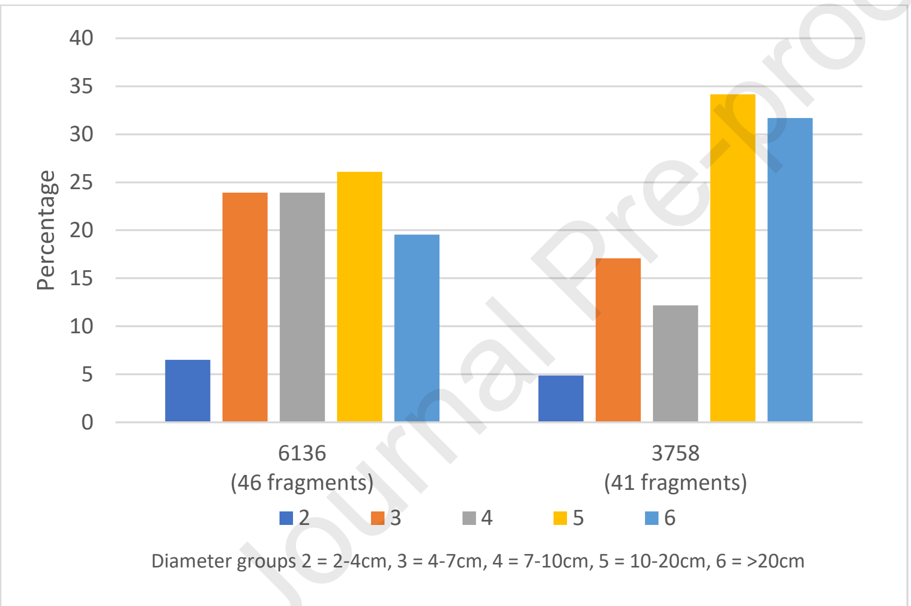


Fig. 14. Dendro-anthracological key for the oak from Higham Ferrers sorted into anthraco-groups

4.2.3. Flixborough

4.2.3.1. Wood diameter

The diameter range at Flixborough varies between 2-4 cm and >20 cm with the highest number of fragments (29.88%) belonging to class 10-20 cm, followed by classes >20 and 4-7 cm. The least represented class is 2-4 cm. The distribution of diameter classes is not the same from one context to the other. Charcoal from the 10-20 and >20 cm classes dominates in context 3758, while there is a relatively even spread across classes 4-7, 7-10 and 10-20 cm in context 6136 (Fig. 15 & 16).



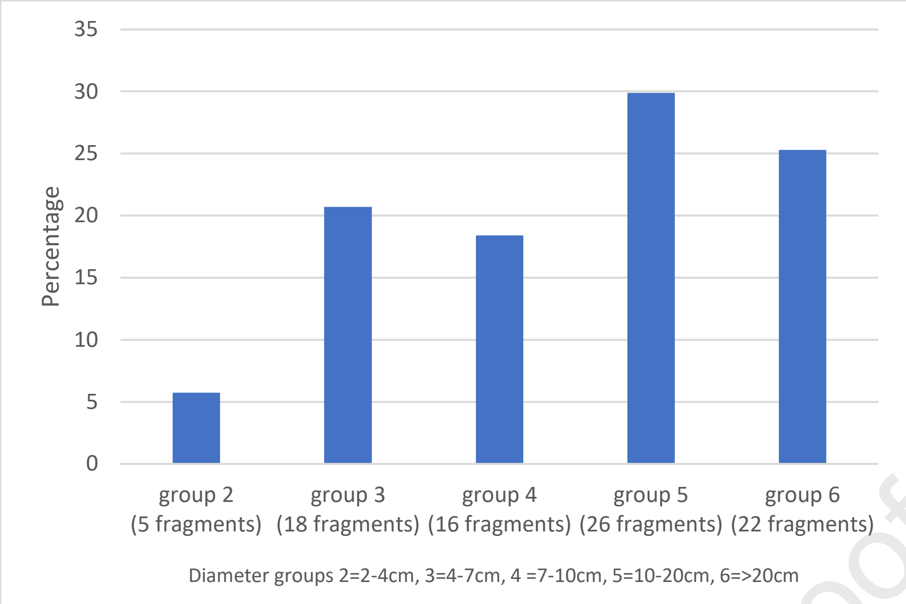


Fig. 15. Charcoal fragments in percentages by context and diameter group.

