H2Teesside Project

Planning Inspectorate Reference: EN070009

Land within the boroughs of Redcar and Cleveland and Stockton-on-Tees, Teesside and within the borough of Hartlepool, County Durham

The H2 Teesside Order

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Planning Act 2008

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APPENDICES

1.0 INTRODUCTION

1.1 Overview

1.1.1 This document has been prepared on behalf of H2 Teesside Limited (the ‘Applicant’). It relates to an application (the 'Application') for a Development Consent Order (a 'DCO'), that was submitted to the Secretary of State for Energy Security and Net Zero (‘DESNZ’) on 25 March 2024, under Section 37 of ‘The Planning Act 2008’ (the ‘PA 2008’) in respect of the H2Teesside Project (the ‘Proposed Development’).

1.1.2 The Application has been accepted for examination. The Examination commenced on 29 August 2024.

1.2 The Purpose and Structure of this document

1.2.1 The purpose of this document is to set out the Applicant’s responses to the Examining Authority’s ExQ1 on Cultural Heritage, which were issued on 4 September 2024 [PD-008]. This document contains a table which includes the reference number for each relevant question, the ExA’s comments and questions and the Applicant’s responses to each of those questions. Appendix 1 of this document, the Oxford Archaeology 2024 Report ‘Assessing the Impact of Tree Roots on Archaeology’ is provided in response to Q1.7.7

Table 1-1 Response to ExQ1 Cultural Heritage

EXQ1	QUESTION TO:	QUESTION:	RESPONSE
Q1.7.1	Applicant	Assumptions and Limitations – Clarification/ Correction. Paragraph 17.3.29 of ES Chapter 17 (Cultural Heritage) [APP-070] refers to maximum heights considered in the 'Rochdale Envelope'. It states the flare has a maximum height of 100m above Ordnance Datum (aOD), whilst all other structures on the Main Site will have a maximum height of 60 m aOD. This paragraph goes on to state: "Impacts derived from visual changes to setting assume these worst-case conditions." However, these heights are less than the heights specified as maximum design parameters as set out in Schedule 16 (Design Parameters) of the DCO. As such how can the measurements set out in this Chapter of the ES be assumed to be the 'worst-case conditions' asset out in Paragraph 17.3.29 or that the 'assessment presents a reasonable 'worst-case' approach' as set out in Paragraph 17.3.34? Please review and explain this discrepancy and revise the relevant parts and conclusions within the ES, where necessary.	Paragraph 17.3.29 of ES Chapter 17: Cultural Heritage [APP-070] incorrectly refers to metres above Ordnance Datum (AOD) and should refer to 100m height. Paragraph 4.6.4 of ES Chapter 4 (Proposed Development) [APP-056] states that the tallest element of the Proposed Development is the flare which would be of maximum 100m height (i.e., ≤108 m AOD). A flare of 100 m height (i.e. 108 m AOD) was assessed in ES Chapter 17 (Cultural Heritage) [APP-070], which is the worst-case scenario in accordance with Paragraph 17.3.29, and in accordance with Schedule 16 (Design Parameters) of the draft DCO [AS-013].
Q1.7.2	LAs (HBC, RCBC and STBC)	Assumptions and Limitations – Views sought. Paragraph 17.3.35 of ES Chapter 17 (Cultural Heritage) [APP-070] states archaeological evaluation in the form of a geophysical (magnetometry) survey (Appendix 17A: Heritage Desk Based Assessment [APP-214]) of agricultural land within the Proposed Development has been undertaken, and that the area planned to be surveyed totalled approximately 59 hectares. However, 8 hectares were inaccessible due to being waterlogged or too overgrown to allow access to the survey equipment. The Applicant explains that given the paucity of result in the remainder of the survey areas, it considered that a review of available aerial photographs and light detection and ranging imagery was sufficiently robust to inform the archaeological baseline in these areas. Irrespective of this the Applicant acknowledged in Section 17.7 of this chapter that additional evaluation and/ or monitoring of intrusive works may be required in these fields nonetheless. Additionally, Paragraph 17.3.36 of Chapter advises *"…some areas of the Proposed Development Site could not be accessed during the site walkovers due to lack of land access" and that "…the survival of remains associated with the Redcar (SMR5711) and Coatham Iron Works (SMR5709) could not be ascertained where 20th century development may not have subsequently removed them…" but "…as a means to mitigate the risk of significant remains being impacted, the area identified as likely to hold such remains… has been removed from Proposed Development Site."* Are the LAs satisfied with this approach? If not please specify what measures need to be undertaken to satisfy the LAs in this regard.	n/a

EXQ1	QUESTION TO:	QUESTION:	RESPONSE
Q1.7.3	Applicant	Geophysical Survey – Clarification/ Correction. Paragraphs 17.6.30 and 17.6.31 of ES Chapter 17 (Cultural Heritage) [APP-070] refers to the impact and effect of the proposed hydrogen pipeline corridor on Geographical Survey (GS) Site 2 and GS Site 3 respectively. In terms of GS Site 2 Paragraph 17.6.30 concludes "The construction of the Hydrogen Pipeline Corridor would… result in a Medium magnitude of impact, resulting in a Moderate Adverse effect, which is Significant.", whilst in terms of GS Site 3 paragraph 17.6.31 concludes the same (a medium magnitude of impact, resulting in a Moderate Adverse effect, which is Significant). However when compared to Table 17-6: Summary of Residual Effects the 'Residual Effect Significance' for both GS Site 2 and GS Site 3 are both recorded as 'Minor Adverse'. Please review, explain this anomaly and correct, where necessary.	The conclusions of impacts to GS Site 2 and GS Site 3 (i.e. Moderate Adverse) outlined at Paragraphs 17.6.30 and 17.6.31 of ES Chapter 17 (Cultural Heritage) [APP-070] are prior to the consideration of essential mitigation. Paragraph 17.3.14 of ES Chapter 17: Cultural Heritage [APP-070] states that, "essential mitigation may offset the impact through recording, and therefore reduce the overall significance of the effect (for example from moderate to minor)". Paragraph 17.8.2 [APP-070] states that the essential mitigation will be applied in the form of preparing a programme of archaeological evaluation, which will excavate and record these assets. This programme will be agreed with the LPA archaeologists and will be secured through a Written Scheme of Investigation and Framework CEMP [APP-043]. This essential mitigation has reduced the residual effect severity to Minor Adverse (Not Significant), as shown in Table 17-6.
Q1.7.4	LAs (HBC, RCBC and STBC)	Geophysical Survey – Views sought. There are a number of references throughout ES Chapter 17 (Cultural Heritage) [APP-070] concerning GS Sites 2 and 3 (Paragraphs 17.4.37, 17.4.38, 17.4.40, 17.4.41, 17.6.30, 17.6.31 and 17.8.1, as well as Table 17-6: Summary of Residual Effects). The ExA would seek your views on the Applicant's assessment and conclusions in regard to these sites (GS Sites 2 and 3).	n/a
Q1.7.5	Applicant and relevant LAs (HBC, RCBC and STBC)	Impact Avoidance – Clarification/ Views sought. The ExA notes the key measures to be employed during the construction of the Proposed Development, to control and minimise the impacts on the environment, as set out in Paragraph 17.5.4 of ES Chapter 17 (Cultural Heritage) [APP-070]. This paragraph also mentions 'Essential Mitigation', as referred to in Section 17.7 of Chapter 17 and the need to develop a Written Scheme of Investigation, which is secured separately through the DCO, and that a final CEMP will set out how impacts upon cultural heritage will be managed during construction. Irrespective of the above, the ExA notes that mitigation on Cultural Heritage does not appear to be specifically secured through Requirement 15 (CEMP) of the DCO. Please can the Applicant explain how the mitigation in regard to Cultural Heritage, including the development of a Written Scheme of Investigation, is to be adequately secured in the DCO as currently drafted. Do relevant LAs consider the Requirements concerning the CEMP (Requirement 15) and Archaeology (Requirement 13), as currently drafted, to be adequate in terms of securing Cultural Heritage mitigation and a Written Scheme of Investigation?	The Framework CEMP includes the measures set out in section 17.7. DCO, specifically paragraphs 17.1.1 and 17.7.2 are included in the fourth row of table 7-10. Requirement 15 requires the full CEMP(s) to be developed in substantial accordance with that outline. DCO Requirements 13 (Archaeology) and the Framework CEMP both require that a programme of archaeological investigations be agreed and approved by the relevant LAs through the production of a Written Scheme of Investigation prior to commencement – this covers paragraph 17.7.3. Requirement 13 (1) explicitly states that 'No part of the authorised development may commence until a written scheme of investigation for that part has been submitted to and approved by the relevant planning authority' while 13 (2) refers back to ES Chapter 17 Cultural Heritage [APP-070]. Paragraph 17.7.1 of the ES Chapter 17 states the intent for the Written Scheme of Investigation to include both evaluation and mitigation (excavation and recording). Paragraph 17.7.2 also states that the scope of the evaluation will be agreed and approved by the LAs. This approach will afford sufficient flexibility in the detailed design following a more comprehensive programme of evaluation as and when the DCO is made.

EXQ1	QUESTION TO:	QUESTION:	RESPONSE
Q1.7.6	Applicant	Impacts and LSEs – Clarification/ Correction. Paragraph 17.6.38 of ES Chapter 17 (Cultural Heritage) [APP-070] states that whilst "no known archaeological remains are present in this field, the works would involve woodland planting which could impact previously unrecorded archaeological remains." What archaeological investigations are proposed to identify previously unrecorded archaeological remains, how will such impact be assessed and mitigated and how will these measures be secured through the DCO?	To the extent that such investigations are required (which would be discussed with STBC), they would be delivered pursuant to Requirement 13 of the DCO [AS-013] It should be noted that a recently published report by Oxford Archaeology 'Assessing the Impact of Tree Roots on Archaeology' on the effects of tree roots suggests that the impacts of tree roots on archaeological remains has been widely overstated. The Oxford Archaeology Report is provided within Appendix 1 of this document. While some impacts to buried remains would be expected, such impacts are likely to be less destructive than consecutive annual ploughing from continued agricultural use. If warranted, significant archaeological remains identified by the proposed field investigations would be either avoided by the tree planting or impacts mitigated through the use of appropriately selected trees. Given that highly significant archaeological remains would be avoided and that remains of lower significance would be subject to limited impacts, no significant effects are anticipated in this field.
Q1.7.7	LAs (HBC, RCBC and STBC)	Essential Mitigation and Enhancement Measures – Views sought. Paragraph 17.7.3 of ES Chapter 17 (Cultural Heritage) [APP-070] notes that some parts of the Proposed Development Site are not suitable for traditional archaeological evaluation measures due to the nature of the ground conditions. (For example, i) made ground on the main development site; and ii) waterlogged and high-moisture content deposits). Therefore, it is recommended that a protocol is adopted to mitigate potential impacts to previously unknown archaeological assets that may be encountered during construction. As such the Applicant proposes a protocol in the Framework CEMP that includes procedures for the reporting, protection and management of unexpected archaeological discoveries. The wording for the protocol is set out in that paragraph. Are relevant LAs satisfied with the Applicant's proposed protocol and its suggested wording in regard to procedures for the reporting, protection and management of unexpected archaeological discoveries.	n/a

APPENDIX 1 OXFORD ARCHAEOLOGY ASSESSING THE IMPACT OF TREE ROOTS ON ARCHAEOLOGY (2024)

Assessing the Impact of Tree Roots on Archaeology

Oxford Archaeology project report for the Forestry Commission

oxford archaeology

August 2024

Endorsements

”It is rare to have archaeology involved in such a pressing issue as the nation's tree-planting. How do you balance the needs of the past, present and future? This report addresses these concerns, as - if our kids are to have a future - the past (i.e. archaeology) should not unduly impede such an essential initiative.” Christopher Evans, Senior Fellow, McDonald Institute for Archaeological Research, Cambridge University

“The need to maintain and enhance biodiversity and increase carbon storage is leading to a growing awareness of the contribution which tree planting and rewilding can make, so careful scientific evaluation of the effects of tree roots on buried archaeological sites and finds is now a priority.” Martin Bell, Professor of Archaeology, University of Reading.

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Assessing the Impact of Tree Roots on Archaeology

Oxford Archaeology project report for the Forestry Commission

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SUMMARY

This report presents the results and findings of the first phase of the Forestry Commission's *Tree Roots and Archaeology* project. The project phase was a collaboration between Oxford Archaeology (OA) and the Forestry Commission, funded by the Nature for Climate Fund.

The Phase 1 study aimed to investigate heritage and forestry professionals' preconceptions and practical experiences of the relationship between tree roots and archaeological remains. It coincides with the UK government's commitment to significantly increase woodland cover across England to meet the net zero target and biodiversity goals (Environment Act 2021), which will raise the incidence of tree planting in areas of archaeological significance. In this context, and bearing in mind the urgency of tackling the global environmental emergency, it is essential that archaeologists and forestry professionals scrutinise their current practices and priorities and build a strong evidence base to guide new tree planting policies relating to the historic environment.

A range of sources were consulted in building this report, including published research, online reports, data held in the Archaeology Data Service (ADS) Library, and heritage and forestry practitioners themselves (via questionnaires and interviews). The findings are summarised in the main report chapters and illustrated with case studies.

The key findings are:

The current approaches to tree planting in areas of archaeological interest are largely built on anecdotal evidence that derives from 'worst case scenarios' where tree roots have damaged archaeology. This view has only been reinforced by the lack of specific detailed field-based research.

Direct investigations of the relationship between tree roots and archaeology are rare. Where these have been undertaken, the findings are complex. The character of the relationship between tree roots and archaeology, including the degree of damage caused, depends on a range of context specific factors and the type of archaeological remains.

There is clear evidence that tree roots do sometimes damage archaeology by displacing and diminishing the preservation of artefacts and ecofacts, blurring stratigraphic relationships, altering the soil matrix and burial environment and making areas inaccessible for further archaeological study. These impacts are primarily localised and unlikely to negatively affect the overall archaeological interpretation of the site.

The level of impact of new tree planting on archaeology needs to be assessed on a case-by-case basis. Afforestation will not be appropriate on all archaeological sites. However, it is likely that past approaches to tree planting in areas of known archaeological interest have overplayed and oversimplified the detrimental impacts of tree roots on archaeology.

Trees also contribute positively to archaeology by enhancing peoples' experiences of archaeological sites, by facilitating the conservation of

upstanding earthworks (helping to stabilise slopes, prevent soil erosion, and discourage anti-social behaviour), by curbing other more damaging forms of land use (e.g. ploughing) and by preventing shrub/fern establishment. In the past, woodland creation has incorporated many archaeological sites and monuments within programmes of long-term land management and these have often been shown to be better preserved than archaeological remains under different land uses or management schemes.

Approaches to tree planting in areas of known archaeological interest are already changing. New 'sensitivity mapping' methods incorporating Historic Environment Record (HER) and LiDAR data are being developed, which will help practitioners to identify the location of archaeological features and to determine their broad significance (Last and Kidd 2023).

The concept of 'adaptive release' – the idea that, in undertaking urgent nature restoration measures, it is sometimes necessary to manage positively the dynamic transformation of heritage assets rather than to stick fixedly to outdated conservation measures built on a thin evidence base (DeSilvey *et al.* 2021) – presents a useful working framework for developing future policies for tree planting in areas of archaeological interest.

Overall, the presence of archaeology should not be seen as a prohibitive block to new tree planting schemes. In the right areas, and with the right planting regimes, it can be seen as a positive step in helping to protect archaeological sites, whilst contributing to valuable biodiversity, carbon capture and environmental goals. However, archaeology should be considered and balanced alongside other ecological and environmental factors, ideally on a site-by-site basis.

ACKNOWLEDGEMENTS

Oxford Archaeology would like to thank the Nature for Climate Fund for funding this project, and the Forestry Commission for collaborating throughout its operation. The Forestry Commission project panel comprised Edward Peveler, Tom Sunley and Jessica Turner.

Thanks also to the Academic Advisory Board for the project: Prof Martin Bell FBA, Professor of Archaeological Science at University of Reading; Prof Michael Charles, Professor of Environmental Archaeology at University of Oxford; and Mr Christopher Evans FBA, Executive Director, Cambridge Archaeological Unit, University of Cambridge.

Thanks to Dr Tim Evans, Department of Archaeology, University of York, for contributing to the project data research stage. Thanks are also extended to all the contributors to the project consultation process, as well as the project interviewees and the questionnaire participants. Anwen Cooper was the internal academic advisor within OA.

The project was managed for Oxford Archaeology by Ianto Wain, head of Heritage Management Services. The interviews were conducted by Anwen Cooper, Carl Champness, Christopher Booth and Maria Bellisimo. Desk-based research was undertaken by David Kay, Carl Champness and Hana Lewis. The final text was written by David Kay, Carl Champness and Christopher Booth. Maria Bellisimo was responsible for the communication strategy and related press.

Left: Creation of new woodland ©Forestry Commission

1-2. *Introduction, aims and methodology*

The purpose of the Tree Roots and Archaeology project is to further our understanding of the interactions and potential impacts of tree roots on archaeological sites and remains within England. A range of sources were consulted in building this report, including published research, online reports, data held in the Archaeology Data Service (ADS) Library, and heritage and forestry practitioners themselves (via questionnaires and interviews). The findings are summarised in the main report chapters and illustrated with case studies.

1 Introduction

1.1 Project Purpose and Background

1.1.1 The purpose of the Forestry Commission's *Tree Roots and Archaeology* project is to further our understanding of the interactions and potential impacts of tree roots on archaeological sites and remains within England. The aim of this project phase (hereafter known as "the project") is to identify and address gaps in the existing published/grey literature and official guidance about the effects of tree roots on archaeology and to carry out a process of stakeholder engagement to provide an assessment of how these interactions may be managed, avoided or mitigated in the future.

1.1.2 The study also aims to investigate and challenge some of the preconceptions that many heritage professionals still hold about the impacts of tree roots on archaeological remains. For many years tree roots have been seen as a significant threat to archaeology, and in particular scheduled monuments. This view was ingrained within the 2008 Monuments at Risk Survey, which reported that 26% of scheduled monuments in the east of England were vulnerable to damage from unmanaged trees, scrub and plant growth. Management solutions were subsequently devised for high-risk monuments, with many sites cleared of trees and shrubs as a part of the overall strategy. Such practices reinforced the idea that trees and roots should necessarily be viewed as a potential threat to archaeological remains.

1.1.3 The timing of this project is opportune, coinciding with a binding commitment by the UK government to plant 30,000 hectares of new woodland per year by 2025 and to further expand woodland cover from its current 14.5% of England's ground surface to 16.5% by 2050 (Shaw 2023, 24). Such goals are integral to meeting the UK's net zero target under The Climate Change Act 2008 (2050 Target Amendment) Order 2019. This will increase the likelihood of tree planting on archaeological sites or in areas of archaeological potential (whether identified or currently unknown). It is therefore of key importance to understand and manage any potential impacts on archaeological resources resulting from new planting schemes.

1.1.4 The UK Forestry Standard (UKFS) makes it clear that heritage assets should be taken into consideration prior to woodland creation. Afforestation (woodland creation on previously un-wooded land over 0.5ha) falls under Environmental Impact Assessment (EIA Forestry) regulations, whereby projects are assessed to determine if they will have a 'significant effect' on the environment. Consideration of impacts on designated and non-designated heritage assets is made through consultation and applicants must submit Historic Environment Record (HER) data as well as evidence of consultation with relevant bodies. The UKFS is used to guide the Forestry Commission's ongoing assessment of afforestation proposals and so applicants are advised to fully utilise it in creating their own woodland plans.

1.1.5 All applications for grants from the Forestry Commission require that these EIA (Forestry) thresholds are met, and all applications must also meet the UKFS's requirements and guidelines. These guidelines state that significant heritage assets should, where possible, be left within areas of open space within wider woodland creation plans. The setting of heritage assets should also be considered as a part of any new planting schemes. Where significant potential has been identified but specific features have not been defined, such areas should be identified within official forest management plans and, if appropriate, then planting should be restricted to smaller trees or shrubs and ground disturbance should be kept to a minimum. If seeking to plant trees in areas of high archaeological potential, then specialist advice should be sought and, if necessary, targeted archaeological surveys undertaken. The archaeological evaluation/mitigation approach adopted by the National Planning Policy Framework (NPPF), most familiar to local historic environment services, does not apply to forestry, given the very different impacts of these two activities. Instead, a risk-based approach is adopted on a case-by-case basis, where avoidance of impacts and "preservation in situ" is the primary solution. Survey work is typically only advised where clarity on the precise extent and character of archaeological features will benefit the aims of the forestry project; otherwise, it is advised that areas of high potential should be omitted entirely.