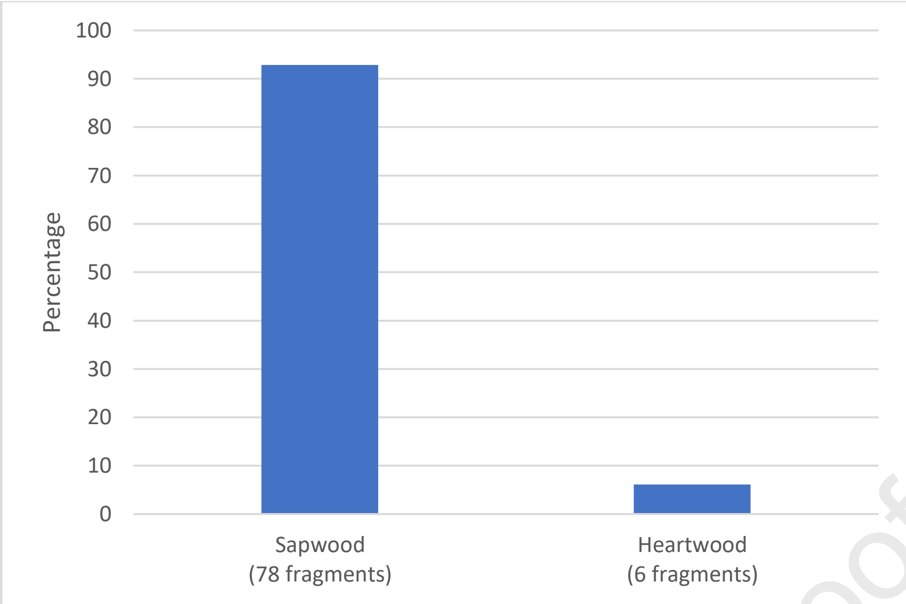
Fig. 16. Charcoal fragments in percentages for the site by diameter group

4.2.3.2. Sapwood vs Heartwood

Sapwood dominates the assemblage with 92.85% of the fragments (Fig. 17). The small amount of heartwood present comes from both contexts.

4.2.3.3. Annual growth

The growth range for the site is between 0.52 mm and 3.27 mm (excluding the outliers) with an average of 1.82 mm. Both samples have similar average growth rates with 1.94 mm for context 3758 and 1.70 mm for context 6136, although context 3758 has a higher range with growth rates up to 3.81 mm (Fig. 18).



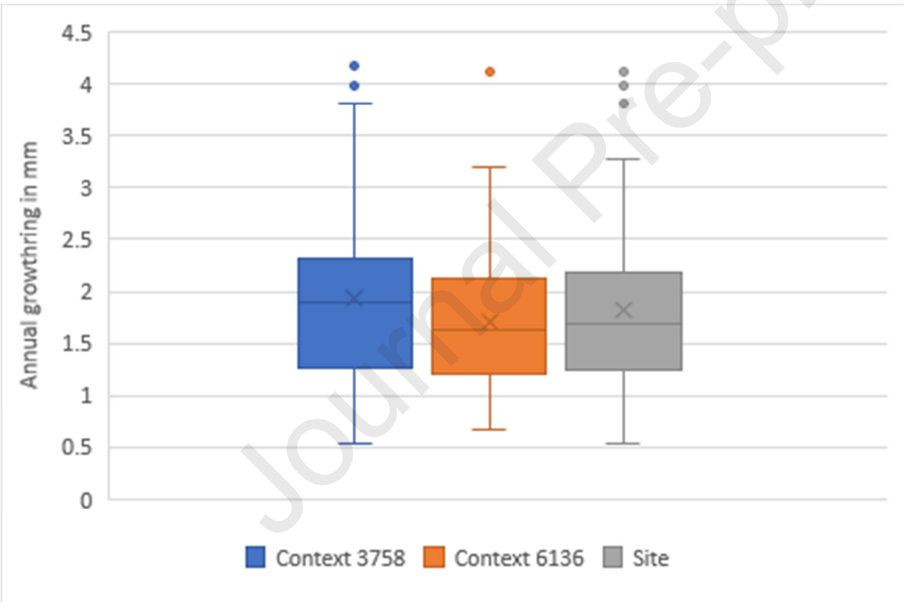


Fig. 17. Distribution of charcoal fragments by sapwood and heartwood.

Fig. 18. Annual growth ring range by context and overall for the site.

4.2.3.4. Anthraco-typological analysis

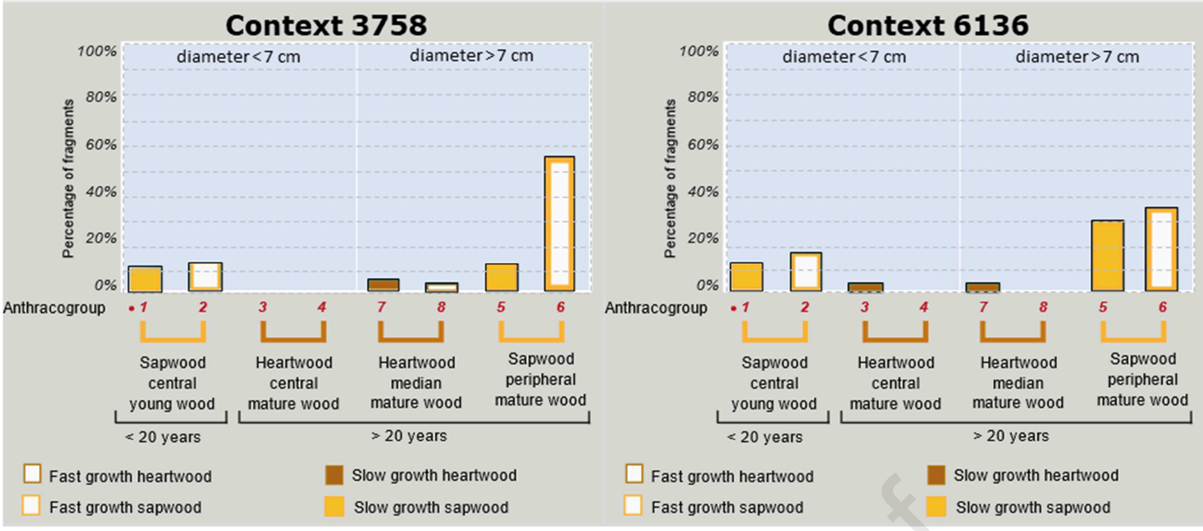


Fig. 19. Dendro-anthracological key for the oak from Flixborough sorted into anthraco-groups

The anthraco-typological results of the two contexts are very similar (Fig. 19, see also SM. 3).

The combination of these three parameters indicates at a site-wide level the exploitation of fast growing sapwood from the periphery of the trunk over 20 years old (anthraco-group 6), representing 44.59% of the charcoal examined. Slow growing sapwood from wood over 20 years old (anthraco-group 5) represents 20.27%. The average diameter of fragments from anthraco-group 6 is 24.02 cm, the maximum diameter is 104.92 cm and the average growth rate is 2.37 mm. The average diameter of fragments from anthraco-group 5 is 16.88 cm, the maximum diameter is 53.44 cm and the average growth rate is 1.16 mm. The maximum diameter in group 5 and 6 may be erroneous due to very large outliers within the sample from context 3758. In addition, they are probably unreliable values as the margin of errors can be very important for diameters bigger than 20 cm (see Dufraisse et al., 2020). The presence of fragments belonging to anthraco-groups 3, 7, 8, 5 and 6 suggest the exploitation of trunks older than 20 years old. Considering the estimated diameters it is likely that heartwood is underrepresented in this assemblage.

Anthraco-group 1 represents slow growing sapwood close to the pith and potentially corresponds to branch wood. 12.16% of the sampled fragments come from anthraco-group 1, these have an average diameter of 4.37 cm, a maximum diameter of 5.56 cm and an average growth rate of 1.02 mm a year.

The presence of wood from group 2 is nearly similar across the two contexts and represents 16.21% of the assemblage. Anthraco-group 2 represents fast growing sapwood from young trees (less than 20 years old). The average diameter of fragments from anthraco-group 2 is 5.16 cm, the maximum diameter is 6.96 cm and the average growth rate is 2.36 mm. There are similarities between the two samples for anthraco-group 2. The average diameter for context 6136 is 5.51 cm and is 4.68 cm for context 3758. The average annual growth rate for context 6136 is 2.28 mm and for context 3758 is 2.46 mm.

5. Interpretation of the anthraco-typological data

5.1. Dando Close

The majority of the wood is fast growing sapwood of less than 7 cm in diameter, followed by fast growing sapwood from the periphery of mature trees of more than 7 cm in diameter. There is no wood with a diameter over 20 cm. All four contexts reflect a similar pattern that little or no heartwood is present. The majority of the wood is sapwood belonging to anthraco-group 2 suggesting trees that are under 20 years old. There are no standout differences between the three samples from the mid 5th to mid 9th century AD period and the one sample from the mid 9th to 10th century. There are similarities between the composition of the anthraco-groups of contexts 3256 and the later context 3274. Both are dominated by similar amounts of young sapwood. They also have similar average growth rates of 1.93 mm and 2.64 mm respectively. The average diameters are also similar, 4.52 cm for context 3256 and 3.96 cm for context 3274. It may be postulated that a similar harvest strategy is being practiced, on trees of a similar age and size at two different periods. Context 3274 is believed to come from the short-term deposit related to the burning down of a grain store, therefore the wood may relate to the building's structure. Context 3256 is ambiguous as it is not associated with any structure. As the sample contains branch wood it is unlikely that this is the burning of a single post.