1.1.6 Following agreement with the Association of Local Government Archaeological Officers (ALGAO) in summer 2023, codified in revision of the Forestry Commission's internal Notification and Consultation procedures in February 2024, all applications falling under the EIA (Forestry) regulations, including woodland creation, must include evidence of contact with the Local Historic Environment Service. Under the requirements and guidelines of UKFS, the applicants must demonstrate that their woodland design takes into account known archaeological finds and features and areas of significant historic environment potential. In addition, during the Forestry Commission's assessment of applications falling under the EIA (Forestry) regulations, FC must again notify the Local Historic Environment Service of the case, offering them a further opportunity to comment. This ensures that Local Historic Environment Services have been contacted twice about these cases and see the final submitted woodland design plan.

1.1.7 To meet the government's Legal Target programme for tree planting, the Forestry Commission identified the need for greater research on the impact of root systems on archaeological assets to better inform new planting schemes. Consequently, this project was set up to review the currently available research on the impact of tree rooting on archaeological preservation; to assess how different factors affect root structure and growth; to explore a range of relevant case studies; to identify gaps within this overarching dataset; and to suggest possible ways that this research could be expanded or enhanced in the future to address those gaps.

2 AIMS

2.1 Project aims

2.1.1 The aims of this project were as outlined within the original tender document issued by the Forestry Commission (2023) and as stated within OA's own project design (OA 2023).

2.1.2 Specifically, the research aims and objectives were:

- to identify current research on the impact of tree roots on archaeological remains;
- to consult with a range of both heritage and forestry professionals about the issues surrounding root systems and heritage impacts;
- to provide a series of suitable case studies that highlight recorded examples of the impacts of roots on archaeological remains;
- to assess the various environmental determining factors that affect root growth, such as tree species, soil depth and type, topography, soil pH, water availability, etc;
- to discuss the physical, chemical and biological impacts of root systems on archaeology;
- to construct an evaluative framework for tree roots and archaeology that will help to inform and guide future decision making;
- to identify gaps in the currently available research and provide suggestions for further research and field testing of assumptions;
- to foster a more positive and collaborative approach amongst heritage and forestry professionals towards tree planting and the protection of archaeology.

2.2 Methodology

2.2.1 The project involved several stages and outputs. Firstly, a literature review was prepared to assess the current state of knowledge and research relevant to the project. It was intended that this should provide a thematic overview of existing research, examining the documented interactions between tree roots and archaeology and identifying gaps in the evidence and source materials which could be addressed by further research. However, the literature review has demonstrated that there are in fact few existing studies on the impact of root systems on archaeological deposits, either within England or beyond (Section 3).

2.2.2 Underpinned by the findings of the literature review, the research and stakeholder engagement stages sought to address the paucity of current research on the subject (Sections 3-5). Key types of interactions between tree roots and archaeology were identified through consultation with a range of heritage and forestry professionals as well as through desk-based data research. Case studies for detailed examination were also selected following the consultation process (Section 4). An overall impact analysis was subsequently undertaken examining the interactions between tree roots and archaeology as collated from the stakeholder engagement and consultation, data research, and case studies findings (Section 7). This data was used to help create an evaluative framework summarising the factors that influence tree root systems and assessing their potential effects on different types of archaeological assets (Section 9). The findings from the project where then used to develop a fieldwork proposal to test the proposed assumptions and address any gaps identified within the existing published/grey literature (Section 10). Finally, the results of the project have been summarised in the concluding section (Section 11), with a communications strategy proposal outlined in Section 12.

Specific methodologies and outputs for each project stage:

2.2.3 Stage 1: Literature Review - Sources for the literature review were initially identified through the scrutiny of references included in the Invitation to Quote document for this project. A review of key bibliographies in those documents was subsequently undertaken to identify further sources. This approach was supplemented by internet-based and in-person research at the Bodleian Library in Oxford to identify and collate additional sources. The literature review includes both UK- and international-based ecological, scientific and archaeological academic publications and unpublished project reports.

2.2.4 This section of the project also included an initial phase of stakeholder engagement, whereby key archaeological contracting organisations were contacted and asked to provide examples of excavation projects which had provided evidence of interaction between tree roots and archaeology. The online Historic Environment Record (HER) Forum Group was also contacted, and its members likewise asked to provide key site examples.

2.2.5 Stage 2: Stakeholder Engagement - A total corpus of 60 heritage and forestry professionals was contacted for further stakeholder engagement. Of these, thirteen key individuals from both forestry and heritage sectors were selected for more detailed consultation. These individuals were then interviewed by the project team at OA and a report produced summarising the results of both these interviews and the findings from the initial literature review.

2.2.6 Stage 3: Data Research and Case Studies - In tandem with the stakeholder engagement process, a data mining search of the Archaeological Data Service (ADS) – the leading accredited archaeology and heritage digital repository in the UK (https://archaeologydataservice.ac.uk/) – was undertaken by Dr Tim Evans at the Department of Archaeology, University of York. The data mining of ADS resources comprised keyword searches of terms such as 'tree root', 'root damage', 'tree throw' and 'clearance'. The search generated some 2,850 results of diverse grey literature sources (unpublished reports and materials produced by various archaeological and other heritage-related organisations).

2.2.7 These results were exported into MS Excel and filtered by the internal project team. Duplicate reports were removed, as well as projects that did not involve archaeological investigations, such as preliminary desk-based assessments. The filtered dataset comprised some 2600 grey literature reports. Due to time constraints, these reports were checked for ready online accessibility, such that online accessible sources were prioritised for relevance. Each report abstract was then assessed for content concerning root and archaeological interactions. This resulted in a pool of c 200 relevant reports, from which a sample of 40 were selected to form the focus of a high-level impact analysis of the effects of tree roots on archaeology (Section 4).

2.2.8 Stage 4: Impact Analysis – A review was undertaken of both the positive and negative impacts of tree roots on the preservation of archaeological resources (Section 7).

2.2.9 Stage 5: Comparing the Impacts with other Land Uses – The impact of root systems on archaeology was compared to the recorded impacts of other land-use activities, eg, arable cultivation (Section 8).

2.2.10 Stage 6: Evaluative Framework Methodology - Building upon the findings of the literature review and results of the stakeholder engagement and impact analysis, an evaluative framework for tree species relative to site and soil types was then produced (Section 9). This is intended as an initial reference tool for assessing the relationships between tree root systems, different environmental variables and types of archaeological assets.

2.2.11 Stage 7: Fieldwork Project Design - Finally, a proposed project design was produced for a separate fieldwork stage intended to address specific gaps within the current research. This fieldwork stage would involve the excavation, recording and assessment of tree root impacts on a selection of representative archaeological sites (Section 10).

2.2.12 Stage 8: Conclusions and Communication Strategy – The results of the different elements of the overall project have been summarised to outline the lessons learned thus far and signpost possible directions for further work (Section 11). A proposal has also been included to indicate how the findings of this report may be disseminated to both forestry and heritage professionals (Section 12).

Left: Sycamore Gap, Henshaw ©Northumberland National Park

3. *Literature review*

To date, there have been very few peer-reviewed papers or technical guidance documents that have focussed on the management and potential impacts of tree and shrub roots on archaeological resources in either England or the wider UK. Of these existing studies, most have focussed on the impacts of tree roots on urban foundations and other structures. Conversely, discussion of the impacts of rooting on archaeological deposits and heritage assets has been largely anecdotal, with relatively few examples of such botanical-archaeological interactions appearing within either published material (reviewed here) or 'grey literature' site reports in any formal capacity.

3 LITERATURE REVIEW

3.1 Introduction

3.1.1 The likelihood of future woodland management, including new tree planting, coinciding with the occurrence of archaeological sites across Great Britain has long been recognised by previous authors (see especially Crow 2004; Crow and Moffat 2005). It is estimated that temperate woodland and forest covers around 11-14% of Great Britain, with over 27,200km2 (2.7 million ha) of land subject to active woodland management (Fig 1). In comparison, some 2.25 monuments exist per sq. km within England alone (Crow 2004, 4; Crow and Moffat 2005, 103), with a significant degree of overlap between the two datasets (see Figs 2-3). This situation emphasises the importance of reaching better understandings of the potential interactions between tree roots and archaeological resources.

See Fig 1: UK land cover, distribution of ancient woodland vs deciduous/broadleaved vs coniferous plantations (Forest Research)

3.2 Previous studies of tree roots and archaeology

3.2.1 To date, there have been very few peer-reviewed papers or technical guidance documents that have focussed on the management and potential impacts of tree and shrub roots on archaeological resources in either England or the wider UK. Of these existing studies, most have focussed on the impacts of tree roots on urban foundations and other structures (eg, Biddle 1992; Cutler and Richardson 1989; Krigas *et al.* 1999; Mishra *et al.* 1995). Conversely, discussion of the impacts of rooting on archaeological deposits and heritage assets has been largely anecdotal, with relatively few examples of such botanical-archaeological interactions appearing within either published material (reviewed here) or 'grey literature' site reports (see Section 5) in any formal capacity. As a result, only a very few synthesised studies have drawn on collated data to assess the form and degree of impacts by tree/shrub roots on the archaeological record, encompassing both *in situ* remains located within discrete sites and more dispersed artefactual/ecofactual assemblages housed in museum collections.

3.2.2 The few UK-based syntheses on this subject include Peter Crow's work for Forest Research (Crow 2005), which reviews the evidence for the effects of tree growth and woodland management strategies on archaeological sites, and his joint work with Andy Moffat (Crow and Moffat 2005) which assesses the primary influencing factors which mediate the management of wooded environments vis-à-vis archaeological landscapes. Research encompassing broader geographical areas include Johnson's (1998) review of archaeology and forestry policy frameworks in Ireland, Tjelldén *et al.*'s (2015) study of the impact of both roots and rhizomes (underground plant stems) on wetland archaeological sites across Europe, and that of Matthiesen *et al.* (2020) in examining the influence of different plant species on archaeological preservation at sites located within the circumpolar Arctic. Overall, most of the existing literature serves to highlight the paucity of relevant information currently available for England or the wider UK. Moreover, non-British-based studies are not necessarily translatable to UK contexts given their tendency to focus on niche environments not found within the British Isles, or which whilst present have not been identified as priority areas for future woodland development.

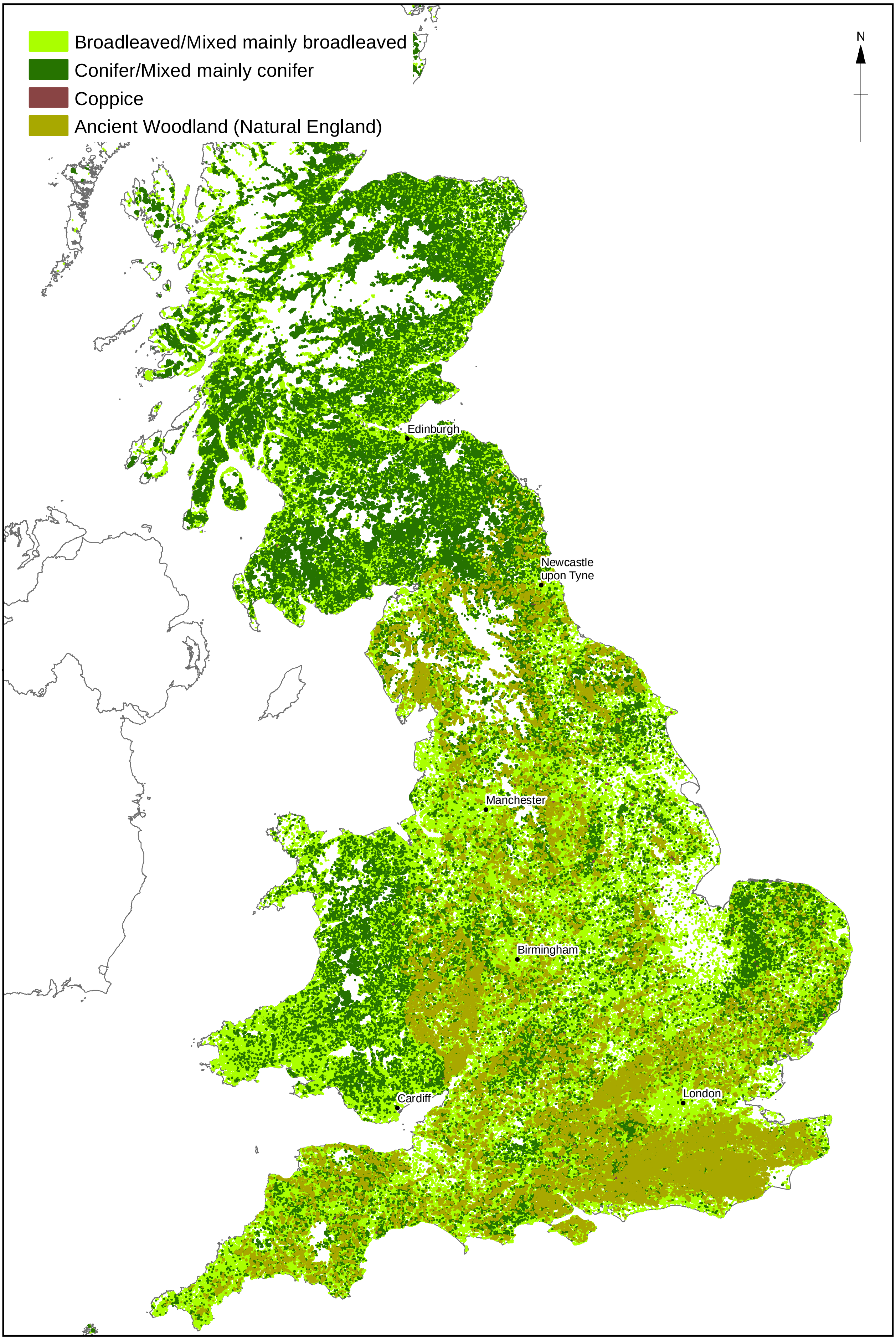

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Figure 1: UK land cover, distribution of ancient woodland vs deciduous/broadleaved vs coniferous plantations

See Fig 2: Sensitivity mapping for future tree planting, and ADS/HER data (Forest Research and ADS)

3.3 General perceptions of rooting impacts

3.3.1 It is generally perceived that tree roots do impact archaeological remains. For instance, Crow and Moffat remark that the expansion of woodland onto former agricultural land may lead to conflict between archaeologists and foresters "because of [the] perceived detrimental effects of tree growth and forestry practices on archaeological evidence" (Crow and Moffat 2005, 103). However, they also point out that such perceptions belie the underlying complexity of the relationships they address, and that flexible woodland management strategies could contribute towards actively conserving archaeological assets in some cases (Crow and Moffat 2005, 103, 112). To explore such possibilities, they advocate for greater consultation between archaeological/heritage professionals, foresters, and land managers (Crow and Moffat 2005, 103, 112-113).

3.3.2 Most of the existing archaeological literature considers rooting, trees, and vegetation in general, to have the potential for both positive and negative effects on the preservation of heritage assets (see especially Caneva 1999; Matthiesen *et al.* 2020, 142).

3.3.3 The principal positive effects of trees on archaeological sites have been identified as:

- the amelioration of anthropogenic noise and visual pollution, eg, from nearby roads (Caneva 1999)
- the shading out of damaging bracken and scrub growth (Crow 2004)
- assisting in the biotic reconstruction of historic landscapes (Caneva 1999)
- reducing weathering vectors and subsequent erosion regimes (Caneva 1999; Darvill 1987; Caple 2016; Gyssels *et al.* 2005)
- stabilising sloped features such as banks and other earthworks (Barclay 1992; Farstadvoll 2019)
- preventing damage caused by agriculture or active development (Crow 2004; Crow and Moffat 2005; Shaw 2023).

3.3.4 Conversely, potential negative effects include:

- physical damage caused by root pressure, etching and mechanical displacement (Caneva 1999; Caneva *et al.* 2006; 2009; Cox *et al.* 2001; Crow and Moffat 2005; Johnson 1998; Tjelldén *et al.* 2015)
- damage and/or complete removal resulting from tree throws and the uprooting of other vegetation (Crow and Moffat 2005; Norman 2003)
- changed preservation conditions arising from altered soil and groundwater chemistry (Aalto *et al.* 2013; Crow 2008; Hollesen and Matthiesen 2015; Matthiesen *et al.* 2015; Mitsch and Gosselink 2015; Tjelldén *et al.* 2015)
- changed soil moisture and/or groundwater levels (Cox *et al.* 2001; Hollesen and Matthiesen 2015; Matthiesen *et al.* 2015; Tjelldén *et al.* 2015)

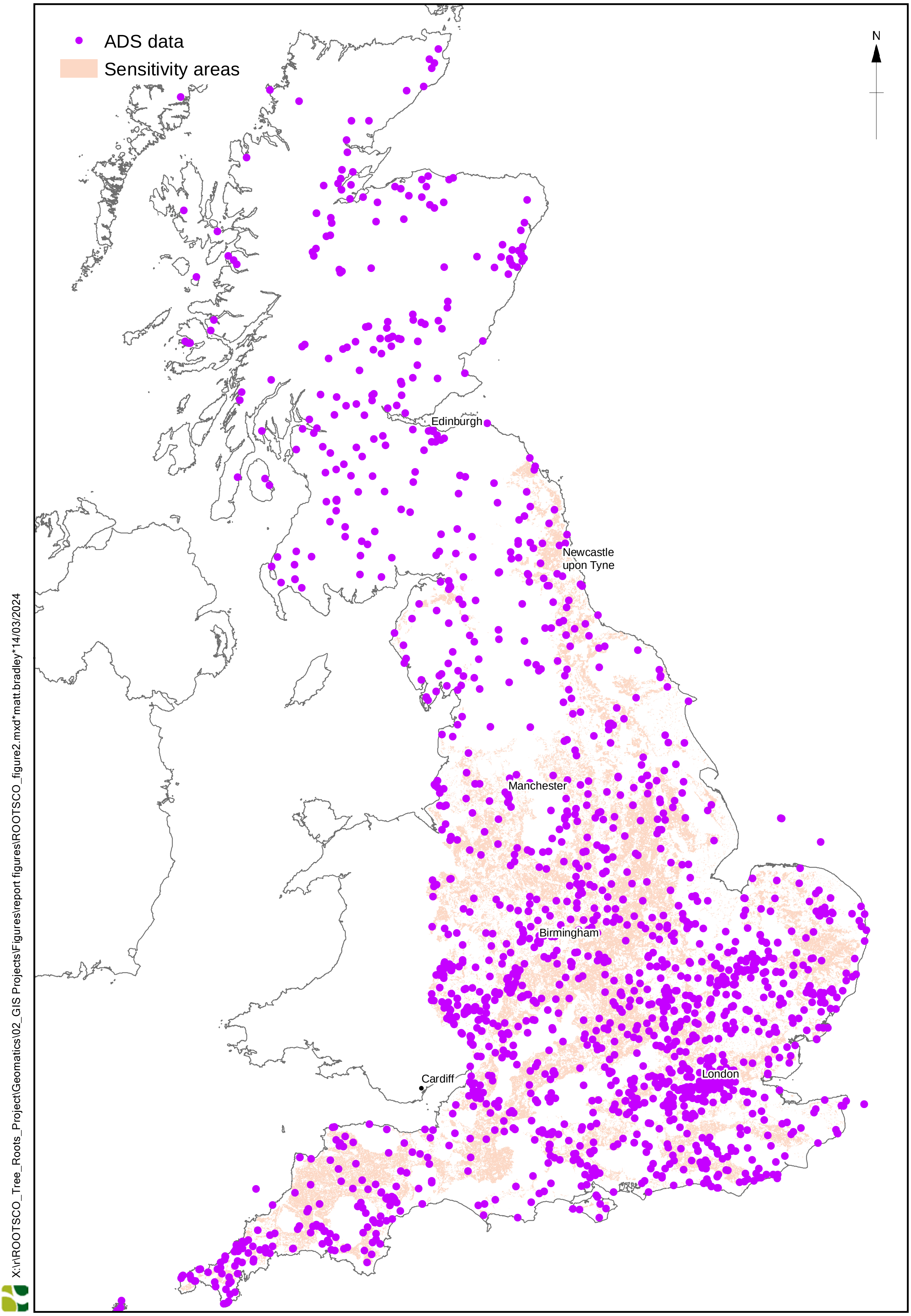

Figure 2: Sensitivity mapping for future tree planting, and ADS/HER data

- increased populations of burrowing animals leading to higher rates of bioturbation (Taylor 1994; Thackray 1994)
- forestry operation such as tree planting and harvesting (Crow 2004; Crow and Moffat 2005; Tjelldén *et al*. 2015).