Context 3295 (the fill of a post hole in a sunken feature building) is believed to represent a long term deposit and therefore may represent the common harvest strategy for domestic fuel. If so, this represents the harvesting of oak up to 14 cm in diameter but also that of branch wood. The average growth for the context is low at 1.66 mm, possibly suggesting the harvesting of wood from dense woodland where light levels are low.

Context 3719 (hearth) is believed to represent a short-term deposit. Its anthracological composition is similar to that of context 3295, as are the dendro-anthracological results. This could represent a similar harvesting strategy for domestic fuel.

5.2. Higham Ferrers

The majority of the wood belongs to fast growing sapwood from the periphery of mature trees. The diameter of the wood is mostly between 4-20 cm with over 95% of the wood being sapwood. The majority of the wood is in anthraco-group 6 suggesting the wood came from the outer section of tree trunks over 20 years old. 22.58% of the fragments from Context 4037 (the malting oven) are in anthraco-group 1. This suggests that some branch wood was used. No charcoal from context 2644 comes from anthraco-group 1. The presence of branch wood in context 4037 could relate to the use of wood trimmed from trees as fuel (Bernard et al, 2006), and could suggest the deliberate addition of branch wood to provide a fast burn at high temperature. The malting oven sample may represent a short-term deposit and therefore could be indicative of the wood selection strategy for the malting process. The earlier context 2644 was exclusively oak and may represent structural wood as it comes from the fill of a post pipe.

5.3. Flixborough

Both contexts represent the dumping of waste material, believed to be the result of the removal or renovation of buildings at the site. The anthracological assessment shows a dominance of oak but also hazel, ash and alder as secondary taxa. The majority of the wood belonged to fast growing sapwood from the periphery of mature trees, followed by wood from slow growing sapwood from the periphery of mature trees. The majority of the wood was above 10 cm in diameter. There is very little heartwood present. The majority of the wood is sapwood belonging to anthraco-group 5 and 6, suggesting trees that are over 20 years old. The growth rates are similar between the two periods. However, the size of wood used appears to have increased in the later context

3758 (mid 9th century) from an average of 18.06 cm for anthraco-group 6 up to 27.90 cm for group 6 in the later period.

6. Discussion

All three sites show a dominance in the use of deciduous oak. This suggests that oak was likely to have been abundant in the local vicinities. These finding support the evidence from elsewhere in Britain during this period of oak being the primary source of wood for fuel and timber. Similarly, the evidence for secondary taxa of hazel and ash is also in agreement (Smith, 2002, Murphy et al., 2001, Huntley, 2010). The calibre of the wood varies from site to site with Dando Close using the smaller size ranges. The diameter of wood being used is greater at Higham Ferrers and greater still at Flixborough where there is evidence of the use of large trunk wood. The size of wood at Flixborough can be explained by the use in structures rather than as fuel. Whereas at the site of Dando Close and Higham Ferrers contextual information suggests that most of these assemblages are the result of the burning of firewood.

The sites of Dando Close and Higham Ferrers are comparable for several reasons. The sites are both rural early medieval settlements, situated in the same region. Both have similar geographic locations set on limestone ridges overlooking the Nene River Valley in a region of sparse woodland. Furthermore, the sampling strategies were similar, and therefore it is possible to compare the results. In the case of Dando Close, the small amount of heartwood present in the samples is significant. In over half these cases this can be explained by most of the charcoal coming from wood that is younger than 20 years old and hence would not have heartwood present. However, this does pose the question of why no heartwood is present in the remaining fragments that are from wood over 20 years old. The site of Higham Ferrers also exhibits a similar absence of heartwood. It is unsure why heartwood is underrepresented. It could be a result of differential combustion or preservation. It should also be noted that the sapwood and heartwood of deciduous oak have different physical properties and therefore different parts of the tree may be selected for different purposes, such as industrial fuel, or timber. Other hypothesis are possible as the variation of the age of the duraminisation can depends on intrinsic and extrinsic parameters such as oak species (including hybridization) and environment.

The annual growth of the wood when separated into anthraco-groups shows that there is similarity between the sites in group 1 and 5 (slow growing sapwood) which may suggest branches growing at similar rates. The fast-growing sapwood of groups 2 and 6 also show similarities between the sites, although fragments in group 6 from Higham Ferrers have slightly larger average ring widths.

In the case of Flixborough the sampling strategy (hand collected fragments) was different to the other sites and therefore it is difficult to draw direct comparisons. However, because of the exceptional preservation of large fragments of charcoal, this has provided an excellent opportunity to assess the growth patterns of these trees.

Much of the charcoal rich contexts were believed to derive from the clearance and replacement of buildings. The original assessment of the contexts and structures carried out by Loveluck and Darrah (2007) postulated that if the structural oak timber posts were 25 cm in diameter, some repair would be needed in the first 20 years and a significant rebuilds every 40 years. If the wood had been seasoned it would last longer, also if heartwood was used it is more resilient to decay and rots more slowly (Loveluck and Darrah, 2007: 54-55). Structural assessments found physical evidence of post pads and trenches cut through to accommodate replacement posts (Loveluck and Darrah, 2007: 55). The assessment found that most of the timber remains would have been roundwood of less than 25 cm in diameter (Loveluck and Darrah, 2007: 55). This is supported by this dendro-anthracological assessment as most of the fragments have an estimated diameter of over 10 cm. Loveluck and Darrah (2007: 55) also state that the wood was sapwood growing at a regular annual rate of up to 2 mm, consistent with trees growing in high forest (a woodland consisting of single stemmed trees growing from seed to their full height). In contrast, the dendro-anthracological assessment of the Flixborough oak showed that 80% of the fragments analysed have irregular growth patterns, suggesting either climatic or human disturbance to the trees (Fig. 20). Abnormal climatic events such as drought, extreme temperatures and precipitation can cause variations in the annual growth rings (Speer, 2010: 10). Physical damage to a tree, like trimming, grazing, coppicing, pollarding, or removing the crown can lead to the reduction in the width of the annual growth ring (Schweingruber et al., 2006: 113). All of these require cutting the stem or branches of broadleaved species. The process relies on the plant sprouting from dormant buds or from suckers from the base of the tree (Deforce and Haneca, 2015). Trees that are coppiced have a higher radial growth rate in the first years compared with trees growing from seed. This is due to the large established root system of the coppice stool (Haneca et al., 2005). Some of the fragments analysed from Flixborough show large ring growth close to the pith for the first few years, reducing thereafter.

Fig. 20. Fragment 28 context 3758, showing large initial growth rings.

The process of pollarding or trimming oak causes an abrupt reduction in growth resulting in a reduced ring. Late wood is reduced, there is no alteration to the earlywood width in the first year after pollarding. The following two years show reduced earlywood and an overall reduction in the ring width. After this point the growth gradually returns to normal (Haneca et al., 2009). It is possible that some of the fragments that come from trees with large diameters show trends that could be the consequence of pollarding or trimming (Fig. 21). Alternatively, these irregular patterns could relate to the understory being cut at regular intervals.

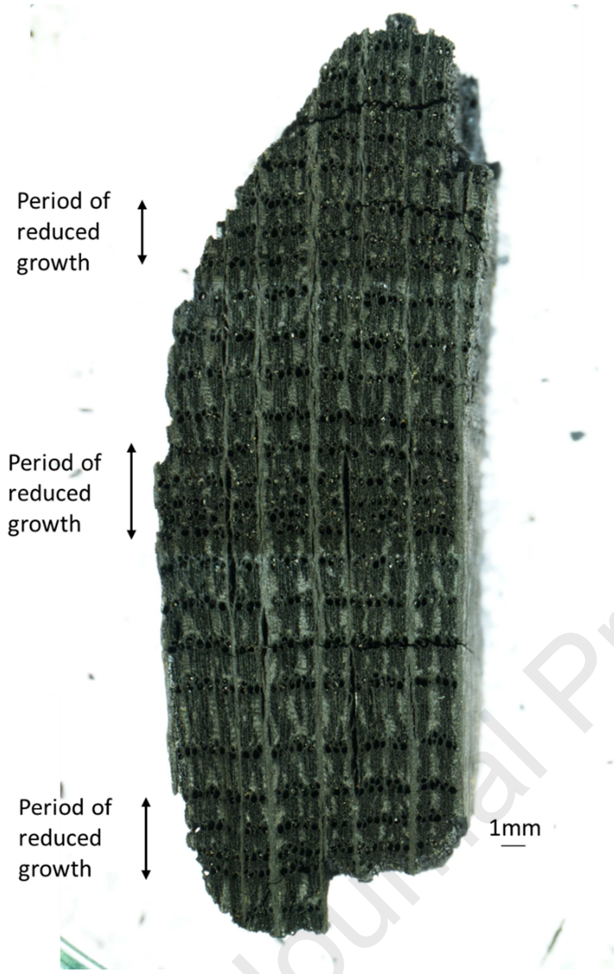


Fig. 21. fragment 10 from context 6136, showing three periods of reduced growth followed by subsequent accelerated growth.