3.3.5 A fuller discussion of the physical, chemical and biological mechanisms underlying these general effects is included in Section 6 of this report, alongside assessments of the degree to which they may potentially impact different kinds of archaeological deposits.

3.4 Tree rooting at specific archaeological sites

3.4.1 There are comparatively few studies focussing on the interactions of roots, or vegetation generally, on archaeological remains and this section highlights some of these examples in a thematic manner. Although there are case studies from archaeological sites in different geographical areas and habitats, examples from within England are scarce.

Dryland landscapes

3.4.2 Very few archaeological projects have explicitly focussed on the effects of present-day vegetation roots (of trees or otherwise) on dryland sites. A notable exception was the Dartmoor Archaeology and Bracken Project of 1999-2011, the aim of which was to quantify the impact of bracken (*Pteridium aquilinum*) rhizomes on the preservation of a prehistoric roundhouse at Teigncombe and other archaeological deposits in the surrounding area (Gerrard 2014). Project members developed a novel methodology to facilitate the rapid assessment of rhizome impacts at various depths and found that whilst bracken rhizomes always incurred sedimentary displacement, the degree to which such displacement disturbed the integrity of archaeological contexts proved highly variable (Gerrard 2014; 2016). This project also highlighted that the presence of trees creating locally closed canopies could restrict light levels, inhibit bracken growth, and thus potentially mitigate the damage that bracken rooting systems were causing to sub-surface heritage assets (see above).

3.4.3 A notable thematic exception to the general trend is the attention that has been paid to the presence and impact of tree throws on dryland archaeological sites, though only rarely has this attention been focussed into specific research agendas. For instance, Norman's (2003) MSc thesis on the subject uses the Wendt archaeological site (a prehistoric lithic quarry workshop) located in Superior National Forest, Minnesota, demonstrated how disruptive uprooting events can be on stratified deposits. They are particularly disruptive of artefactual assemblages, whereby select artefacts are pulled from the soil with the roots, before falling back later as a biologically sorted group (Norman 2003, 104). Such effects are especially disruptive on lithic sites like Wendt where context integrity and careful stratigraphic control during excavation are vital to the subsequent interpretation of the assemblage/site.

3.4.4 Langhor's (1993) review of predominantly European tree throw morphologies further identified that the sedimentary scars left by uprooting events can vary in their size and shape according to a) tree species, b) substrate type, c) topographic location, and d) force vector, but that regardless of such variances they remain common across all soil-geomorphic units. He again observes that tree throws can lead to considerable reordering of archaeological deposits and the loss of context integrity, though notes that in some cases parts of the original profile may remain internally cohesive albeit reoriented within the surrounding matrix. Artefact assemblages are also liable to mining from lower contexts and can become admixed with the material residue of later activities that took place within/near the tree throw hollow itself (Langhor 1993, 42-45).

3.4.5 Lastly, more recent landscape-scale projects making use of LiDAR (Light Detection and Ranging) technology have identified many instances where large swathes of the historic landscape have been beneficially preserved within current woodlands (Crow *et al.* 2007; Crutchley 2008; Lennon and Crow 2009; Schindling and Gibbes 2014). A key example is the 2014-2017 Secrets of the High Woods project, which captured LiDAR data from across the South Downs of West Sussex. This project revealed a complex archaeological landscape extending from the first Neolithic farmers right up to the Second World War, all protected by the blanketing tree cover from damage that is otherwise likely to have occurred via other land uses such as agricultural ploughing or active development (Manley 2016). However, it should also be noted that such methods are only able to discern the presence of archaeological features where they leave a topographic imprint on the ground surface itself (either positive or negative), and not where such features lie more deeply buried within the sedimentary profile or have already been truncated/ploughed to a level surface.

Wetland sites

3.4.6 Tjelldén *et al.* (2015) recognise that whilst waterlogged (ie, anoxic) environments can lead to remarkable levels of preservation for organic archaeological remains, the beneficial impact of these conditions may be adversely affected by the presence of both roots and rhizomes (Tjelldén *et al.* 2015, 370-371, 376-377). Changing water tables in wetland environments can result in habitat changes that favour the colonisation of new plant species (particularly those which prefer higher oxygen levels within the rhizosphere), which in turn may damage *in situ* archaeological materials and/or deposits (Tjelldén *et al.* 2015, 370, 381-383). The authors of this project stress the need for more interdisciplinary approaches to assessing the impact of plant roots on wetland archaeological sites, and in considering which vegetation control strategies may be most appropriate (Tjelldén *et al.* 2015, 372).

3.4.7 Relatedly, Cox *et al.*'s (2001) evaluation of the Neolithic Abbot's Way wooden trackway in Somerset has stressed that appropriate management practices need to be deployed not just on sites themselves but also neighbouring land parcels. In this case, deliberate planting of birch trees on the fringes of the site had led to further tree colonisation and significant dewatering from 1983-1992. The lowered groundwater table and increased seasonal fluctuations had resulted in significant degradation through attack by aerobic fungi and bacteria. Lignin-based organic compounds in particular had been greatly affected by both white rot fungi (*Phanerochaete* spp.) and mycorrhizal species associated with both birch (*Betula* spp) and willow (*Salix* spp) (Cox *et al.* 2001, 1082-1083; cf Hasselwandter *et al.* 1990). The roots of birch were themselves observed to have caused mechanical deformation and fragmentation of the Neolithic timbers, and to a lesser extent those of willow and rosebay willowherb (*Chamaenerion angustifolium*) (Cox *et al.* 2001, 1072-1073). Importantly, these factors had been exacerbated by the presence just outside the site of extensive mid-twentieth century peat cuttings and a modern-day deep drainage channel, both of which acted as sumps further drawing groundwater away from the site itself. Such effects not only adversely affected timber preservation, but through facilitating the fungi-stimulated breakdown of chitin compounds led to the almost total loss of palaeo-entomological remains, precluding the site from any future archaeological insect analyses (Cox *et al.* 2001).

3.4.8 Similar dewatering effects have also been noted for the nearby Sweet Track, albeit to a lesser degree, and again linked to the growth of secondary woodland where the track runs through what is now Shapwick Heath National Nature Reserve. In this case, excavations in the early 1980's uncovered dense root mats extending down to 0.4m below ground level, with large desiccation cracks visible through the peat down to the level of the trackway itself at c 0.8m depth. However, such effects were only observed on a localised basis, and not in every excavation trench. Moreover, peat extraction since 1940, coupled with the more recent drainage of nearby agricultural land and quarrying, has probably had a far greater impact on sub-surface dewatering than recent tree growth *per se*, particularly when considered over a longer period (Brunning *et al.* 2000, see also Brunning 2013, Chapter 3). In such cases, tree felling within *c* 10m-wide buffer zones running directly alongside the buried archaeological timbers has been pursued as an effective means of reducing evapotranspiration and maintaining the waterlogged site conditions preferred for the continued preservation of organic remains, though almost always in conjunction with more direct methods such as water pumping and bunding (Brunning *et al.* 2000; Holden *et al.* 2006).

Low Artic / periglacial landscapes

3.4.9 Though less directly relevant to the UK, a study into the effect of rooting damage to archaeological sites in West Greenland also identified issues of reduced access and visibility resulting from vegetation overgrowth (Matthiesen *et al.* 2020). As average temperatures across the region increasingly rise (Stocker *et al.* 2013), so previously frozen landscapes are beginning to thaw, both causing the direct deterioration of sub-surface palaeoenvironmental archives (Hollesen *et al.* 2018) and the expansion of shrub-dominated vegetative communities into both tundra and montane habitats (Formica *et al.* 2014; Matthiesen *et al.* 2020, 142; Myers-Smith *et al.* 2015; Normand *et al.* 2013). The larger and more extensive root systems of these shrub species were in turn found to have adversely affected *c* 38% of the bone fragments collected from six archaeological test pits, causing etching/fragmentation of the bone inclusions alongside displacement of the archaeological horizons, and in some cases increasing oxygen levels within previously anoxic layers (Matthiesen *et al.* 2020, 143-150). The study further deduced that "the potential damage from roots depends on root depth, which determines if damage only occurs in the uppermost soil layers or continues down through the archaeological deposits", with deep rooted species like field horsetail (*Equisetum arvense*) having much greater impact than shallowly rooted ones, such as grey willow (*Salix glauca*) (Matthiesen *et al.* 2020, 145). These findings may well be mirrored in some UK contexts, particularly those in more montane environments not dissimilar to those of the peri-Artic, although targeted research would be required to verify if this is indeed the case.

Urban sites

3.4.10 Most archaeological studies that have focussed on the effects of tree rooting are those concerned with their impacts on building foundations and standing masonry structures, both of which are commonly associated with urban sites (whether past or present). The case of the Emperor Nero's Domus Aurea (Golden Palace) in Rome is a particularly oft-cited example. This grand building was completely buried shortly after Nero's death in AD 68, with the remaining walls used as foundations for the extensive bath complex subsequently erected by Trajan. The Horti Traianei public gardens were then established on the site during the twentieth century, with the ground surface now lying some 3-4m above the Roman archaeological remains (Caneva *et al.* 2006, 163-164). Recent excavations demonstrated that tree roots (principally those of stone pine *Pinus pinea*, holm oak *Quercus ilex*, northern white cedar *Thuja occidentalis*, chinaberry tree *Melia azedarach* and tree of heaven *Ailanthus altissima*) from garden plantings had damaged the buried building's vaults, in some cases resulting in considerable structural problems, including the displacement and collapse of multiple ceiling stones.

3.4.11 The particularly deep and extensive roots systems of exotic chir pine (*Pinus roxbourgii*) had caused by far the greatest damage, with roots not only causing displacement of the archaeological substrate through direct penetration and pressure exertion, but also by creating destabilising voids and water access points within the masonry structures as roots died and decayed. It was also noted that the removal of a large *Thuja occidentalis* specimen had caused additional damage to the underlying archaeology where structural consolidation efforts had not been subsequently undertaken (Caneva *et al.* 2006, 163-167). Similar effects were also noted on the subterranean Jewish catacombs of the Villa Torlonia, also in Rome, where the strong root systems of garden-planted specimens of fig (*Ficus carica)*, holm oak, fan palm *(Washingtonia filifera)* and stone pine had caused ingress and weakening of the below-grown hypogea (Caneva *et al.* 2009). These two studies both highlight how tree roots can directly impact archaeological structures, but also how horticultural/silvicultural and site management practices interact with such botanical factors, particularly in cases where exotic species have been planted in garden contexts over archaeologically sensitive deposits.

3.4.12 Whilst trees may themselves impact on archaeological structures in this way, so too will associated woodland species, especially those with strangler characteristics. Common ivy (*Hedera helix*) has been shown to have particularly damaging effects, the most benign being simple visual impact, whilst the more serious involve the loss of jointing or small stone fragments through rooting pressure (Bartoli *et al.* 2017). Admittedly, the study in question again focusses on Mediterranean contexts where hot-climatic weathering effects are significantly greater than in temperate Britain, such that the correlations with ivy rooting are unlikely to be the same in both cases. However, the point stands that rooting of trees and associated woodland species have been reported as causing significant impacts on both below- and above-ground archaeological structures.

3.5 Conclusion

3.5.1 The literature review has highlighted that although select studies have specifically investigated the impact of tree roots on different types and classes of archaeological assets, they have been relatively few respectively to the scope of the wider issue. This is particularly true for studies located within the UK itself. Moreover, whilst there is some supporting evidence for both positive and negative aspects to the interaction of trees with archaeological deposits, the data is widely scattered, and only occasional attempts have been made at a broader synthesis. As such, the following Section 4 of this report returns to the biological framework of tree root developmental and their varied responses to/effects on other environmental factors, before considering again the implications these may have for the preservation of heritage resources, both as already reported and with a view to framing the new research reported in Sections 4-9.

Left: Rodmartin Long Barrow, Cirencester ©GCCA services

4. Data Research and Case Studies

This section presents a high-level impact analysis of archaeological fieldwork projects in England, along with some comparative examples from Scotland, that have documented the interaction of tree roots and archaeology. Following on from the data collected above, together with the examples identified by the interviews and literature review, a range of more detailed case studies were selected to illustrate some of the main issues raised.

4 DATA RESEARCH AND CASE STUDIES

4.1 Introduction

4.1.1 This section presents a high-level impact analysis of archaeological fieldwork projects in England, along with some comparative examples from Scotland, that have documented the interaction of tree roots and archaeology. The data underpinning the analysis was obtained from Archaeological Data Service (ADS) data research, and the methodology is described in Section 2 of this report. The findings support the overall impact analysis for the project, presented in Section 7.

4.2 ADS Sample Set

4.2.1 The c. 50,000 grey literature reports held by the ADS were key word searched for root-related activities. A total of 2,600 records (representing only 5% of the dataset) were flagged for the keywords and forty sites or entries were select for more detailed consideration. This broke down into twenty four of the sites contained buried archaeological resources, Thirteen had structural remains, and 3 sites contained both buried and structural archaeology. The forty sites were divided in terms of:

- location (over 20 English shires/counties represented, and five sites in Scotland);
- archaeological investigation type (watching briefs, evaluations, surveys, etc);
- site types (rural sites, urban sites, scheduled monuments);
- archaeological features and finds (buried archaeology, such as ditches, layers or tree-throw holes, structures, such as walls, artefacts, ecofacts, including human remains, etc).

Fig 3: ADS data with UK land-use (Forest Research and ADS)

4.3 Data Research Findings: Impact Analysis

4.3.1 Analysis of the ADS demonstrated that the large majority of the archaeological investigations do not mention any root or tree impacts, and those that do are very specific (Tables 1 and 2). This finding was somewhat unsurprising given that the data research methodology involved keyword searches such as 'root damage/disturbance', tree-throws, tree clearance and tree covered archaeology (see Section 2).

4.3.2 The significantly smaller number of sites with no or unclear impacts can, at least in part, be attributed to the broader tendency for archaeological reports to not document tree roots if only minimal (or no) negative impacts were observed. Therefore, whilst the archaeological literature does contain examples of site damage through forest operations or tree throws, there are exceptionally few that provide any detail on the direct impacts of tree growth or root impacts. Tree roots are rarely recorded during archaeological excavations and few references are made to them in published reports. Direct impacts are often not mentioned in reports, and only recorded as dotted lines on stratigraphic sections that will not be recovered in data searches. Moreover, where no concerns or reports of damaged archaeology within woodlands have been raised, so such sites will be considerably underrepresented within any data-

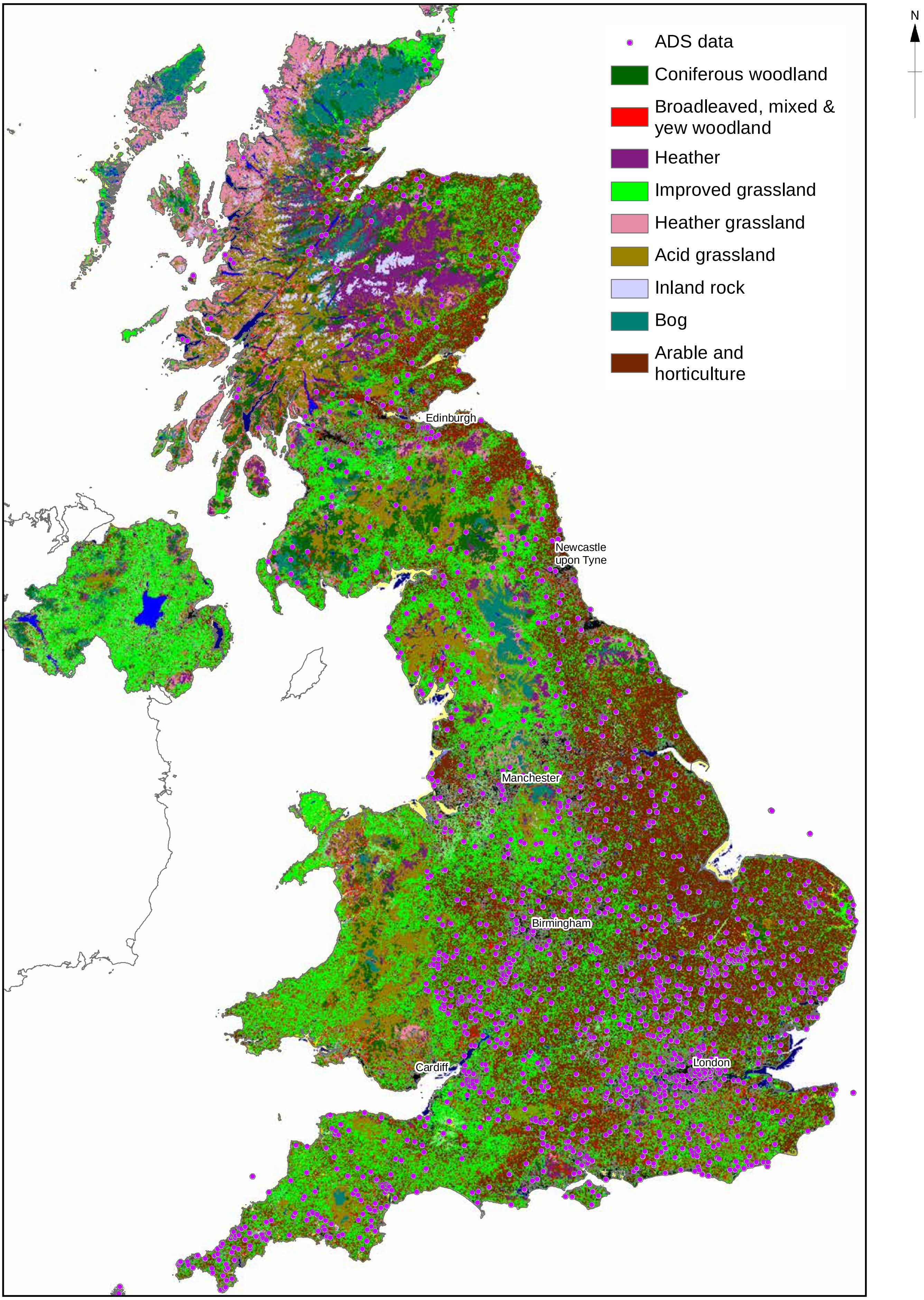

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Figure 3: ADS data with UK landuse

mining exercise. Within this particular sample set, the few examples of non-harmful impacts included tree and tree root features, notably tree-throw holes and boles, which were recorded as being present on sites but not disturbing the archaeological record itself.

Table 1: ADS sample set: archaeological impacts

Archaeological impacts	Number of sites
Identified impact	33
No impact	4
Unclear impact	3

Table 2: ADS sample set: impacted archaeological resources

Impacted archaeological resources	Number of sites
Buried features	21
Structures (ie walls; moat etc)	14
Finds (artefactual / ecofactual)	4

4.3.3 Several key impacts on archaeological resources were documented within the sample set (Table 3). Stratigraphic (buried features) impacts, followed by structural impacts, were by far the two most common types, reflecting the predominantly buried and structural archaeological assets of the sites concerned (see Table 2). The key impacts were caused by roots themselves or, less commonly, *in situ* tree stumps. There were also instances of recorded animal activity, potentially highlighting associations between woodland habitats and faunal disturbance.

Table 3: ADS sample set: type of impact

Type of impact	Number of sites
Stratigraphic Impacts eg – *archaeological feature truncation; archaeological disturbance/obstruction from rooting or in situ tree stumps; bioturbation etc*	21
Structural Impacts eg – *subsidence; destabilisation; collapse; warping etc*	14
Artefactual Impacts eg – *artefact intrusiveness / residuality (redeposition); archaeological context dating insecurity, due to in situ artefact uncertainty etc*	2
Ecofactual Impacts eg – *ecofact intrusiveness / residuality (redeposition); ecofact deterioration due to root interaction including root etching (roots adhering to bone) etc*	2
Animal activity	3

Impacts eg – *animal burrowing truncating archaeological features etc*	

4.3.4 The identified impacts were primarily either:

- localised impacts, eg, root and/or animal disturbance present in one or some areas of the total investigated site area; or
- potentially repairable or reversible impacts, eg, partially collapsed walls or subsiding structures and surfaces.

4.3.5 As a result, general interpretation and dating of the archaeological resource remained possible at most sites.

4.3.6 All key impacts of the ADS sample set were also identified in the consultation process, questionnaire and interview responses, demonstrating the occurrence of these impacts. An overall detailed impact analysis for the combined responses and findings of the project is presented in Section 7.

4.4 Case Studies

4.4.1 Following on from the data collected above, together with the examples identified by the interviews and literature review, a range of more detailed case studies were selected to illustrate some of the main issues raised. These are discussed further below and summarised in Table 4.

Table 4: Summary of case study findings

Case study	Site	Type of archaeology	Primary tree species	Observed impact on archaeology
1	Danebury, Hampshire	Iron Age hillfort	Beech (*Fagus sylvatica*)	General pattern of root disturbance throughout thin soils and fracturing/chemical disintegration of underlying bedrock. Tree throws uprooted some archaeological remains but did not significantly impact the interpretation of the wider site.
2	Highwood, Oxfordshire	Romano-Celtic temple	Beech, oak (*Quercus* sp.), holly (*Ilex aquifolium*)	Presence of buried walls partially masked by root disturbance during geophysical survey. Roots disturbed some floors/areas of roof collapse, with stumps growing adjacent to walls. Limited evidence of root penetration of wall foundations themselves (preferred to grow around them). Woodland provided overall greater protection of earthwork features

				than adjacent arable fields.
3	Welshbury, Gloucestershire	Post-medieval charcoal platform	Conifer (species not recorded)	Archaeological deposits completely displaced by tree bowls, but intact below. Presence of roots made access difficult and their removal delayed progression of excavation. Wider feature retained stratified deposit sequence and good preservation of charcoal/other palaeoenvironmental remains.
4	Teigncombe, Devon	Prehistoric roundhouse	Bracken (*Pteridium aquilinum*) (trees not recorded)	Significant displacement of shallowly buried archaeological deposits by rhizome activity, plus direct damage from stipes. Chemical exudates observed to increase weathering of wall orthostats. Experimental stocking to control bracken growth caused even greater damage to underlying archaeology. Local tree cover reported to reduce bracken growth.
5	Hampton Court, London	Medieval to post-medieval palace	Norway maple (*Acer platinoides*)	Extensive, near-surface, large horizontal roots largely overlay archaeological remains and rarely penetrated buried brick structures. Area of greatest impact observed where root penetrated through pre-existing weakness in brick wall.
6	Windy Harbour, Lancashire	Mesolithic to Neolithic waterlogged remains	Alder (*Alnus* sp.)	Fine root systems partially blurred stratigraphic boundaries and resulted in some mixing of artefacts and environmental remains. Carbon dating revealed presence of small number of intrusive cereal grains, though majority of assemblage appeared to remain *in situ*.

7	Burnham Beeches, Buchinghamshire	Prehistoric or medieval earthworks	Beech	Extensive near-surface rooting obscured stratigraphic relationships and introduced some intrusive material. Little to no impact on more highly compacted deposits. Unclear extent to which rooting actively affected interpretation of features.
8	Hope Shale Quarry Derbyshire	Roman civilian settlement associated with a fort	40 year old mature trees	The preservation of archaeological features was found to be no less clear under the wooded area than the other three unwooded fields. The only mention of root disturbance in the preliminary report was a limited number of artefacts emanate from the observation of tree plucking within the purported vicus annexe that had been displaced and were not found stratified within features.

Case Study 1: Danebury Hillfort, Hampshire

4.4.2 One of the most prominent examples is the Iron Age hillfort at Danebury in Hampshire, which had widespread woodland cover. Excavations occurred annually on the monument between 1969 and 1988 (Cunliffe and Poole 1991). The hillfort is one of the most extensively studied examples in Europe and a Scheduled Monument and part of a Site of Special Scientific interest. When Hampshire County Council purchased the hillfort in 1958, the earthworks were covered in beech trees. Most of these trees had reached a stage where they had become unstable due to disease and prone to tree-throw. A long-term program of removal began from the 1960s to protect the earthworks and buried archaeological remains.

4.4.3 At the time of the Cunliffe and Poole report, 0.9ha (17% of the fort interior) remained covered with mature beech. By 1988, 3.1 ha (57.3 % of the interior) had been excavated. Out of the six volumes that formed the Danebury Report (Cunliffe 1995) there were little references relating to tree growth or the impact of roots on the archaeology. Volume one (Cunliffe 1984) referred to the uprooting of beech trees following the death of diseased trees and the increased exposure of the remaining crop due to the canopy being broken.

4.4.4 A general pattern of root disturbance in the soil was observed in the field but not reported. This was described as a thin soil, typically only 20cm thick overlying chalk into which roots had penetrated to a depth of 50-60 cm causing it to fracture and lift. Chemical disintegration was also seen, with the chalk becoming "grey and pasty". Often the tree root/chalk mass was lifted, and soil had entered the interface between the lifted chalk and the *in situ* bedrock. One estimate of the extent of disturbance was that an average mature beech tree severely damaged an area 2-3m in diameter, to a depth of 0.6-1.0m.

Fig 4: Photo of the excavation showing the tree stumps at Danebury (Cunliffe 1991-95)

4.4.5 The outer rampart on the southern side of the monument remains wooded today with beech trees, although the inner ramparts have been cleared. A flock of sheep graze at Danebury. Hampshire County Council website says: "The Countryside Service work in partnership with a local grazier to provide a 'conservation flock' of Manx Loughton sheep. This is a traditional breed that are very similar to the sheep that would have been at Danebury in the Iron Age".

Fig 5: Present data image of the partly wood and cleared earthworks at Danebury (©Google)

4.4.6 The focus of the Danebury project was to study, interpret and record the archaeology of the site and not specifically to examine the rooting habits of mature beech trees. It is therefore not surprising that published references to the roots were rare. The field observations provide useful information, any archaeological evidence located within shallow deposits and near to a mature tree was at risk of disturbance or damage. The impacts of the former beech tree-throw were not sufficient as to detrimentally impact the interpretation of archaeological remains at the site. Areas of tree-throw, where the roots had uprooted the archaeological remains, was where the most impacts were recorded.

Case Study 2: High Wood Roman-Celtic Temple, Harpsden, Oxfordshire

4.4.7 The site of High Wood lies in mainly deciduous woodland in Harpsden, South Oxfordshire, at an altitude of 90m and covers about 0.4 hectares. It is located on a plateau of high ground, surrounded by chalk lands, and lies on Winter Hill Gravels. The deciduous woodland cover is underlain throughout with brambles and bracken and extensive clearance was needed to reveal the terrain. Mature beech, oak and holly trees surrounded the site and constrained excavation.

4.4.8 In 2015, the South Oxfordshire Archaeological Group (SOAG) started a four-year programme to investigate the reports of Roman finds and the discovery of potential walls (Hall *et al.* 2022). They found a site that had evidence of widespread looting and Roman ceramic building material strewn across the area. The Henley Archaeological and Historical Group (HAHG) originally explored the site and excavated a potential mound between 1977 and 1983, which they initially believed to be a windmill mound. The discovery of a significant concentration of Roman finds and metal artefacts, including 1 tonne of building material, frequent pottery, animal bone and wall plaster.

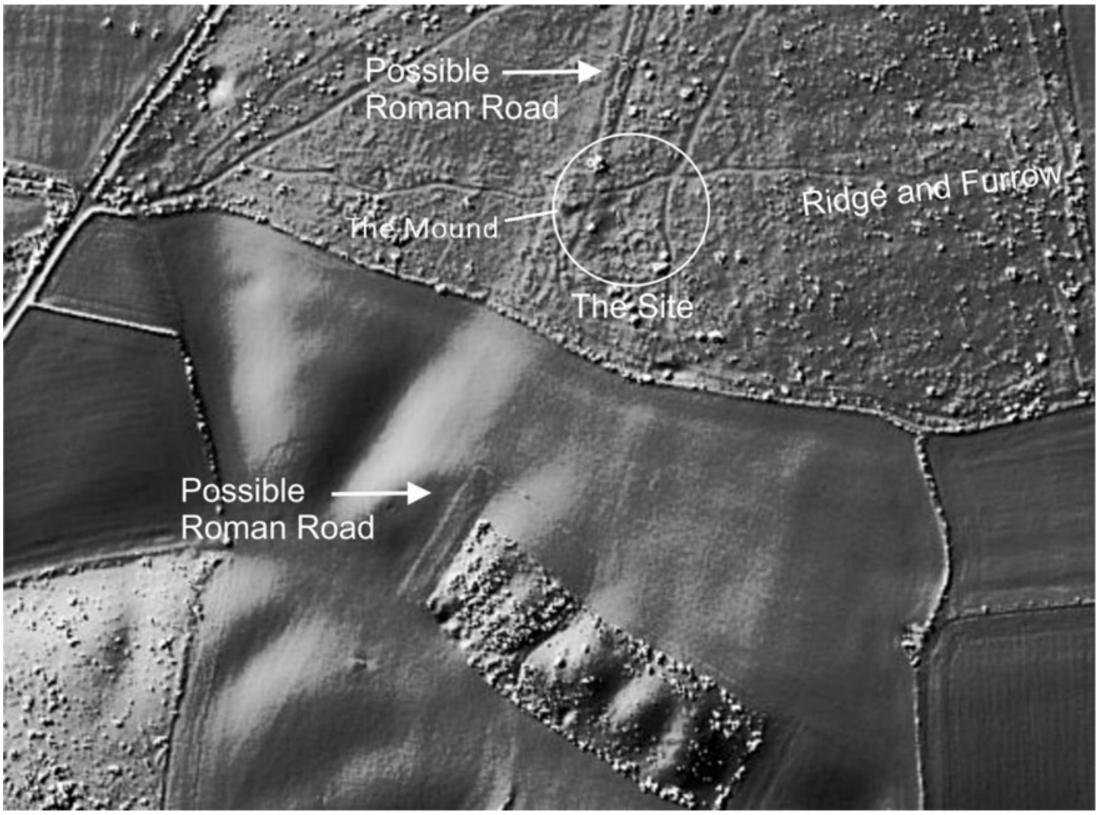

Fig 6: LiDAR image of High Wood, Harpsden, Oxfordshire, showing earthworks preserved in the woodland (©Oxford Archaeology)

4.4.9 Investigation of the area to the east of the mound identified an apparent wall and significant quantities of quern/millstone pieces during the initial vegetation clearance of the site. A geophysical survey revealed no clear structures, but the presence of walls appeared to be masked by root disturbance and flint spreads. Only a program of test pitting focusing in areas of the looting pits were able to provide evidence of structural remains.

Fig 7: Photo of tree stump next to the Roman temple wall at High Wood, Harpsden, Oxfordshire (©Oxford Archaeology)

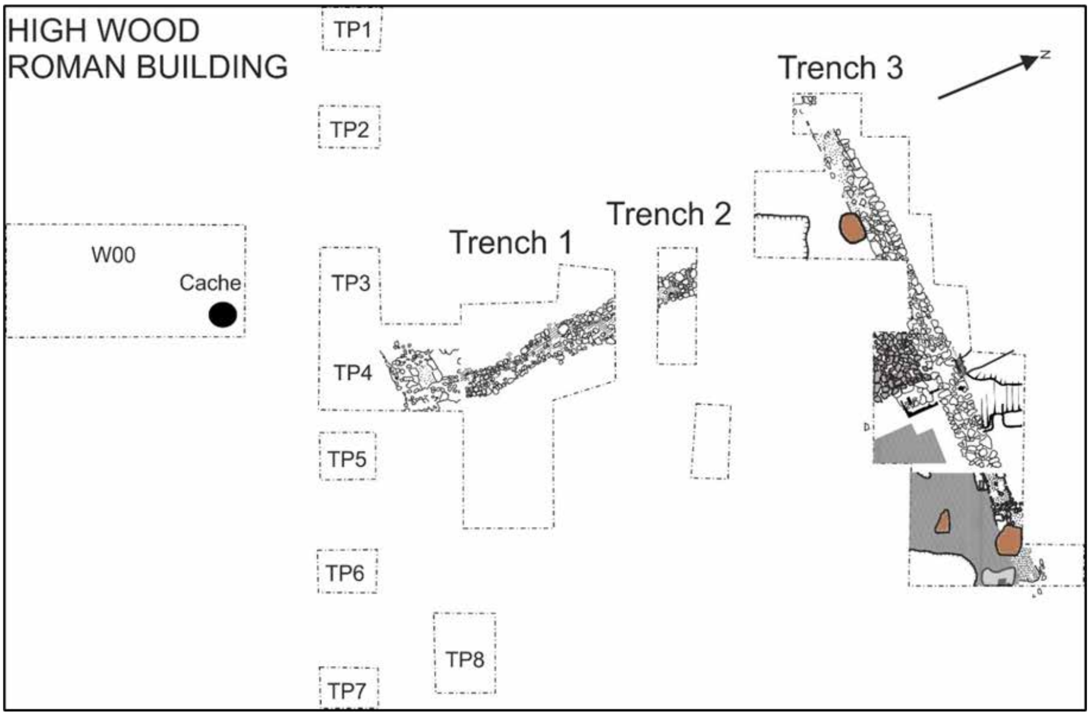

Fig 8: Plan of tree impacts and Roman archaeological remains at High Wood, Harpsden, Oxfordshire (Hall 2022)

4.4.10 The remains of a Roman-Celtic temple were revealed with intact cobbled stone walls, collapsed roof tiles and floor surfaces (Hall 2022). The impact of roots can be seen on the photos and plan of the site (Figs 7 and 8), where tree roots had encountered the walls. Tree stumps can be seen growing adjacent to the walls and also localised areas of the floor surface and areas of roof collapse showed signs of root disturbance. Only limited evidence of root impacts was identified on the wall foundation which were very solid and substantial. Instead, the roots were not seen to penetrate the walls but rather the larger roots grow above, while the inner roots surrounded some of the walls. The roots could be seen to follow 'the path of least resistance' and only penetrated parts of the structure which had already seen disturbance, collapse or decay.

4.4.11 Both the earthwork and buried Roman structures were seen to be preserved under the woodland, and still allowed for the interpretation of the features and site. Some of the earthwork features did not survive outside of the woodlands in the areas of arable cultivation. The most significant evidence of disturbance was from antiquarian digs and nighthawking (illegal metal detecting) at the site that has occurred since the early 1980s. Including the remains of Roman chainmail armour that was found in Tesco's bag at the site along with modern spades and shovels.

Case Study 3: Welshbury Charcoal Platform, Forest of Dean, Gloucestershire

4.4.12 An investigation of a charcoal platform was undertaken at Welshbury, in the Forest of Dean, Gloucestershire (Hoyle 2008) to assess the impact of tree roots and other forestry operations on the archaeological survival. A secondary aim was to assess the archaeological survival of the charcoal platforms, and their potential preservation for dating and palaeoenvironmental material.

4.4.13 Charcoal platforms are the surviving remains of a process of charcoal production in which wood was converted to charcoal by roasting in earth-covered stacks or clamps (Kelley 1996). This method of production was used throughout the Romano-British, medieval and post-medieval periods and provided industrial grade fuel, primarily for the smelting of iron, and it is likely that charcoal production was a significant industry in this area from the Romano-British period until the introduction of the coke fired blast furnace in the early 19th century (Hoyle 2003b, 3.3.2.1).

4.4.14 The surface of approximately one half of the platform was cleared and cleaned by the removal of debris and loose overburden, which consisted of a thin deposit of incompact conifer litter that had constituted the surface of the woodland floor prior to excavation. The roots of two mature conifers were within the excavated area and two others were immediately adjacent to the area. They were recorded in the main section of the excavated trench.

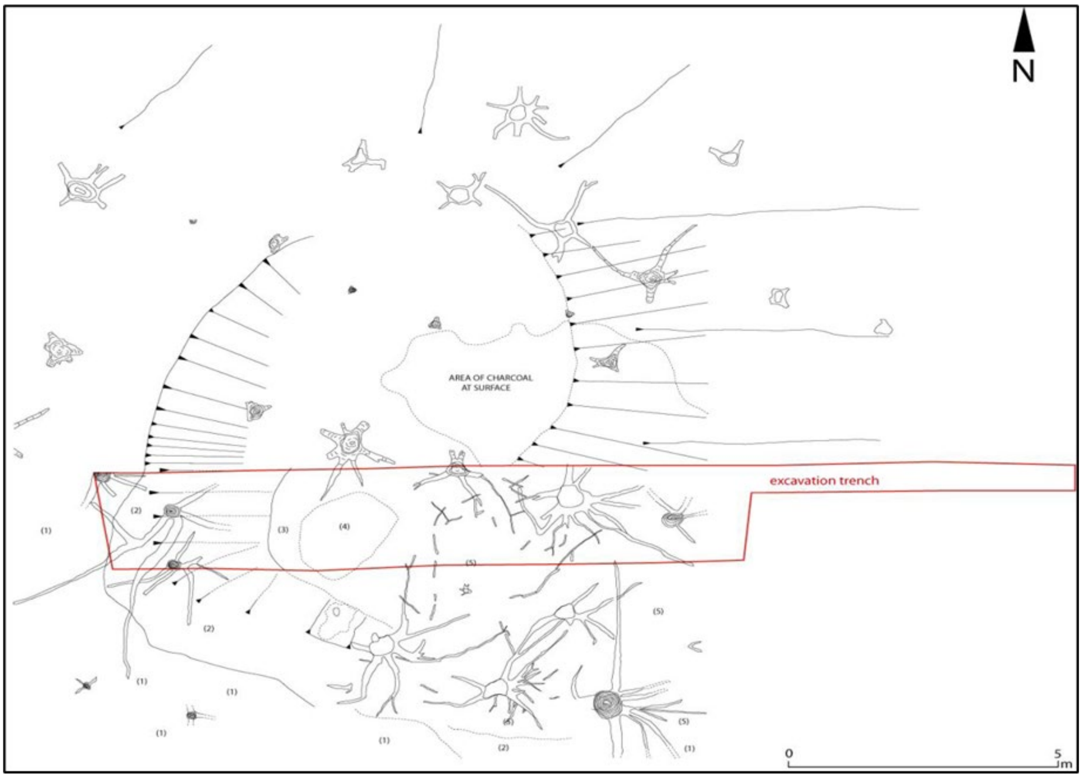

Fig 9: Welshbury Wood 2003: Pre-excavation plan of charcoal platform showing stumps, roots and excavation trench (Hoyle 2008)

4.4.15 The main root bowls of these penetrated up to c. 0.20-0.30m below the ground surface, although individual roots branching from these did penetrate below this level, and the area which could be entirely taken up with the root bowl was c. 0.5-0.8m in diameter. Although the area of the actual root bowls (see above) themselves could be considered to have displaced all archaeological deposits, charcoal deposits survived intact below these, affected only by occasional individual roots.

Fig 10: Welshbury Wood 2003: Root in section, view – north, scale 1m and 0.5m (Hoyle 2008)

4.4.16 The presence of tree roots did, however, have a significant effect on the ease with which these deposits could be accessed. Excavation was generally difficult requiring the time-consuming removal of root systems, and the removal of these added significantly to the time required for excavation and also added to the physical difficulty of this process.

4.4.17 However, the platform was found to have been sufficiently well preserved to allow for the identification of different sedimentary boundaries and features. The remains of charcoal and other environmental remains were found to still be preserved to facilitate dating and palaeoenvironmental assessment.

Case Study 4: The Dartmoor Archaeology and Bracken Project

4.4.18 The project commenced research in 1999 to quantify the impact of bracken rhizomes on archaeological sites on Dartmoor, Devon (project website: https://acearchaeologyclub.wordpress.com/archaeology-and-bracken-project/). The final report for the project was published in the 2016 Devon Archaeological Society Proceedings (Gerrard 2016).