It is our hypothesis that a form of woodland management is happening at this site. During the early medieval period, woodland is believed to have been broadly divided into coppice-wood and pasture wood (Rackham 1995:54). Reviewing the evidence provided by the dendro-anthracological assessment, it is unlikely that the wood comes from wood pasture as the average growth rate for a free standing tree would be higher at around 4mm (Rackham 1995: 13). Furthermore the presence of wood from younger trees would not support wood pasture unless they were being protected from grazing animals. One suggestion that would accommodate the findings is that of coppice with standards whereby selected trees would grow to maturity within coppiced woodland. Alternatively, the standards may be having their branches trimmed periodically in a form of pollarding. The larger trees are witnessing periodic reduced growth, either as a result of the tree being damaged or as a result of the light level being steadily reduced. Once the canopy is opened up and light levels increase the trees show a growth increase.

7. Conclusion

The aim of this study was to expand the interpretation of the archaeological charcoal assemblages for the three study sites beyond the identification of taxa present and the diversity of the harvested wood. The anthracological analysis showed that deciduous oak was the main taxa being exploited with hazel and ash as secondary taxa. The application of dendro-anthracological tools have shown remarkable results, with data shedding light on the age range of the fragments, their size, growth rate and potential harvesting strategies being employed. The samples from Dando Close provided evidence that the majority of the charcoal came from fast growing sapwood from trees of less than 20 years old, with an estimated diameter of between 2 – 7 cm. The charcoal from the samples from Higham Ferrers represent a majority of fast-growing sapwood from trees older than 20 years and with an estimated diameter of between 4 – 20 cm. The samples from Flixborough show that the majority of the charcoal came from fast growing sapwood from large trunks over 20 years old and of between 10 cm and in excess of 20 cm in diameter. The evidence from all three sites exhibit the lack of heartwood present. The irregular growth patterns visible on the large fragments from Flixborough suggest episodic disruption to the growth rate of the wood, which we postulate is being caused by a woodland management regime such as pollarding or the management of coppice with standard.

To take this interpretation further the dendro-anthracological sampling of the three sites needs to be increased so as to create a more expansive dataset. Additionally, it would be desirable to apply the dendro-anthracological tools to the next most abundant taxa, those of hazel and ash. This would allow for a wider interpretation of harvesting strategies and woodland management.

Acknowledgements

This study represents part of the objectives of R Francis' PhD thesis *Agriculture, Horticulture, Woodland Management and Society in England, c. AD400 – 1100: integrated perspectives. (From archaeobotany, dendroanthracology, textual sources and experimental archaeology).* R Francis is funded by a PhD grant from the Arts and Humanities Research Council Funding. AHRC funding through the Midlands4Cities Doctoral Training Partnership. The authors acknowledge the curators of the archaeobotanical material Rebecca Nicholson of Oxford Archaeology, James Rackham of Environmental Archaeology Consultancy and Rose Nicholson of the North Lincolnshire Museum and thank them for the loan of the charcoal assemblages analysed.

The authors acknowledge M. Lemoine (CNRS) assistance in dendro-anthracological data curation.

The authors would also like to thank the guest editor, Eleni Asouti, for the invitation to participate in this special issue.

Formatting of funding sources

This work was supported by the Arts and Humanities Research Council Funding. AHRC funding through the Midlands4Cities Doctoral Training Partnership [grant numbers M3C1299, M3C1509]

Authorship contribution statement

Robert Francis: Dendro-anthracological methodology, Anthracological and dendro-anthracological data curation, Writing - original draft, Writing - review & editing, Funding acquisition.

Alexa Dufraisse: Dendro-anthracological methodology, participation to Writing - original draft, Writing - review & editing

Bibliography:

Ashworth, H., Semmelmann, K., 2003. Land at Dando Close Archaeological Assessment Report. Heritage Network, Baldock.

Asouti, E., Austin, P., 2005. Reconstructing Woodland Vegetation and Its Exploitation by Past Societies, Based on the Analysis and Interpretation of Archaeological Wood Charcoal Macro-Remains. Environmental Archaeology. 10. 1-18.

Bernard, V., & Renaudin, S. & Marguerie, D. 2006. Evidence of trimmed oaks (Quercus sp.) in north western France during the early middle ages. Charcoal Analysis: New Analytical Tools and Methods for Archaeology. 103-108.