4.4.19 The project included excavations at the Teigncombe round house and the investigation of ten interventions on archaeological deposits at Teigncombe and Pattiland Farm in Devon, between 1999 and 2011 (Gerrard 2014). A methodology was devised by the project to facilitate rapid assessment of rhizome impact at depth within archaeological deposits (Gerrard 2014). The project found that, in all cases where bracken was present, an archaeological deposit was subject to displacement by rhizome activity, although the degree of damage varied considerably (Gerrard 2014; 2016). The results of the project highlight both the damage roots may cause, and the positive condition that the presence of some trees creating a closed canopy at archaeological sites may inhibit bracken and shrub growth.

Fig 11: Teingcombe Round House, Dartmoor: View from the west showing bracken growing within the prehistoric house (Gerrard 2016)

4.4.20 The house lies within a contemporary and very well-preserved Bronze Age coaxial fieldsystem. The site was first recorded in 1974 and managed within a working forest. As part of this management several trees within and in the vicinity of the building were cut down between 1976 and 1978, although ironically and sadly the removal of these trees allowed the bracken onslaught. The site was described briefly by Jeremy Butler in his Dartmoor Atlas of Antiquities.

4.4.21 Within the rhizome mat itself it is possible to establish a minimum level of displacement caused during the past 20 years. Within the parts of the upper rhizome mat examined, an average of 8.3% of the soil has been displaced and in areas most severely affected this figure rises to 23%. This level of damage is in addition to the damage caused by the stipes alone. Taken together the rhizome mat and stipes have in the past 20 years displaced over 20% of the archaeological deposits extending up to 0.26m below the surface (Gerrard 1999).

Fig 12: The upper rhizome mat being revealed in Trench 2 at the Teingcombe Round House, Dartmoor (Gerrard 2016)

4.4.22 Most archaeological deposits on Dartmoor are relatively shallow and well within the reach of the rhizome mat uncovered. The study suggested that the active damage to the archaeological deposits at this level is insignificant, but clear indications of much more extensive disturbance in the past indicate that this is a cumulative effect.

4.4.23 This study concentrated on the obvious physical impact of bracken. It is however observed that fluids leaking from rhizomes can also set up chemical changes in the soil. In a small number of locations visual evidence of this took the form of nodules of clay forming in the vicinity of some rhizomes. Perhaps more significant was the observation that rhizomes in contact with stones including the house wall orthostats appeared to be causing significantly increased weathering.

4.4.24 A follow up study between 2011-2014 funded by English Heritage, looked at six different plots with different management regimes (ARS 2014). Two were fenced in order to pen large numbers of sheep for short periods. Another two were used for cattle foddering, while the remaining two were left with no stock treatment. Within each plot, the bracken in one sub-plot was cut in August each year, and in another sub-plot it was bashed. The third sub-plot was left with no mechanical treatment to act as a control. The objective of all the treatments was to reduce the density and vigour of the bracken and promote the development of a grassy sward that might be less damaging to the underlying archaeology.

4.4.25 The results suggest that the stocking regime had more of an impact on the archaeology than either of the mechanical bracken treatments, and that the intensive trampling treatments did significant and rapid damage. Cattle trampling was the most destructive. The mechanical treatments appeared to decrease disturbance to the stone grids, presumably by increasing grass growth around the stones which can act as an anchor to hold the remains in-situ. Bracken cutting appeared to cause the least disturbance to the stone grids, however, this was not a statistically significant result.

Case Study 5: Hampton Court Palace, London

4.4.26 In the first half of 2023 Oxford Archaeology had a small team at Hampton Court Palace, London, assisting with the remediation of diesel contaminated ground hampered by tree roots in an area in front of the palace next to the Thames (Fig 13). The site was near to the main public gates and the approach to the classic picture-postcard view of the West Front (dominated by the central Great Gatehouse to Cardinal Wolsey's Base Court) is a wild-flower meadow, a line of trees (Norway maple) and the Thames beyond. This area was occupied for 350 years by a large range of riverside courtyarded brick service buildings called the Houses of Offices that were first constructed under Henry VIII with the last building finally demolished towards the end of the Victorian period.

Fig 13: Photo of the Norway maple (*Acer platinoides*) tree root system at Hampton Court Palace, London (©Oxford Archaeology)

4.4.27 Small details of the buried remains from these buildings had previously been revealed during observations afforded by modern service trenches, but historic maps and views exist in abundance. From documentary sources it is known this range contained a 'scalding house' (scalding the carcasses of animals, as well as utensils) a 'poultry house' (keeping chickens shelter/and yard?), a 'bakehouse', a 'rush house' and a 'woodyard'...with timber jetties onto Thames for deliveries. This was the first chance to gain further insights from more extensive excavations as to the survival and nature of this forgotten part of the palace complex.

4.4.28 The presence of the non-native Norway maple colonnade forms part of the cultural heritage of the site. It was originally planted as part of the ornate gardens of the estate. The protection of the tree was therefore seen as equal importance as protecting the buried structural remains. The ground around the roots were carefully excavated with an air gun or vacuum and main roots were protected and wrapped to protect them during the excavation.

4.4.29 The roots of the maple tree can be seen to extend out up to 4-6m from the tree trunk. Surprisingly the thickness of the root system can be seen to be significantly larger (10-15cm) than would be expected for the size of the tree. This might be partly explained by the fact that most of the roots did not penetrate through the brick structure and were relatively shallow and concentrated within the 0.30m in depth. It may also be explained that the roots were longer and wider, to locate the nearest water source which was the River Thames.

Fig 14: Photos of tree root systems over the historical remains at Hampton Court Palace, London (©Oxford Archaeology)

Fig 15: Photo of root disturbance through an area of weakness at Hampton Court Palace, London (©Oxford Archaeology)

4.4.30 As can be seen from the photos most of the structures and archaeological deposits were not significantly impacted by the root system. Where the most significant impact occurred was where a root was able to exploit a previous weakness in the structure where it was able to penetrate the brick structure (Fig 15).

Case Study 6: Early Prehistoric Wetland site at Windy Harbour, Lancashire

4.4.31 Between 2020-2021 Oxford Archaeology undertook an archaeological and geoarchaeological excavations along the route of the proposed A585 Windy Harbour to Skippool Improvement Scheme, in Lancashire. The scheme crossed four valley sequences that provided high potential for the preservation of palaeoenvironmental and early prehistoric remains in waterlogged conditions. Areas of significant *in situ* early prehistoric activity were identified at shallow depth along the wetland/dryland interfaces following the valley margins (OA 2020).

4.4.32 Nationally significant Mesolithic and Neolithic remains were recorded at multiple locations along the wetland-dryland interface (Fig 16). The excellent survival of palaeoenvironmental remains allowed for the recovery of extensive early prehistoric organic remains. Following the abandonment of the site the area was covered by a natural succession of alder carr woodland. The impacts of this woodland development on the archaeology were recorded throughout the subsequent excavations.

Fig 16: Aerial photo of archaeological excavations at Windy Harbour, Lancashire (©Oxford Archaeology)

4.4.33 The fine roots system of the alder carr was seen to partially blur stratigraphic boundaries and make them less well defined and may also have resulted in the movement and mixing of artefacts and environmental material of different periods. Radiocarbon dating of cereal grains revealed an early prehistoric grain assemblage, but in select cases intrusive grains of later date were found within the same horizon or archaeological context. There are various physical mechanisms by which artefacts and environmental material can be moved or vertically displaced through sedimentary profiles, including the action of soil organisms, surface cracking, and/or direct root action. The development of the alder carr across the site was seen as a key vector for the mixing of archaeological/palaeoenvironmental material where it was seen to occur.

Fig 17: Photo of mixed stratigraphy at Windy Harbour, Lancashire (©Oxford Archaeology)

Case Study 7: Burnham Beeches, Earthworks and hillfort, Buckinghamshire

4.4.34 This site was subject to two phases of archaeological evaluation as a part of the Chilterns Conservation Board's Beacons of the Past project. Both phases targeted earthworks situated within semi-natural woodland predominantly composed of mature beech trees exhibiting extensive surface/shallow rooting systems.

4.4.35 An initial phase of community-led evaluation in 2019 focused on a linear bank and ditch at Lord Mayor's Drive that may have been associated with the nearby Seven Ways Plain prehistoric hillfort, or alternatively comprised a boundary pale / internal deer course linked to the adjacent Hartley Court medieval moated site, itself a possible former hunting lodge (Bashford 2020). Resolving the earthwork's relationship to either site proved problematic due to the general paucity of both finds and datable ecofacts. Moreover, the excavation team noted that a profusion of roots throughout the archaeological deposits (see Fig 18) made the existing artefactual and environmental evidence potentially unreliable, as evidenced by the profusion of modern root material in the soil samples and their flots (alongside modern insect and fungal remains) and the presence of clearly intrusive material, such as an early 17th century pipe bowl located immediately next to a particularly large tree root. The stratigraphic relationships between certain deposits were also reported to have been obscured by rooting activity, further hindering their archaeological interpretation (Bashford 2020: 9-12). Conversely, a linear deposit to the southeast of (and post-dating) the bank proved so highly compacted that it exhibited little to no penetration from tree roots. This deposit was interpreted as a surface layer, possibly an older footpath pre-dating the current path to the north of Lord Mayor's Drive (Bashford 2020, 14).

Fig 18: Photo of bank and ditch at Lord Mayor's Drive, Burnham Beeches, both profusely penetrated by large beech roots (Bashford 2020: Plate 4)

4.4.36 A second community-led evaluation at nearby Egypt Wood in 2022 targeted another section of linear earthwork, probably a continuation of that excavated in 2019. As in 2019, no suitable material was recovered with which to date the bank and associated ditch, such that neither a prehistoric nor medieval origin could be discounted (Bashford 2022). Modern roots and associated organic material were again abundant within the soil samples, to the exclusion of any obviously archaeological material. Likewise, the profusion of roots within the deposits themselves often made the in-field interpretation of stratigraphic relationships particularly problematic (Bashford 2022: 10-11; see Fig 19).

Fig 19: Photo of ditch at Egypt Wood, Burnham Beeches, profusely penetrated by beech tree roots (Bashford 2022: Plate 3)

4.4.37 In this case, extensive near-surface tree rooting was seen to have directly impacted the underlying archaeology through the transport of small quantities of intrusive material and the obfuscation of stratigraphic relationships within exposed sections. However, it should also be noted that the features in question were relatively simple in terms of their stratigraphy and largely sterile in terms of both artefactual and ecofactual material. As such, it is difficult to gauge the extent to which tree rooting had impacted the archaeology since similar interpretations may have been obtained even without the complications of standing tree cover.

Case Study 8: Roman Archaeology at Hope Shale Quarry, Derbyshire

4.4.38 In an as-yet unpublished excavation in advance of the expansion of Hope Shale Quarry in Derbyshire, three fields and a block of woodland were excavated adjacent to the Roman Legionnaire Navio's fort. Navio had a strategic military role in suppressing the Brigantes and guarding the east to west routeway across the Hope Valley and Navio fort was strategically placed to help protect the important lead industry. A *vicus* (civilian settlement) was established to the south east of the fort and the archaeological excavation undertaken at the quarry between 2019 and 2020 identified the southwestern extent of the *vicus*, which had a defensive circuit of at least two phases and north-western annex, probably added in the 2nd century AD.

4.4.39 As part of the project Archaeological Research Services developed a new methodology to remove the stumps of 40-year-old trees initially planted as a screen for the existing quarry (ARS 2019). To do so with minimal disruption to the shallow archaeological horizon, a custom ditching bucket with a 60º chisel-like edge was fabricated and used to lever the stumps up and sever the largest tap roots whilst allowing access for hand cutting of the other large roots spreading from the stump. This left other roots *in-situ* to prevent the prior disruption of archaeological contexts which were then excavated by hand.

4.4.40 The tree and stump removal were considered a success, allowing for minimal damage to the shallow archaeological remains of the *vicus*. The preservation of archaeological features was found to be no less clear under the wooded area than in the other three fields. The only mention of root disturbance in the preliminary report relates to a limited number of artefacts that emerged during the extraction of tree stumps and boles by mechanical lifting ("plucking") from the ground. The trees that were so removed had been planted in 1986 as part of a tree planting programme and were around the purported *vicus* annexe. The recovered artefacts had been displaced from their original context and were not found stratified within features.

4.5 Case Study Findings: Impact Analysis

4.5.1 The case studies presented here provide just a snapshot of the archaeological sites and monuments that have been reported to have been impacted by tree (or bracken) root disturbance. Other, and in some cases more recent, examples do exist but permission to obtain or use information was not always possible.

4.5.2 While these case studies identified where tree roots had been recorded and shown to have impacted upon archaeological remains, none of them indicated that the impact was to such a level that significant information was lost, or the interpretation of the wider site significantly hindered. Although evidence of impacts on individual deposits/features and artefacts were mentioned, these were typically localised and were not detrimental to the interpretation of the wider feature sets or past activities represented at the site.

4.5.3 Roots were seen to find and exploit weaknesses existing within built structures, such as those at Hampton Court, and in some case to exacerbate these issues by either enlarging cavities and/or undermining the structures. These impacts tended to be highly localised and partly related to where sites had been left unmanaged or abandoned such that vegetation was able to encroach and become established across them. Depending on the maturity of the tree concerned, removal could prove just as damaging to the archaeology as if it had been left *in situ*, if not more so.

4.5.4 New tree planting programmes would not, however, be suitable for shallower and more sensitive sites such as Windy Harbour, with its assemblage of early prehistoric lithic and associated waterlogged remains. However, such sites are less likely to be considered for afforestation in any case due to the level of waterlogging. When excavated, root systems were seen to have caused bioturbation through the mixing of fine sediment boundaries and the movement of artefacts and organic macrofossils and microfossils across otherwise secure archaeological contexts. As nationally important sites where heritage conservation forms the priority goal, sites such as this should remain under grassland cover or within managed clearings as outlined with UKFS guidance.

Fig 20: Photo of Ferworthy Stone Row, Devon, located within a managed clearing previously covered by forest (©Rutter Forestry Commission)

4.5.5 In some cases, tree rooting was also shown to have a positive stabilisation effect on earthworks, improving slope protection and helping to protect monuments from detrimental soil erosion. They have also increased public accessibility to selected monuments, provided adequate information has been provided and the monument itself incorporated within long-term management plans.

Fig 21: Prehistoric round barrows in a fenced clearing within managed woodland at Chipperfield Common, Hertfordshire (©Oxford Archaeology)

Left: Training session for Woodland Officers, Cannock Chase Forest in the Midlands © Forestry Commission

5. Stakeholder engagement

A key element of this research project involved an initial phase of consultation across both heritage and forestry sector stakeholders through an anonymous online questionnaire, followed by a series of more detailed interviews with selected individuals. The online survey received 20 responses, 7 of whom self-identified as forestry professionals and 13 of whom worked in archaeology and heritage.

5 STAKEHOLDER ENGAGEMENT

5.1 Introduction

5.1.1 A key element of this research project involved an initial phase of consultation across both heritage and forestry sector stakeholders through an anonymous online questionnaire, followed by a series of more detailed interviews with selected individuals. The online survey received twenty responses, 7 of whom self-identified as forestry professionals and thirteen of whom worked in archaeology and heritage. Detailed qualitative interviews were then undertaken by project team members with thirteen further stakeholders, comprising 10 heritage and 5 forestry professionals. The interview responses became more weighted in favour of the heritage sector since those participants responded more positively when approached to take part in the study and generally held stronger views on root impacts. This may in part reflect the nature of the study, being largely heritage based.

The project received strong and engaged responses, with many stakeholders suggesting case-studies and providing observational or anecdotal evidence of the impacts of tree roots and forestry practices more generally on the preservation of archaeological remains. Several of the stakeholders emphasised that they thought this project was a timely review of the relationship between trees and archaeology given the context of the ongoing climate crisis and the financial pressures of current land management regimes and noted that they hoped it would lead to further research and increased collaboration across the relevant sectors.

Table 5: list of interviewees

Heritage professional		Forestry Professionals	
Interviewee/s	Position	Interviewee/s	Position
Jim Williams and Vince Holyoak	Historic England Senior Science Advisor and Head of Environmental Management	Peter Crow	Forest Research Landscape and Environmental Scientist
Steve Trow	Member of New Forest National Park Authority and archaeology and historic environment adviser to The National Trust. Former Director of Research at Historic England	James Shallcross	Forestry Commission Woodland Officer
George Lambrick	Former Director of the Council for British Archaeology and Deputy	Andy Poore	Woodland Manager for SelectFor, practitioners in

	Director of Oxford Archaeology		Continuous Cover forest management
Richard Havis and Maria Medlycott	Principal Historic Environment Consultant and Senior Historic Environment Consultant, Essex County Council	Clive Whitbourn	North Dorset National Trust Ranger
Lucy Lawrence	Buckinghamshire County Council Archaeological Officer	Tim Screen	Cherwell District Council Landscape Architect
Tom Parker	Freelance Archaeologist		
Natalie Ward	Senior Conservation Officer, Peak District National Park		
Neil Redfern	Executive Director of the Council for British Archaeology		

5.2 Questionnaire and Interviews

5.2.1 The questionnaire and interview questions can be found in Appendices C and D of this report. An OA ethics form was also distributed with the interview questions to comply with GDPR requirements, of which a blank copy is included in Appendix E.

5.3 Consultation Findings: Impact Analysis

5.3.1 There were several key themes that became apparent across both the survey responses and in-depth interviews, with some notable differences emerging between professionals from the two sectors.

Forestry professionals

5.3.2 Broadly speaking, the forestry professionals who responded to the questionnaire believe that archaeologists can sometimes be overly hostile to new tree planting and forestry schemes. Whilst they acknowledged that tree roots actively proliferate within aerate, nutrient-rich and moisture retentive soils – all of which may be more common within the fills of archaeological features than the surrounding 'natural' soils – they believe that the impacts are more limited than is often assumed, and in some cases can be beneficial, for instance by stabilising earthworks, reducing pressure from ploughing, and preventing soil erosion. In the opinion of these professionals, it should be a primary goal of this and subsequent projects to create an evidence-based rather than anecdotal approach to the interaction of trees and archaeology.

5.3.3 The forestry professionals also highlighted how they protect heritage assets as part of the design for new planting schemes. The consideration of impacts on heritage forms one of the key pillars of the UKFS and new planting schemes will not be funded (or will be asked to resubmit) if they display insufficient consideration of potential heritage impacts. This includes placing areas of known archaeology within clearings and integrating them within long-term management plans. Over the last 5-6 years the Forestry Commission has greatly enhanced its in-house capacity to provide relevant advice and has increased the number of historic environment datasets incorporated within sensitivity mapping to help identify areas for suitable woodland planting.

5.3.4 The responses of forestry professionals did, however, acknowledge several risks associated with the impact of tree roots on archaeology. First, although shallow rooting scrub species have limited below-ground impact themselves, they do provide cover for burrowing animals which can have a more significant impact on the buried archaeological resource. Secondly, species with significantly larger roots can destabilise structures through their growth over time. Finally, the most significant impact mentioned was that of wind-induced tree throws, as in such instances the sudden displacement of 1-2m-deep root plates can severely disrupt any underlying archaeology. Referring specifically to the recent Storm Arwen (25th November 2021), several stakeholders suggested that archaeology in well managed forests saw little to no impact from storms and wind blow. However, they noted that poorly managed, historic plantations with large scale planting across areas of known archaeology exhibited significant damage caused by tree throws during times of high wind.

5.3.5 The potential for damage was thus largely seen as site specific and dependent upon the nature of the archaeological resource in question, the surrounding soil environment, the type of tree cover, and the management regime in place. It is notable that many of the concerns and observations raised by heritage professionals (see below) are the result of historic planting regimes, and that more recent planting and land management schemes have come a long way to address these issues under the umbrella of the UKFS.

Heritage professionals

5.3.6 Respondents to the questionnaire who worked solely within the archaeological/heritage sector often displayed a notable suspicion regarding the impact of tree roots on archaeology. One respondent simply stated, "[t]ree roots have a significant impact on archaeology", whilst another said that trees are likely to be "damaging of archaeological stratigraphy, features and/or deposits through the presence of roots […] leading to displacement and disturbance". Other potential impacts noted by respondents included the reduction of water-levels in previously waterlogged strata, trees providing cover for burrowing animals, and possible changes in soil chemistry which may affect artefact and ecofact survival. Many of these concerns were anecdotal rather than based on direct fieldwork observations or empirical research.

5.3.7 Some heritage professionals did note that woodland is often a heritage asset, and that earthworks often survived better within areas of well managed woodland than elsewhere. Some of the former monument inspectors interviewed indicated that archaeological remains were, in their experience, better preserved under woodland compared to other land uses, such as arable cultivation. Other more moderate responses included the acknowledgement that "tree roots growing through stratigraphic layers of archaeological deposits tended not to affect the interpretation of the site to any great degree", and the fact that the most significant damage from tree roots comes from the wind-throw of shallowly rooted, non-native commercial trees tree and/or within poorly managed forests. However, woodland cover was also stated to hinder access for archaeological surveys and/or excavation work in the long-term (though see discussion of LiDAR in Section 3.4.5 of this report).

5.3.8 It was broadly agreed by respondents working across commercial archaeology, local government planning teams, and in the conservation of archaeological sites and landscapes, that there is a lack of data on the direct effects of tree roots on archaeological resources. Moreover, it was acknowledged that the issue is a complex one, which necessarily requires careful consideration, the balancing of competing priorities, and the acknowledgement that in certain cases trees can have positive benefits for archaeological landscapes as well as negative ones.

5.3.9 Peter Crow provided one such positive example concerning the M3 motorway corridor through Micheldever Woods: "The whole woodland is just riddled with archaeological features. Banjo enclosures, and burial mounds. In the spring it's crawling with people out photographing the bluebells and appreciating the burial mounds some of which have interpretation boards. It's a great site to visit."

5.4 Impacts from existing tree roots

5.4.1 Respondents to the stakeholder questionnaire and interview participants were both asked for their experience of the impacts of tree roots on buried and structural archaeology through their work. Most participants responded to these questions, and several included specific case-studies (discussed further below).

5.4.2 The forestry professionals who responded to the survey had limited direct experience of the interaction of roots on archaeology. However, anecdotal evidence regarding the Palace of Westminster, Lambeth Palace, Chatsworth House, and many National Trust properties, reported no conflicts between tree-roots and buried archaeology. Respondents with experience of both forestry and heritage preservation suggested that there were no significant impacts of tree roots on buried archaeology, as good data can still be retrieved even when tree-throws are present on a given site. However, it should also be noted that these respondents did emphasise that differing geologies and tree types have the potential to impact buried archaeology in different ways. For instance, beech trees growing on chalk will lift deep sub-circular tree bowls and are more prone to falling as they age, while coniferous trees on sands and gravels will create large but relatively shallow tree bowls. Non-natives tree species were considered to be the most problematic (including shrubs like *Cotoneaster*, *Buddleia*, etc) because they are often much harder to get rid of and their rooting behaviours can pose a bigger threat to native grasslands and archaeological features alike. In the shallower soils of the British uplands, trees were observed to root deeper in search of nutrients. In these cases, disturbance to archaeology was noted as more likely.

5.4.3 Whilst the heritage respondents generally pointed to examples where they had encountered varied impacts of tree roots on archaeology, the archaeologists specifically stated that the impacts of tree roots did not adversely affect the broader interpretation of sites. Nonetheless, they emphasised that tree roots are known to disturb cemeteries and burials, especially where fallen trees had been seen to lift/otherwise displace skeletal remains and masonry structures. They were also reported to impact the preservation of material suitable for palaeoenvironmental investigation and radiocarbon dating, for instance by inducing desiccation through a lowering of the water-table.

5.4.4 Turning to structural archaeological remains, the forestry-based respondents often mentioned subsidence caused by large trees planted near stand-alone masonry structures and noted that tree roots can distort the profile of earthworks, whilst also providing suitable habitats for burrowing animals which will in turn cause more significant damage. Heritage respondents, however, had most often encountered adverse impacts from animal burrowing in areas which were under scrub (eg, bramble and bracken) rather than mature tree cover. All respondents agreed that the most significant impacts of existing tree roots came not from their growth but from the damage caused when trees were uprooted by high winds. It was noted by many respondents that this risk can be mitigated through appropriate woodland management practices (eg, coppicing).

5.4.5 The heritage respondents to the questionnaire provided several specific examples of structural archaeological assets damaged by tree roots, including the banks of holloways, hillforts and World War One training trenches across the Midlands and north of England (eg, Sherwood Pines, Nottinghamshire; Casswell 2022). However, they also noted that the scale and nature of the damage was subject to so many variables (eg, tree species, age of tree, type of planting, type of archaeological structure, topography; climate, potential for windblow, etc) that it simply is not possible to make broad generalisations in this regard.

5.4.6 Conversely, both sets of respondents noted that there are examples where tree roots have actively stabilised earthworks and prevented erosion (whether human, animal or climatically induced) and protected them from damage by active cultivation, eg, ploughing. Additionally, established trees, whilst possibly causing localised damage or disruption, suppress the regeneration of other trees and scrub (including bracken) which may otherwise cause more widespread rooting across a site. It was noted that the desiccation of waterlogged deposits can occur from any vegetation cover, not just trees. For instance, grass roots can reach well over 1m in depth and will draw up significant volumes of groundwater throughout the summer.

5.4.7 Overall, stakeholders from both forestry and heritage sectors agreed that there are mechanical and, to a lesser extent, chemical aspects to the adverse impacts of tree roots on archaeological contexts, but that these impacts are unlikely in most cases to adversely affect the overall interpretation of a given site.

5.4.8 This is not to say that there are no negative impacts. For instance, rooting was perceived as often causing a loss of resolution, especially across more sensitive sites and discrete remains, causing damage to human and animal bones (root etching obscuring pathology or butchery marks, for example), or the movement of small artefacts out of their original positions within graves or buried horizons. Tree roots may also cause significant damage during uprooting events, as caused by wind throw, disease or active felling. In these circumstances the trees need to be proactively managed to minimise the risk of falling, and to be planted in the first instance following the principle of 'right species for the right location'.

5.4.9 Most respondents also noted that in certain circumstances tree roots can be beneficial for the archaeology through stabilisation of earthworks, prevention of plough damage to monuments, and, in some cases, reinforcing masonry structures which otherwise may have collapsed (such that the tree cannot now be removed without causing significant further damage). One respondent stated that "forestry could be the lesser of three evils" when compared to arable cultivation and modern development, in other words it still negatively impacted archaeological preservation, but less so than some other forms of land use.

5.5 Rooting impacts resulting from new tree planting

5.5.1 The stakeholders consulted throughout this project emphasised that the most significant impacts on archaeology arising from forestry were likely to occur during active planting and harvesting, or when senescent or damaged trees fall. The specific planting methods employed therefore need to be considered when assessing the impact of tree roots, as planting, harvesting, and management methodologies can in turn impact the rooting profile, likelihood of weather and disease related falls, and damage induced during harvesting. For instance, mixed species planting mitigates some of the pest and disease-related risks which can otherwise require the clear felling of large areas of woodland in single episodes.

5.5.2 The forestry professionals noted that predicting the impact of new tree planting schemes on archaeology is complex because the nature of the tree rooting will be dependent on species, intended age, soil type, topography and local weather conditions, such that each site would have to be assessed on an individual basis. For example, heavy clay soils may limit root penetration whilst thin, sandy topsoils may permit greater lateral range. Peaty substrates were seen as inappropriate for afforestation, as tree planting would dry them out and destroy any palaeoenvironmental data that might be preserved within the buried profile. They also noted that root systems are typically adaptive to different conditions, for instance staying above the water-table even in otherwise deep-rooted species. Species selection for new planting is itself a complex issue which requires the consideration of climate, availability, and cost in addition to the nature of the site-specific historic environment.

5.5.3 The concerns of many of the heritage stakeholders with regards to new woodland creation typically stemmed from the precedents of historic plantations and woodland management practices. As such, whilst few of the heritage respondents had direct experience of afforestation schemes (because these lie beyond the archaeologically relevant aspects of the planning process), they were nonetheless concerned that tree species should be matched to the soil and type of historic environment in which they were to be placed. There was widespread belief that significantly greater negative impacts would arise from inappropriate conifer plantations which required clear felling to harvest, and in areas where deep rooted species such as oak were to be planted. Further information made available to, and collaborative involvement of, heritage professionals would be likely to help address many of these concerns. One respondent suggested that the natural regeneration/expansion of woodland might be preferable to artificial plantations, as such saplings are generally stronger rooted and less likely to be blown down in later life. Conversely, another respondent suggested that there are even more issues concerning areas left to regenerate naturally as their long-term management can be more challenging.

5.5.4 The heritage professionals were also concerned that the push to increase forest cover across the UK will lead to tree planting schemes on inappropriate or sensitive landscapes which have a particular historic character, such as the Yorkshire Dales. Major land-use changes can impact historic landscapes through visually obscuring monuments, but also through changing the setting and wider viewsheds of important sites/character areas. One local authority archaeologist specifically asked why a significant monument, viewshed or site which would otherwise warrant some form of mitigation or alteration of the plans for development is not afforded the same standard of care when it comes to forestry. Likewise, whilst discussing the case of the 1990s plantation adjoining the Rollright Stones and King's Stone in the Cotswolds, one heritage respondent was concerned that there are no protections for the setting/wider context of ancient monuments if they are impacted by afforestation as opposed to building development. However, the UKFS does now guide forestry professionals to avoid such impacts to known archaeological features and their settings, and forestry plans are now frequently altered to protect heritage assets in this way.

5.5.5 In general, the heritage professionals were more concerned about the methodologies used to afforest an area than the potential impact of the trees themselves. They noted that heavy machinery used to plant saplings or harvest timber are likely to have a significant negative impact on both above ground and buried archaeology, as was also acknowledged by the forestry professionals. Planting within previous ploughsoils, however, was thought to unlikely to be more damaging than the ploughing itself had been. Whilst these impacts are officially accounted for by the UKFS's guidance for the preparation and understanding of sites prior to tree planting, several of the heritage stakeholders professed a desire for more information or further pre-mapping surveys prior to afforestation taking place.

5.5.6 It was suggested that if geophysics or LiDAR are used to define areas within which planting should not take place, these could form open glades within the woodland mosaic which would provide biodiversity benefits alongside archaeological protection. However, it is important to note that geophysical surveys are not necessarily suitable for all sites, as many types of archaeological site (for example prehistoric lithic scatters, discrete features, and waterlogged organic remains) cannot always be identified in this way. Moreover, geophysical techniques are typically more effective on some geological substrates than others, especially depending on the techniques used. Therefore, every sizeable planting scheme would have the potential to impact unknown archaeological remains even in the case of prior non-invasive prospection. For particularly sensitive landscapes such as floodplains or wetland edge, geophysics and LiDAR survey may not necessarily form the most appropriate techniques for detecting previously unrecorded archaeology. In such cases, the involvement of archaeological specialists from early in the planning process would be of benefit to the overall tree planting scheme and design of its ongoing management.

5.6 Impacts from the management and harvesting of woodlands

5.6.1 The final category of potential impacts that was mentioned by both groups of respondents was related to the management and harvesting of woodlands, both new and extant. These largely comprise secondary impacts arising from the presence of trees on areas with archaeology that needs to be actively preserved. It is therefore important to consider whether new planting schemes will form managed semi-natural woodlands or commercial plantations, as these will have different damage profiles with regards to any archaeology contained therein.

5.6.2 Respondents across both sectors noted that in commercial plantations, trees are typically cut down at ground level, leaving the roots in the ground to decay before replanting. Here, whilst decay related voids can impact archaeological deposits, the damage would be far greater if the stumps are ground or pulled out with machinery.

5.6.3 Even for managed semi-natural woodland rather than strictly commercial settings, forestry professionals noted through the questionnaire that all heavy machinery has the potential to cause damage to surface features, dependent to some degree on the weather at the time of its use. Similarly, the greater the volume of timber removed the greater the chance of soil (and archaeological) damage. Upstanding earthworks were considered to be more vulnerable by the interviewees, such that their management would require substantial resource expenditure. Nevertheless, it was suggested that a pervasive 'phobia' of machinery as used in forestry management has more to do with traditional/received views than any evidence that it is significantly more damaging or disruptive than machinery used in arable farming.

5.6.4 The heritage professionals generally agreed that all woodland management (both public and privately owned) should follow the UK Forestry Standard, which states that it is often appropriate to safeguard known archaeological sites by placing them in open space (Forest Research 2023). To better protect unknown archaeological resources, they suggested that the least impactful form of tree cover was likely to be that of low intensity managed, semi-natural woodland, ie, one managed primarily for biodiversity with coppicing and chainsaw felling, the use of low-pressure tyres or tracked vehicles on track mats and only in suitable weather and ground conditions. Several interviewees, including James Shawcross, agreed that the biggest risks posed by forestry is to the archaeology that nobody knows is there. For instance, researchers from Sheffield Hallam University have highlighted how damage can be done to unrecorded historical structures in ancient woodland by harvesting machinery (Rotherham and Ardron 2006).

5.6.5 There was a significant amount of concern from both heritage respondents and land managers that trees should not be removed from archaeological landscapes unnecessarily, especially where that removal is likely to cause significant below ground disturbance. This includes damage from the removal process itself and subsequent management (or lack thereof) of the land which could lead to increasing bracken and shrub cover, higher populations of burrowing animals, and possible anti-social behaviours such as fire setting and off-trail mountain-biking/motocross which would cause even more damage to the site and surrounding landscape. The example of Caeser's Camp, Bracknell, was raised as one instance where the monument saw significantly increased damage from mountain bike erosion once shrub and trees had been removed from parts of the monument. One respondent specifically thought that the removal of trees, particularly from scheduled monuments and upstanding earthworks, may do more harm than good depending on how the area will be managed thereafter. Multiple interviewees emphasised that public buy-in is important in such cases, and that both landscape and heritage-specific managers would need to inform users about changes in land management practices and why there were being undertaken.

5.6.6 Relatedly, a significant number of both forestry and heritage-based respondents identified possible benefits of sensitively managed woodland cover on archaeological landscapes. Amongst the forestry professionals the identified benefits included the regulatory costs and logistical barriers to removing mature trees providing buffers against other forms of development. Amongst the heritage professionals, one respondent noted that an open woodland setting can improve the general character and setting of archaeological monuments, and that individual trees/woods can be heritage assets in their own right, for instance the now-felled Sycamore Gap tree on Hadrian's Wall. As summarised by Steve Trow: "It depends on what the access regime is for land that's being put into woodland as well. If it comes with public access, then you might have opportunities for people to be able to visit and see an interpretation as well".

5.6.7 Although many of the issues highlighted in this consultation are technically addressed by existing professional standards (Forest Research 2023), the stakeholders' responses would suggest that these standards are not always being followed, and damage can still be incurred to heritage assets as part of forestry works. Moreover, better communication across forestry and heritage sectors is clearly needed to highlight how what standards are and how they should be implemented, as well as to ensure that that implementation does take place to the required standard.

5.7 Highlighted Examples

5.7.1 The respondents to this survey, primarily those who work within the heritage sector, provided several case-studies which illustrate the challenges and opportunities discussed above.

Welshbury Hill Fort, Welshbury Woods

5.7.2 A small-scale exploratory excavation after several tree falls on the wooded northern side of the hillfort revealed somewhat disturbed Romano-British iron smelting platforms which would otherwise not have been excavated (but also not damaged) had the trees not fallen (Izzard 2018). The questionnaire respondent stated that it was recommended to clear the trees from the north side of the monument and leave a 30m buffer from the scheduled area within which trees should not be planted or allowed to regenerate.

Tamshiel Rig, Scottish Borders

5.7.3 An archaeological evaluation on a recently felled commercial forest on behalf of the Forestry Commission and Historic Scotland was undertaken specifically to establish the impact of forestry operations on archaeological preservation. The excavation revealed a small Iron Age hillfort with round houses of later Iron Age/Roman date, as well as associated a field system and several field banks. Roots had penetrated the archaeological deposits, smearing boundaries between contexts, uplifting stones, and causing some localised oxidisation of the underlaying clay soil. This led to some irreversible changes, though these were not observed consistently across the site (Cressey 1996).

Woodbury Castle, East Devon

5.7.4 This site, an Iron Age multivallate hillfort with surviving buried features including possible roundhouses, was subject to rescue excavations in the 1970s and a geophysical survey and remedial repairs in 2009 (Caldwell 2009).

5.7.5 Set within heathland, the site was covered by a 19th-century beech plantation which also exhibited a 20th-century laurel infestation and some pine and scrub growth which had been largely unmanaged until the 21st century. The geophysical survey highlighted some areas of potential archaeological loss due to falling trees and rooting. A significant amount of the vegetative cover was subsequently removed, and where mature trees were retained, they have since been regularly surveyed to reduce risk of collapse. Any failing trees were carefully felled, whilst no new trees were to be planted on the site. It is important to note that only half the site has been managed in this way, the other half has remained under unmanaged woodland and dense scrub cover, which has led to significant badger activity which is itself likely to have caused significant damage to the underlying archaeology.

Nesscliffe Hill Camp, Nessclife Country Park, Shropshire

5.7.6 A non-commercial research program of geophysical survey, auguring, trial trenching and open area excavation was triggered by extensive storm damage to trees within the inner enclosure of the hillfort (Hankinson 2019). The site is now being managed with a view to returning to natural upland heath, with heather, rattle, whinberry, etc, being encouraged alongside selective preserved stands of native oak and beech. Trees that were removed include *Sequoia* and large stands of larch (*Larix* sp.), as well as silver birch (*Betula pendula*) which was noted as especially impactful due to the development of dense root meshes within the shallow sandy hilltop soil. The excavation revealed extensive tree root damage to stone revetted banks, whilst the earthworks proved very difficult to reinstate due to the sandy substrate.

Hillforts in Southwest England

5.7.7 One interviewee mentioned several sites which had been cleared of trees or otherwise managed as part of the Wessex Hillforts project (Payne *et al.* 2006), including Hambledon Hillfort, Hod Hillfort and King Barrows Ridge. At Hod, the project funding allowed the removal of scrub and a coppicing project within grassy glades. At Hambledon, the eastern side of the monument is now managed as a wood-pasture mosaic with a 10m buffer surrounding the scheduled area. The respondent noted that one Inspector of Ancient

Monuments wanted all trees removed across the site, which, whilst following official guidance at the time, was not realistic and so a compromise was negotiation. At King Barrows Ridge, the respondent noted that there had been significant damage incurred from planted beech and hazel trees toppled by storms in 1987 and 1990. The risk of further falls was mitigated by extensive pollarding, and it is likely that these trees will not be replaced once they senesce and are removed. This approach balances the value of the trees as they are with the need to preserve the monument for the long-term.

5.7.8 However, the interviewee noted that the 'good condition' of these monuments achieved by the Wessex Hillforts Project is no longer sustainable in the long-term due to increasingly wet winters and arid summers hindering seasonally appropriate clearance work, as well as greatly increasing the associated costs. Perhaps a different approach is needed?

Felsted, Essex

5.7.9 A recent excavation by Archaeological Services and Consultancy as part of a proposed new housing development in Felsted, Essex, identified several impacts of scrub vegetation on underlying archaeology. The site was covered by what was described as 'modern scrub', and the extent of root disturbance was described as significant, impacting both the initial machining and the subsequent excavation. The area had previously been left for 10-20 years to naturally regenerate, in which time significant shrub cover had developed over the site. These shrubs were mostly under 1m in height, with a root system that impacted below the modern topsoil. Once the scrub and topsoil had been removed, archaeological features proved difficult to identify and record due to the presence of what was described as a dense root system.

5.8 Discussion

5.8.1 The responses to the stakeholder consultation make clear that there is some level of conflict between heritage and forestry practitioners within archaeologically sensitive landscapes, but also examples where compromises were successfully reached to balance the needs of the natural and historic environments. For example, on hillforts where grazed pasture was previously the main form of land-use and was proving increasingly expensive to manage, a scrub mosaic including blackthorn, hawthorn and field maple is now recognised as an appropriate alternative, if well managed.

5.8.2 Many stakeholders emphasised that the default position of simply not allowing trees on archaeological sites/landscapes needs to be more flexible. There is a need to build trust and improve reciprocal understanding between arboriculturists, foresters and heritage professionals to allow for closer collaboration and compromise. The most anticipated outcome for this project from interviewees and questionnaire respondents alike was for a more nuanced, multidisciplinary approach that identifies the need for future research to understand the specific archaeological resources present within areas either currently under woodland and/or to be newly planted, to consider the impacts of alternative land use options, and which requires clearly delineated management regimes to ensure adequate long-term results.

5.8.3 Several of the interviewees described this approach as 'striving for equilibrium'. It was acknowledged by all respondents that the initial planting and establishment of a sapling will negatively impact any underlying archaeology, but that past a certain point in its growth the impacts of removing that tree will far outweigh those of leaving it in place. At the end of a tree's life, or if it suffers from a disease which makes a weather-related fall and resulting tree throw more likely, then removal through appropriate methods once again becomes the preferable option.

5.8.4 Many of the issues raised by the stakeholders consulted for this project were not related directly to the impacts of tree roots, but rather associated or secondary effects, especially those associated with various woodland management practices. Whilst the current UKFS and other guidance documents (Forestry Commission 2021; Forest Research 2023) do include management advice to protect the historic environment, this survey highlighted that incidences of poor management in the past have greatly influenced many heritage professionals' negative views of new afforestation schemes.

5.8.5 Respondents to this consultation repeatedly brought up the need for accurate site mapping and characterisation of heritage assets, both designated and non-designated, within current/planned woodlands. They also stated that the soils should be characterised across the site, and the most suitable tree species should be selected for multi-species planting schemes. The planting plan, developed collaboratively between heritage professionals, land managers, arboriculturists, and other forestry professionals, should ideally include open glades over the most significant archaeological sites and monuments, thus creating a mosaic of wooded and open glade areas also beneficial for overall biodiversity.

5.8.6 New woodland should be created with a management plan already in place, and that management plan funded and monitored over the long-term to ensure the continued preservation of both woodland and archaeological resources. The management plan would include pro-active maintenance to minimise wind-throwing, animal burrowing, and anti-social behaviour, which might damage both the trees and the historic landscape. Further advice was mentioned surrounding procedures to harvest timber whilst maintaining a closed canopy (as most harvesting is undertaken by contractors rather than the Forestry Commission directly), and not compacting or rutting the ground surface with heavy machinery when ground conditions are not suitable. Some respondents recommended greater flexibility in the granting of felling licences, which currently operate within tight time windows that are not always in tune with periods of wet weather.

5.8.7 Some stakeholders also suggested focussing woodland creation efforts on areas which were previously forested or under arable agriculture, as these areas will already have been negatively impacted in terms of archaeological preservation. Others similarly suggested focussing tree planting within old quarries or other areas subject to modern disturbance.

5.8.8 Overall, a consistent theme emerged from the responses that every site is different and will require its own assessment and implementation/ongoing management plans. The overriding response from heritage professionals was to prioritise tree planting on areas where archaeological potential is relatively low. Even so, there was still concern that negative impacts can still occur where there is currently limited oversight of non-designated heritage assets, especially in smaller, private woodlands.

5.9 Suggestions for further research

5.9.1 The stakeholders across both professional groups pointed to areas where further research is needed to fully understand the impacts of tree roots (and associated factors) on archaeology.

5.9.2 Several respondents suggested that long-term practical experiments could be funded to examine the relationships between different types of archaeological features within varied soil types and in relation to different tree species.

5.9.3 George Lambrick specifically suggested that a project be created to compare the predicted and actual impacts identified by Environmental Impact Assessments for new woodlands, which would allow for better understandings of the interactions between trees and archaeological assets to underpin future proposals. He also suggested that the interaction between trees and other vegetation on waterlogged deposits should be systematically studied, as this is an area where there is a notable lack of evidence at present.

5.9.4 Most of the respondents who were familiar with the current project suggested that whilst a simple ground-truthing exercise would be a valuable exercise, they thought there were too many variables to draw meaningful conclusions, and that a larger, long-term research project would be needed to properly grapple with the issues at hand. Together, they suggested that this report, the proposed ground-truthing exercise (see Section 10), and the conclusions of a further, longer-term research project should be brought together to create a comprehensive toolkit to define best practices that balanced woodland creation with heritage conservation.

Left: Trees growing on an earthwork © Neil Redfern

6. Tree root growth and determining factors

The volume and distribution of a tree's roots do not necessarily correlate with the spread of the canopy or its height. Indeed, the total spread of a tree's roots is frequently underestimated and can extend for many tens of meters beyond the branch spread, or 'drip line', albeit predominantly as a relatively fine network. The determining factors can be grouped under three main headings – physical, chemical and biological – albeit with considerable overlap.

6 TREE ROOT GROWTH AND DETERMINING FACTORS

6.1 Tree root networks: development and forms

6.1.1 All trees are sustained by their root networks, which penetrate the underlying soil and supply the greater organism with water and nutrients, as well as serving as a means of food storage and structural support (Crow 2005; Crow and Moffat 2005, 107). More recent research has also highlighted how interconnecting root systems can enable some forms of communication and resource sharing amongst tree communities, particularly when conjoined through extensive mycorrhizal networks (Henriksson *et al.* 2023; Simard 2018).

6.1.2 The development of tree root systems generally follows a common initial pattern across species, in which the germinated seed sends a single vertical radicle, or taproot. Rapid root growth will follow in the following few years, with (sub-) horizontal lateral roots emerging from the tap root, or which those nearest the soil surface expand to greater thicknesses to provide additional structural support for the young sapling. Over time, between 4-11 of such lateral roots will typically expand to 30cm or more diameter near their juncture with the main stem, before rapidly tapering to around 2–5cm diameter at 2-3m distance. Lateral roots may continue to extend for many metres beyond this reach, but usually as fine structures only 1–2cm in diameter. Non-woody 'absorbing', or 'feeder' roots will in turn grow out from the laterals, forming a complex fan or mat extending throughout the well aerated topsoil (Dobson 1995; Stokes *et al.* 2009, 12).

See Fig 22: Diagram of rooting diameter (adapted from Smiley 2008)

6.1.3 There are differences which occur amongst tree species within the general developmental schemes outlined above. For instance, ash (*Fraxinus excelsior*), cherry (*Prunus avium*), blackthorn (*Prunus spinosa*) and some pines (*Pinus* spp) all extend their largest lateral roots within the upper 10cm of underlying soil. Conversely, the 'oblique laterals' of other species such as birch (*Betula*), lime (*Tilia*) and oak (*Quercus*) typically descend diagonally to a depth of 20-50cm at a distance of about 2m from the trunk before radiating out in a more horizontal fashion. After this rooting structure is established, the central taproot generally declines, such that few mature trees retain a sizeable taproot. Although some tree species display a greater disposition towards retaining their taproot into maturity, including oak, pine and fir (*Abies*), even it often does not persist within individual specimens. Where they do persist, retained taproots are commonly largest just below the base of the main trunk, before tapering to a depth of 0.5-1m and dividing into a network of much smaller downward-growing roots (Dobson 1995; Stokes *et al.* 2009, 12).

6.1.4 In many cases, the initial taproot does not even follow a strictly vertical growth pattern, as injury to the growing tip may occur due to browsing by soil fauna, root rot, the presence of obstructive soil horizons and inclusions, or cutting in the case of artificial transplanting. As such, most tree species display much shallower root systems than is commonly believed by the general public (Patch and Holding 2007; Tjelldén *et al.* 2015, 373). Indeed, 90% of all tree roots occur within the upper 60cm of the soil profile, with very few roots penetrating below 2m in depth (Dobson 1995; Crow 2004, 16; Crow 2005; Crow and Moffat 2005, 107; Patch and Holding 2007). Following the infamous storm of October 1987, the

Royal Botanical Gardens at Kew undertook a survey of 4511 windthrown trees across southeast England and found that that only 5% of trees had rooting deeper than 2m, and none deeper than 3m, notwithstanding the possibility that deeper rooted trees had not been displaced (Cutler *et al.* 1990).

6.1.5 Moreover, the volume and distribution of a tree's roots do not necessarily correlate with the spread of the canopy or its height (Helliwell 1992; Crow 2005; Crow and Moffat 2005, 107). Indeed, the total spread of a tree's roots is frequently underestimated and can extend for many tens of meters beyond the branch spread, or 'drip line', albeit predominantly as a relatively fine network (Dobson 1995; Crow 2005; Tjelldén *et al.* 2015, 373). Conversely, the 'zone of rapid taper' typically located at around 2-3m from the trunk means that larger roots are mostly restricted to within this inner 'root plate'. This zone concurrently marks the point at which failure most commonly occurs, for example in storms (Dobson 1995; Ziemiańska and Suchocka 2013, 21). The great majority of tree throws are thus restricted to this inner root plate.

6.1.6 Despite this general similarity across tree species, Crow (2004, 10; 2005, 3; cf Büsgen *et al.* 1929; see also Ghestem *et al.* 2011) has identified three principal forms of rooting system that are still evident as broadly distinctive types:

- *Taproot systems*: root systems where a strong main root descends vertically from the underside of the trunk. Examples typically include English/penduncculate oak (*Quercus robur*), Scots pine (*Pinus sylvestris*) and silver fir (*Abies alba*), though as noted above not all specimens maintain the original taproot into maturity.
- *Heart root systems*: root systems where both large and smaller roots descend diagonally from the base of the trunk, often before continuing to radiate out horizontally. Examples typically include birch (*Betula*), beech (*Fagus sylvatica*), larch (*Larix*), lime (*Tilia*) and Norway maple (*Acer platanoides*).
- *Surface root systems*: root systems where large, horizontal lateral roots extend just below the soil surface, from which smaller (typically 1-2cm diameter) 'sinker roots' grow vertically downwards before splitting into much finer networks. Examples typically include ash (*Fraxinus excelsior*), aspen (*Populus tremula*), Norway spruce (*Picea abies*) and white pine (*Pinus strobus*).

See Fig 23: Diagram of different root system forms (Kutschera and Lichtenegger 2002)

6.1.7 Notably, these rooting categories are not mutually exclusive within single species, or even individual specimens, nor do they necessarily correlate with the overall extent (both vertical and horizontal) of a given system (Crow 2005; Sutton 1969). For instance, ground-penetrating radar (GPR) studies of mature sessile oak (*Quercus petraea*) trees growing on freely draining, slightly acid but base rich loamy soils clearly identified the presence of both radial heart and surface roots, with only minor evidence of relatively shallow relict taproots. The trees under study exhibited a maximum rooting depth of 2m, with most roots confined to a depth of between 0.2 and 1.6m (Hruska *et al.*

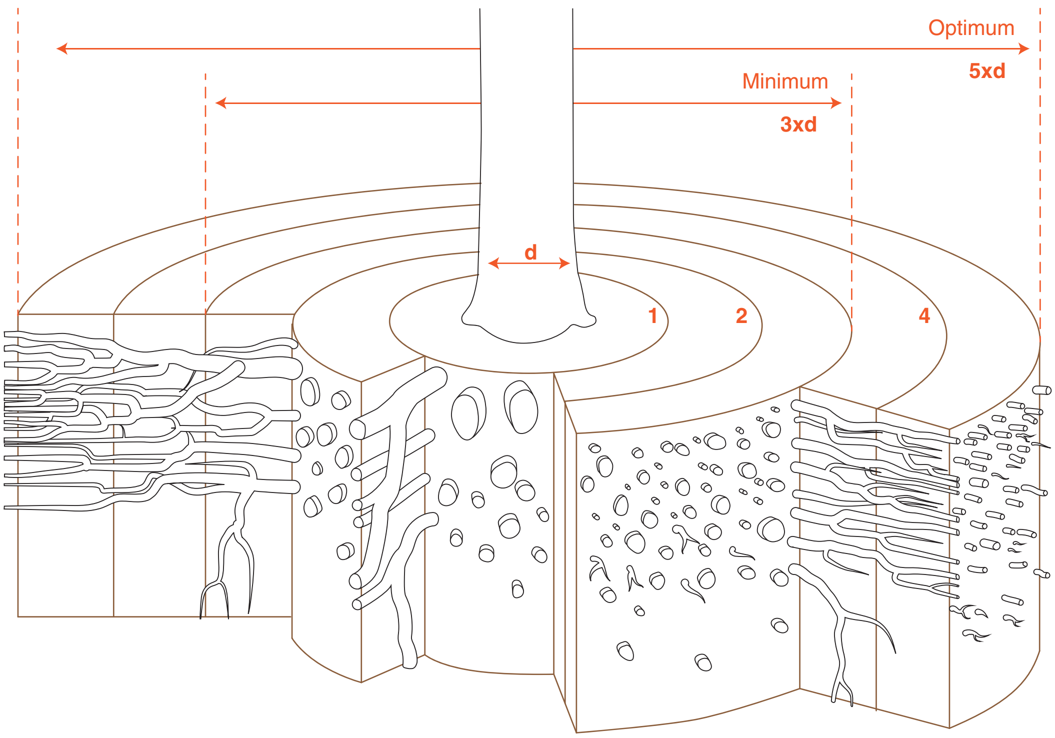

Figure 22: Diagram of rooting diameter

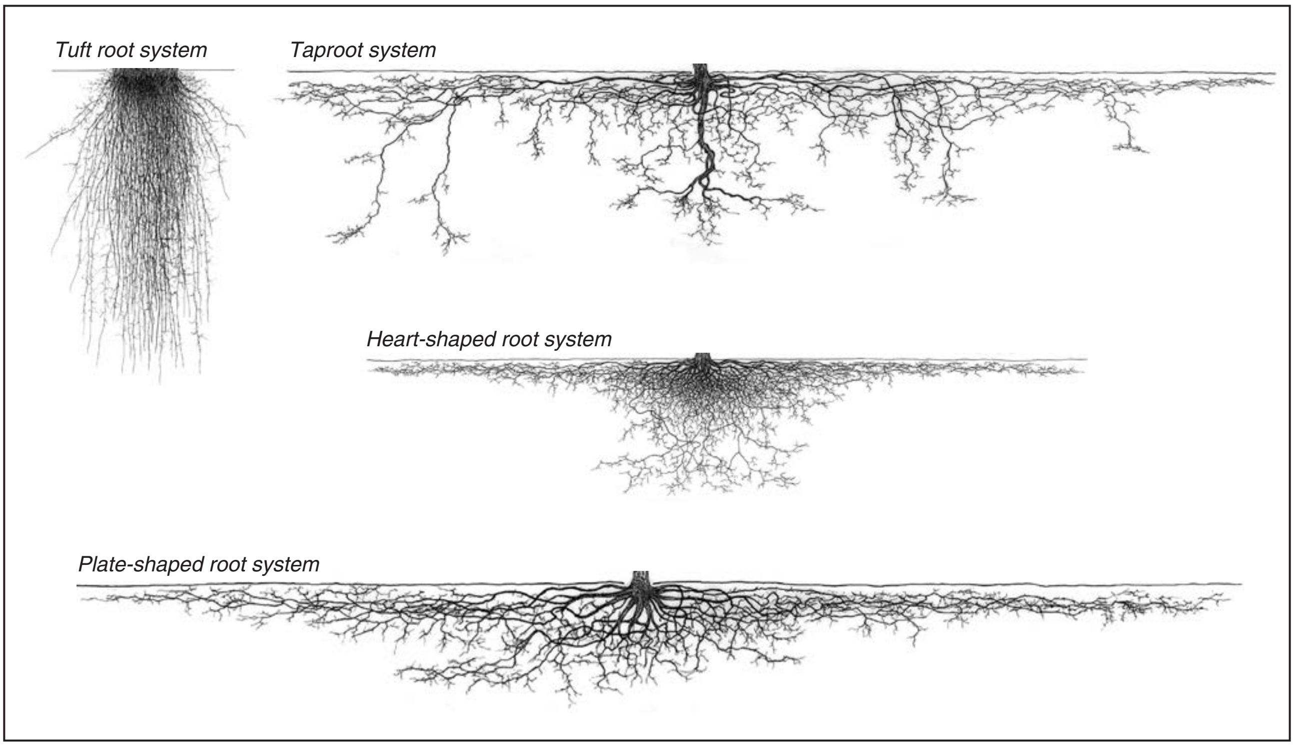

Figure 23: Diagram of different root system forms

1999). Similarly, experimental GPR survey and test excavation of a black pine (*Pinus nigra*) growing on deep, compacted loess-clay garden soils revealed a two-tiered pattern of horizontal lateral roots extending from a central taproot occurring within the top 0.2m of the soil profile and again at 0.8m depth (Stokes *et al.* 2002).

6.1.8 Above all, the root growth of all tree species is fundamentally *opportunistic*, such that roots will proliferate where conditions most favour both physical ingress and resource extraction (ie, loose, well aerated, nutrient rich and relatively moist soils). It is for this reason that a "root will grow along the path of least resistance" (Crow and Moffat 2005, 107), and why the majority of tree roots occur within near-surface soil horizons (cf Dobson 1995). The main factors influencing this basic principle of root growth are discussed further in the section below.

6.2 Factors affecting tree root growth

6.2.1 As noted above, various factors influence the rooting habits of trees, particularly those related to site-specific soil conditions. The most influential of these factors are described below, following the categorisation schema of Dobson and Moffat (1993; see also Crow 2004; 2005), with soil pH included as an additional factor influencing fertility.

6.2.2 *Mechanical resistance*: roots will preferentially avoid penetrating soil horizons with a high bulk density due to the high energy expenditure and risk of injury entailed in doing so. This includes layers of bedrock and iron panning, as well as compacted fine sediments as occurs in many clay-rich soils. Roots will likewise avoid obstacle-causing inclusions such as large stones, and areas in which the abundance of such inclusions is particularly high. Importantly, such qualifiers are often relative, such that roots may still penetrate, for instance, bedrock layers if sufficient weathering has presented fractures and fissures of softer material, or finer gravelly soils where larger rubble deposits are also present.

6.2.3 *Aeration*: virtually all common tree species found within the British Isles have root systems that need oxygen to respire. For most tree species root respiration is impeded and root growth restricted when soil oxygen levels drop below 10-15%. Root growth typically stops completely when oxygen levels fall below 3-5%. Such conditions occur when soil oxygen is replaced by either more soil (ie, through compaction), water (ie, in sustained waterlogging), or by other gasses such as carbon dioxide, hydrogen sulphide or methane.

6.2.4 *Fertility*: fertile soils are defined as those with particularly high levels of accessible nitrogen and phosphorus, which tend to occur in organic-rich horizons close to the ground surface. Trees growing within such soils will generally produce more vigorous, well branched roots that may descend deeper into the soil, whereas infertile soils beget longer, shallower and more poorly branched root systems.

6.2.5 *Moisture*: saturated soils result in poor gas exchange between tree roots and the surrounding substrate, thus depleting the soil of oxygen and eventually leading to anaerobic conditions and subsequent root death (with the exception of some water-loving species, such as alder). Excess soil moisture content, especially when long-lasting, usually results in the formation of particularly shallow root systems. Conversely, excessively dry conditions will also induce some tree species to develop wide-ranging but shallow root systems to maximise precipitation capture as it infiltrates the soil surface. *In situ*ations where there is little precipitation but a deeper sub-surface supply of water, roots may well exploit it by extending deeper tap- or sinker roots, though such situations are relatively rare in the U.K.

6.2.6 *pH*: most tree species will grow best in soils with a pH of between 6 and 7.5 (i.e, neutral to slightly acid), wherein nutrients become most readily available for uptake by plants' roots. That said, some species do prefer more acidic conditions, including pines (*Pinus* spp.), spruce (*Picea* spp) and dogwoods (*Cornus* spp). Conversely, other trees such as limes (*Tilia* spp.) and elms (*Ulmus* spp) are much more tolerate of base-rich soils. Many factors can affect soil pH, from excessive rainfall (typically lowering pH) to the increased input of organic matter (raising pH). Numerous studies have also shown that trees are able to adapt their root morphology to changing pH conditions. For instance, both maritime pine (*Pinus pinaster*) and cherry (*Prunus avium)* seedlings have been found to increase root length in acidified soils (Arduini *et al*. 1998; Neilson *et al*. 1990), whereas Japanese cedar (*Cryptomeria japonica*) saplings reduced root length but engaged in greater network branching (Hirano and Hijii 1998).