Braadbaart, F., & Poole, I. 2008. Morphological, chemical and physical changes during charcoalification of wood and its relevance to archaeological contexts. Journal of Archaeological Science, 35(9), 2434–2445.

British Geological Survey, Geology of Britain 2020, viewed 25 July 2020, <http://mapapps.bgs.ac.uk/geologyofbritain/home.html>

Chabal, L., L. Fabre, J.-F. Terral, and I. Théry-Parisot 1999 "L'anthracologie," in La botanique. Edited by C. Bourquin-Mignot, J.-E. Brochier, L. Chabal, et al., pp. 43-104. Paris: France.

Collop, C., 2011. Lincolnshire Biodiversity Action Plan 2011-20. 3rd edition. Greater Lincolnshire Nature Partnership.

Crew, P. Mighall, T. 2013. The fuel supply and woodland management at a 14th century bloomery in Snowdonia: a multi-disciplinary approach. The World of Iron. Proceedings of a Conference at the Natural History Museum 2009. 473-482.

Dark, P., 2000. The Environment of Britain in the First Millennium A.D. London, Duckworth.

Deforce, K., Haneca, K., 2015. Tree-ring analysis of archaeological charcoal as a tool to identify past woodland management: The case from a 14th century site from Oudenaarde (Belgium). Quaternary International. 366. 70-80.

Dufraisse A., S. Coubray, O. Girardclos, N. Nocus, M. Lemoine, J.-L. Dupouey, D. Marguerie (2018a). Anthraco-typology as a key approach to past firewood exploitation and woodland management reconstructions. Dendrological reference dataset modelling with dendro-anthracological tools. Quaternary International, Vol. 463, Part B: 232-249 https://doi.org/10.1016/j.quaint.2017.03.065

Dufraisse A., S. Coubray, O. Girardclos, A. Dupin, M. Lemoine (2018b). Contribution of tyloses quantification in earlywood oak vessels to archaeological charcoal analyses: estimation of a minimum age and influences of physiological and environmental factors Quaternary International Vol. 463, Part B: 250-257 https://doi.org/10.1016/j.quaint.2017.03.070

Dufraisse A., Bardin J., Picornell-Gelabert Ll., Coubray S., Garcia-Martinez M.S., Lemoine M., Vila Moreiras S. 2020. Pith location tool and wood diameter estimation: validity and limits tested on seven taxa to approach the length of the missing radius on archaeological wood and charcoal fragments. Journal of Archaeological Science Reports, 29: X-XX. https://doi.org/10.1016/j.jasrep.2019.102166

Forestry Commission, National Forest Inventory 2020, viewed 25 July 2020 http://data-forestry.opendata.arcgis.com/datasets/

Gale, R. M O. 2007. Appendix 3: charcoal. Proceedings of the Hampshire Field Club & Archaeological Society. Vol 62, pp. 67-68.

Gearey, B., Richer, S., 2017. From Rackham to REVEALS: Reflections on Palaeoecological Approaches to Woodland and Trees. Environmental Archaeology. 23. 286-297.

Hall, A. 2000. Technical report: Plant remains from excavations at Flixborough, N. Lincolnshire (site code: FLX89). Reports from the Environmental Archaeology Unit, York.

Hall, A. and Kenward, H. 2004. Setting people in their environment: plant and animal remains from Anglo-Scandinavian York. In: Aspects of Anglo-Scandinavian York. The Archaeology of York . Council for British Archaeology, York, UK , pp. 372-426.

Haneca, K., Van Acker, J., Beeckman, H., 2005. Growth trends reveal the forest structure during Roman and Medieval times in Western Europe: a comparison between archaeological and actual oak ring series (Quercus robur and Quercus petraea). Annals of Forest Science, 62(8). 797–805.

Haneca, K., Cufar, K., Beeckman, H., 2009. Oaks, tree-rings and wooden cultural heritage: A review of the main characteristics and applications of oak dendrochronology in Europe. Journal of Archaeological Science, 36. 1-11.

Hardy, A., Charles, B.M., Williams, R.J., 2007. Death and taxes. The archaeology of a Middle Saxon estate centre at Higham Ferrers, Northamptonshire. Oxford Archaeology Monographs 4.

Hather, J ., 2000. The identification of the northern European woods. Archetype publications, London.

Hazell, Z., Crosby, V., Oakey, M., and P, Marshall. 2017. Archaeological investigation and charcoal analysis of charcoal burning platforms, Barbon, Cumbria, UK. Quaternary International, Volume 458, 178-199.

Hooke, D., 2010. Trees in Anglo-Saxon England. Boydell Press, Woodbridge.