6.2.7 Soil particle composition, water, and air content thus all significantly contribute to the propensity for changes in tree root growth within a given soil (Crow 2005, 3). For example, root penetration may be hindered by obstructions such as hard, poorly aerated soils, including compacted clay horizons, iron pans, chalk or other particularly stony soils (Dobson 1995, 3; Crow and Moffat 2005, 107). In such conditions, even taproots may be unable to penetrate downwards, resulting in either dieback or its horizontal deflection (Dobson 1995, 3). As all soil profiles typically become denser and less oxygenated with increased depth, so higher soil horizons present more suitable conditions for root growth, and it is here that the zone of 'preferential root growth' is most usually located (Crow and Moffat 2005, 107). Accordingly, total soil depth is not necessarily correlated with greater rooting depth but is instead dependent on many other variables (see below).

See Fig 24: Figures for UK soil types (Soilscapes and Forest Research)

6.2.8 Root proliferation will extend beyond 'normal' parameters if conditions allow. For instance, trees may develop root systems that extend below 2m where there are particularly deep nutrient and moisture-rich soils whose resources can be exploited to fuel further above-ground growth and/or reproductive investment, especially where those soils retain relatively low bulk densities and/or abundancies of obstructive inclusions (Dobson 1995, 3; Crow 2005, 4; Tjelldén *et al*. 2015, 377). Similarly, soils where moisture retention is higher (as in clayey or loamy soils, particularly those with a high organic content) the need for extensive root growth to access dispersed water resources is reduced, whilst looser, free-draining soils (eg, sands and gravels) often support more extensive and possibly deeper root systems (Crow 2005, 3). In such conditions roots will frequently follow the principle of 'hydrotrophism', whereby they preferentially grow in the direction of sensed water sources (Crow and Moffat 2005, 108; Tjelldén *et al*. 2015, 377). Although rooting may be deeper and/or more extensive in pockets of more fertile soil

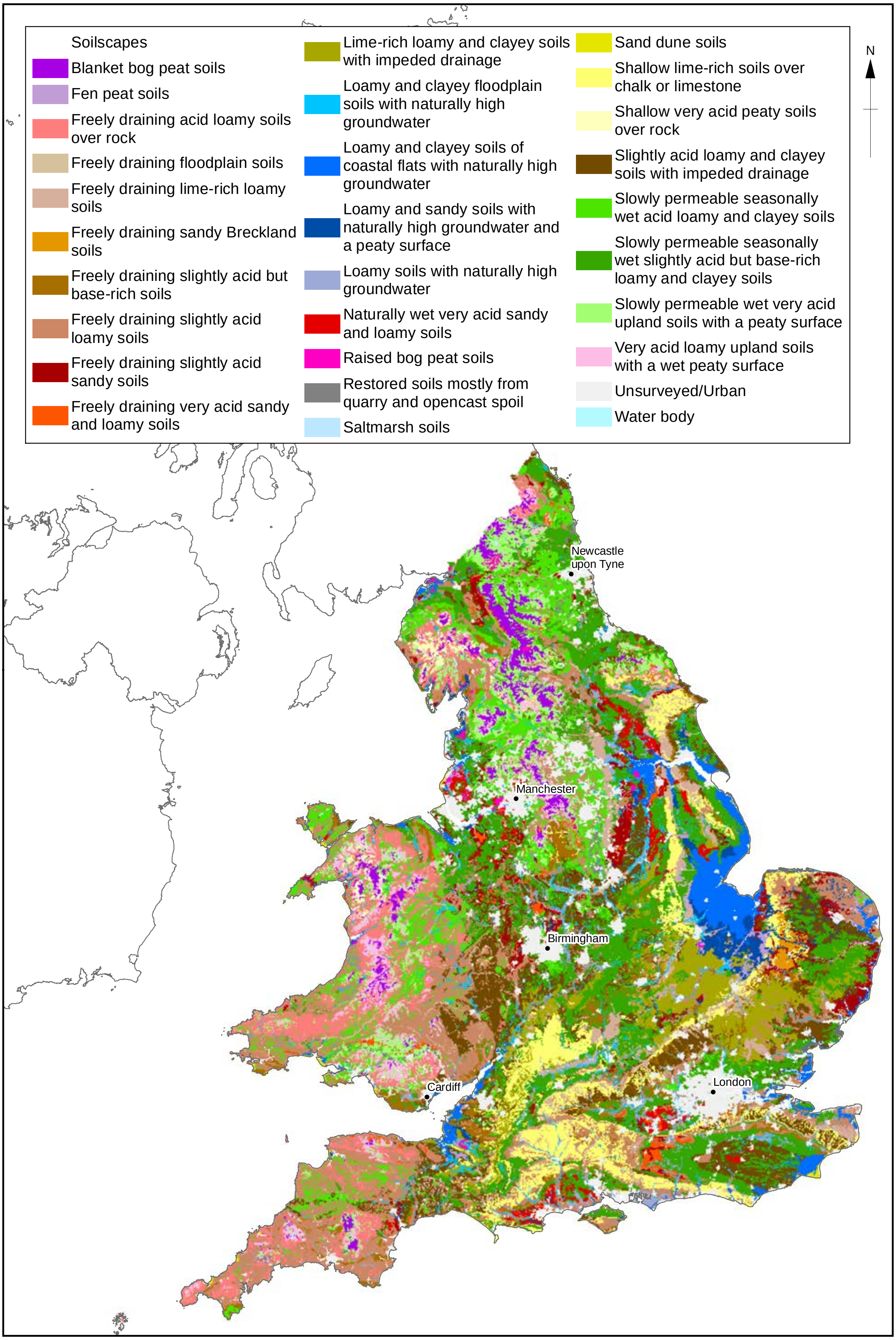

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Figure 24: UK soil types (Soilscapes)

where tree roots are already present, there is no known correlate to hydrotrophism in which roots will actively seek out more distance nutrient-rich

6.2.9 deposits (Crow and Moffat 2005, 108).

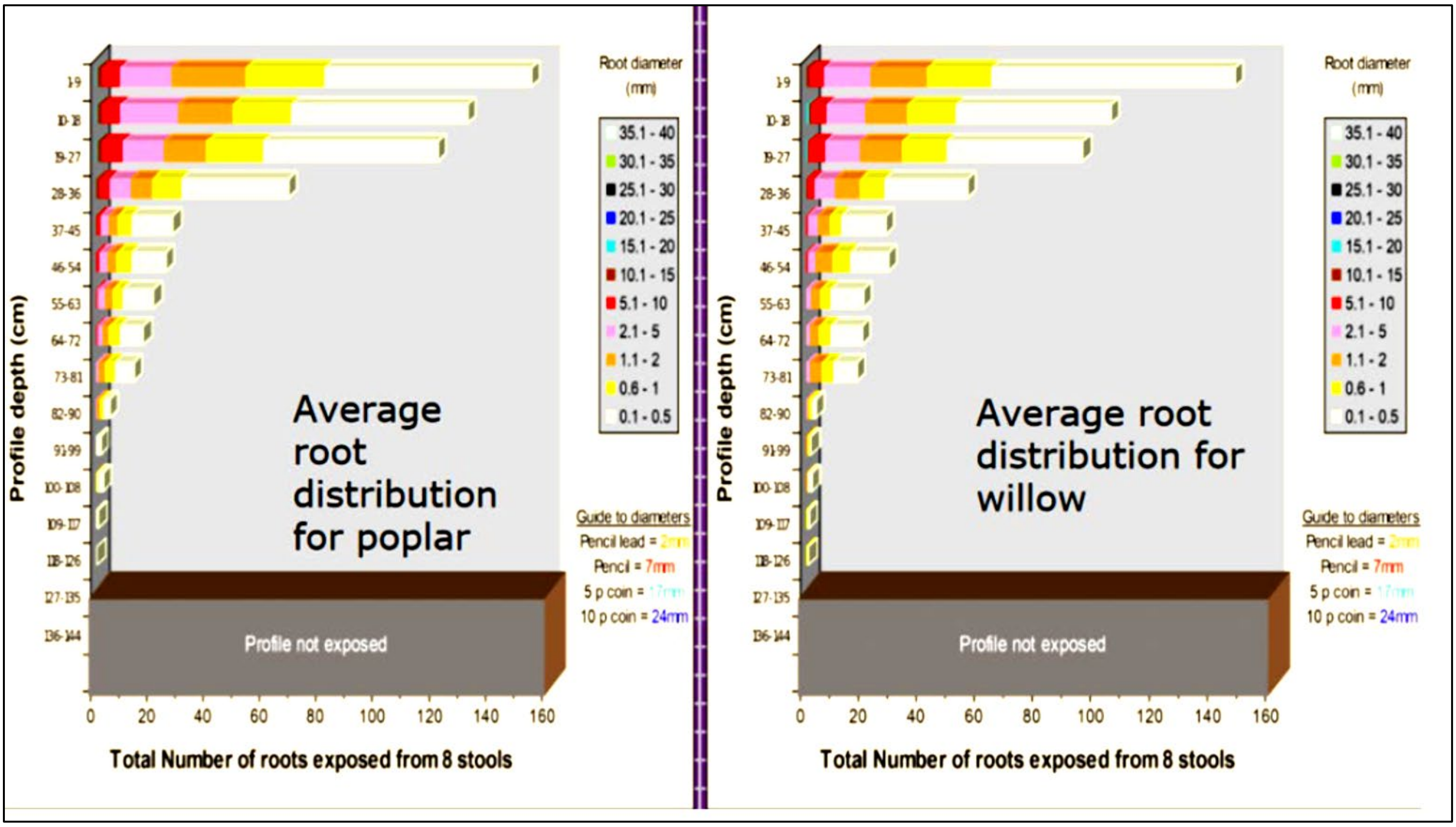


Fig 25: Typical rooting depths of poplar and willow (Crow 2003)

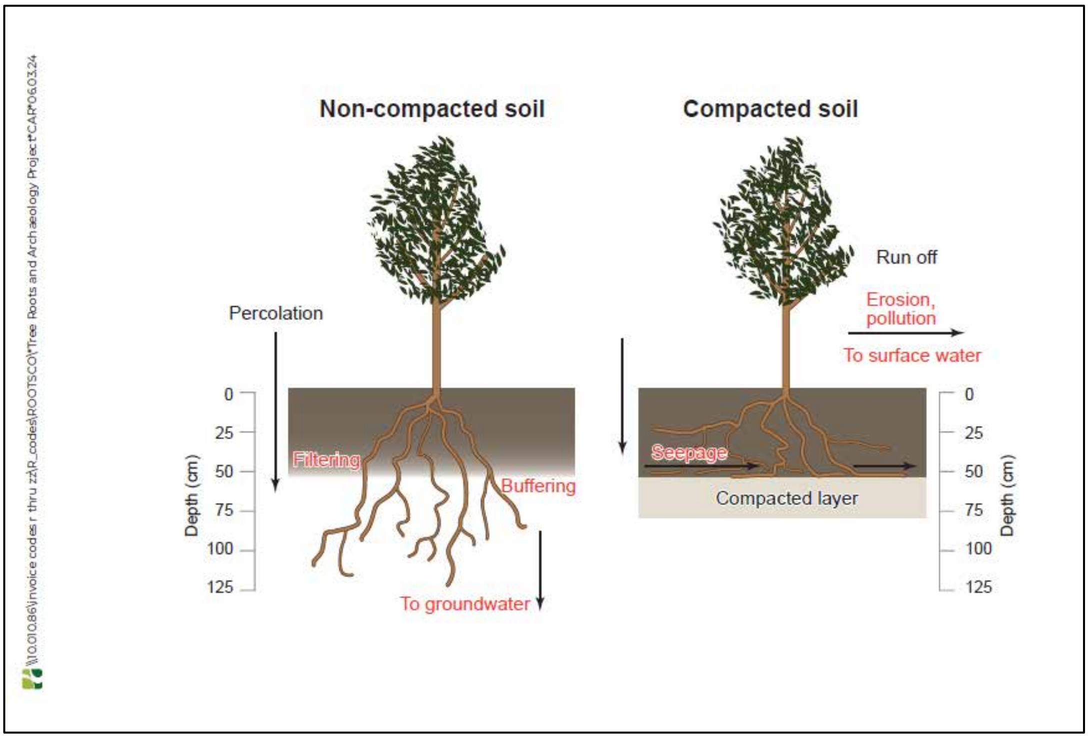


Fig 26: Same tree species rooting to variable depths under different soil/hydrological conditions (adapted from Jones *et al.* 2004)

6.2.10 Numerous other factors can affect the growth (rooting or otherwise) of mature trees subsequent to their initial development. The most significant of these is disease, which in some cases can weaken otherwise healthy trees to the point where the chances of structural collapse, splitting or wholesale uprooting are greatly increased. This is true of diseases (or similar pest stressors) which affect the above-ground extent of the tree as well as those which directly attack the roots (Kelsey *et al.* 1998; Moorman 2023). A pertinent example within the present-day UK comprises ash die-back, a fungal (*Hymenoscyphus fraxineus*) infection causing the widespread death of mature ash trees, whereby the initial infection takes hold in the crown before running down within the trunk and rotting out the lower tree bole (Mitchel *et al.* 2014). If left unmanaged the fungus will weaken the base of the tree to such a degree that it will either break off at the base of the trunk and eventually form a rotted-out stump hole, or fall in a twisting manner which causes more widespread unearthing of the below-ground rooting structure (see Fig 27).

Fig 27: Photo of tree throw caused by rotting of trunk by ash dieback (©David Kay)

6.2.11 At a more anthropogenic level, the relative benefits and downsides of tree staking have become increasingly debated within both horticultural and forestry circles over recent decades, insofar as whilst initial staking may be necessary to stabilise transplanted saplings, prolonged artificial support can reduce the impetus for sustained root growth on behalf of the plant itself. This can lead to later-life weaknesses, especially amongst species which are already shallowly rooted and present larger 'wind sails' in their top growth (Appleton *et al*. 2008; Harris and Bassuk 1993). It is likely that other human-centred planting practices are likely to affect the development of roots among various tree species and is certainly a topic that would benefit from further research.

6.2.12 Such caveats notwithstanding, the general rooting habits (including average depths) for most common UK tree species are summarised in Tables A.1 and A2 in Appendix A, including their typical response to differing soil conditions and other environmental factors. From the data included in that table, it is apparent that the average (mean/mode) rooting depth for most common UK tree species (both native and introduced) is in the region of 1.5m below ground level (here including the fine roots in addition to the principal coarse root architecture). In comparison, relatively shallowly rooted trees are represented by the species of beech (*Fagus*), field maple (*Acer campestre*), grand fir (*Abies grandis*), noble fir (*Abies procera*) and Norway maple (*Acer platanoides*), all of which typically root to a depth of c 1m. Conversely, the following species are all typically deeper rooting: black or Corsican pine (*Pinus nigra*), English/ pedunculate oak (*Quercus robur*), European larch (*Larix decidua*), lodgepole pine (*Pinus contorta*), Sitka spruce (*Picea sitchensis*: 1.5-2m), common alder (*Alnus glutinosa*), common walnut (*Juglans regia*), Douglas fir (*Pseudotsuga menziesii*), Norway spruce (*Picea abies*), Scots pine (Pinus sylvestris), silver fir (*Abies alba*), sweet chestnut (*Castanea sativa*), white poplar (*Populus alba*: 2m), Japanese larch (*Larix kaempferi*), white willow (*Salix alba*: 2-2.5m), and crab apple (*Malus sylvestris:* 2-3m).

6.2.13 Most species will then trend towards deeper rooting in particularly fertile, loamy soils, particularly pedunculate oak (to depths of c 4m). Some species are also particularly adapted towards increased rooting in deep, highly permeable substrates in order to reach deeply buried water sources, including aspen and sweet chestnut (to c 2.5m), and particularly European larch and Scots pine (to 4m and 3m respectively). Conversely, although relatively few species are well adapted to totally waterlogged conditions (eg, alder, black poplar and the various willows), in such cases their roots are likely to be relatively shallow given the overabundance of accessible near-surface water resources. The implications of these variable rooting depths with regards to the specific preservation of archaeological sites are considered further in Section 9 of this report.

6.3 Effects of trees and tree roots on underlying sediments

6.3.1 Whilst all plants will affect the soils in which they grow, trees will have greater such effects due to both their size and longevity (Miles 1986). These effects can be grouped under three main headings – physical, chemical and biological – albeit with considerable overlap.

Physical effects

6.3.2 *Soil texture:* as tree roots penetrate the surrounding soil, they create channels and macropores which increase soil aeration and gaseous exchange (Gyssles *et al.* 2005, 195-196; Miles 1986, 55-56). They also increase soil aggregate stability by secreting exudates which enmesh fine particles into stable microaggregates, drying the soil environment and binding clay particles within the rhizosphere (the ensemble composed of the roots and immediately surrounding bioactive soil matrix), supplying organic residues, supporting both microbial and soil fauna populations, and increasing polyvalent cation availability (Frouz *et al.* 2013, 87; Ghestem *et al.* 2011, 870; Gyssles *et al.* 2005, 195-196). At a microscale root growth can also increase soil bulk density by occupying existing pore spaces and compressing the surrounding sediment (dependent on soil type). However, this is generally truer of coarse (>2mm) roots than the far more frequent and spatially pervasive networks of fine (<2mm) roots, the latter of which instead typically reduce soil bulk density (Gyssles *et al.* 2005, 195-196).

6.3.3 As tree roots increase porosity so they will concurrently affect soil drainage properties (Miles 1986, 55-56). Many of these pores comprise the channels created around live roots, those formed by dead/decaying roots, and old channels reoccupied by new roots. Water will then preferentially flow through these channels, improving subsoil drainage, and on slopes significantly reducing the risk of mass wasting events (Ghestem *et al.* 2011). Conversely, the high decay and emission rates of fine roots can lead to the formation of clusters of sponge-like structures that soak up higher quantities of water during heavy rain and create nodes of high-water pressure within otherwise free-draining substrates (Ghestem *et al*. 2011, 875; Stokes *et al*. 2009, 16).

6.3.4 *Hydrology:* all trees will remove moisture from the upper soil horizons in which they are rooted, though the degree of uptake is conditioned by both species- and specimen-level variations in hydraulic conductance (fine root conductivity and total fine root surface area), root distribution, and the ability to dynamically produce new roots, in addition to soil water availability and the presence of mycorrhizal fungi (Bond *et al*. 2006, 19). Conversely, increased surface porosity is liable to induce greater rates of infiltration, which in combination with greater moisture retention properties induced by the cyclic incorporation of organic matter (see below) can stabilise or even raise localised water tables (Reubens *et al*. 2007, 386; Young 2004, 179-180).

6.3.5 Deeply rooted trees are more likely to draw on groundwater resources than moisture held within upper soil horizons, particularly in dry summers or other times of drought (Pinto *et al*. 2013). In some cases, these properties have been deliberately employed to lower groundwater tables and counteract the effects of salinisation (Khamzina *et al*. 2006). The effect of trees on local hydrological regimes is thus likely to vary with both species and season, in addition to longer term trends conditioned by climatic changes. However, research on this topic remains comparatively sparse, especially when comparing below-ground effects (eg, tree roots' influence on soil hydraulic properties and preferential flow paths) with above-ground transpiration and moisture interception (Bond *et al*. 2006, 7).

6.3.6 Peat deposits are particularly sensitive to dewatering, including that induced by tree cover. It should be noted that peatland areas are often not the target (or suitable) for woodland creation. However, afforested peat deposits will dry rapidly through both rainfall interception loss and transpiration by the planted trees, causing shrinkage and erosion of the peat in an often-irreversible manner. Lodgepole pine (*Pinus contorta*) monocultures seem to have a particularly great effect in this regard (Miles 1986). Moreover, this process is often greatly exacerbated by mechanical drainage schemes conducted ahead of planting operations (Anderson 2001: 2-3; Johnson 1998; Miles 1986: 55-56). The afforestation of blanket, raised and intermediate bogs will also cause significant dewatering of the surrounding land, with the effects increasing in spatial extent and magnitude according to both the size of the forest block and the number of repeated cycles of felling and replanting (Anderson 2001: 5-6).

6.3.7 It is here important to note that UKFS (v4) Guidelines on Forests and Climate Change (p 70