Huntley, J P., 2010. A Review of Wood and Charcoal Recovered from Archaeological Excavations in Northern England, Res Dept Rep 68/2010, English Heritage, Portsmouth.

Leney, L., Casteel, R, W., 1975. Simplified procedure for examining charcoal specimens for identification. Journal of Archaeological Science, 2. 153-59.

Loveluck, C.P., 2007. Rural Settlement, Lifestyles and Social change in the later first millennium AD. Anglo-Saxon Flixborough in its wider context. Excavations at Flixborough, Volume 4, Series ed. C.P. Loveluck, Oxbow Books, Oxford.

Loveluck, C., Darrah, R., 2007. The Built Environment: The Buildings, Aspects of Settlement Morphology and the Use of Space' in Loveluck, C., (ed.). Rural Settlement, Lifestyle and Social Change in the Later First Millennium AD: Anglo-Saxon Flixborough in its Wider Context, Excavations at Flixborough 4. Oxbow, Oxford.

Ludemann, T. 2008. Experimental charcoal burning with special regard to anthrocological wood diameter analysis. In Charcoals from the Past: Cultural and Palaeoenvironmental Implications, G. Fiorentino, and D. Magri (eds). British Archaeological Reports, International Series 1807, 147-157.

Marguerie, D., Hunot, J.-Y. 2006. Charcoal analysis and dendrology: data from archaeological sites in north-western France, Journal of Archaeological Science. 34. 1417-1433.

Met Office, Climate averages 2020, viewed 25 July 2020,<https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-climate-averages/>

Moffett, L. C., 2007. Charred plant remains in Hardy, A., Charles, B.M., Williams, R.J., Death and taxes. The archaeology of a Middle Saxon estate centre at Higham Ferrers, Northamptonshire. Oxford Archaeology Monographs 4.

Murphy, P., Hillam, J., Groves, C., 2001. Review of wood and macroscopic wood charcoal from archaeological sites in the west and east midland regions and the east of England. Centre for Archaeology Reports 23/2001: 54.

Nelle, O, 2002. Charcoal burning remains and forest stand structure – examples from the Black Forest (south-west Germany) and the Bavarian Forest (south-east Germany). In Charcoal Analysis: methodological approaches, palaeoecological results and wood uses, S. Thiébault (ed.). British Archaeological Reports International Series 1063, 201-208

Northamptonshire County Council 2020. Biodiversity Action Plan 2015-2020 viewed 25 July2020 https://www3.northamptonshire.gov.uk/councilservices/environment-andplanning/planning/planning-policy/archaeology-biodiversity-andlandscape/documents/PDF%20Documents/Northamptonshire%20BAP%202015-2020.pdf

Paradis-Grenouillet, S., Dufraisse, A., 2018. Deciduous oak/chestnut: Differential shrinkage of wood during charcoalification? Preliminary experimental results and implications for wood diameter study in anthracology. Quaternary International. 463, 258-267.

Rackham, J. , 2003. Ecofact assemblage. In Ashworth, H., Semmelmann, K., Land at Dando Close Archaeological Assessment Report. Heritage Network, Baldock.

Rackham, O., 1994. Trees and Woodland in Anglo-Saxon England: The Documentary Evidence' in Rackham, J., (ed) Environment and Economy in Anglo-Saxon England (Council for British Archaeology Report 89). York: Council for British Archaeology, pp. 7-12.

Rackham, O., 1995. Trees and woodland in the British landscape. Weidenfeld and Nicholson, London.

Rackham, O., 2006. Woodlands. Collins. London.

Robinson, M. 1997. Charred plant remains from a Medieval pottery kiln. In The excavation of two medieval pottery kiln sites and two sections through the London-Lewes Roman road at Clacket Lane, near Titsey, 1992. Surrey Archaeological Collections, 84, 1-87.

Schweingruber, F.H., 1982. Microscopic wood anatomy, second edition. F Fluck-Wirth, Teufen.

Schweingruber, F.H., Börner, A., Schulze, E.-D., 2006. Atlas of woody plant stems. Evolution, structure, and environmental modifications. Springer-Verlag, Berlin.

Smith, W., 2002. A review of archaeological wood analyses in southern England. English Heritage Research Department, Swindon.

Speer, J.H., 2010. Fundamentals of Tree-Ring Research. University of Arizona Press, Tucson.

Thompson, G., Francis, R., 2007. Charcoal. In Hardy, A., Charles, B.M., Williams, R.J. Death and taxes. The archaeology of a Middle Saxon estate centre at Higham Ferrers, Northamptonshire. Oxford Archaeology Monographs 4.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: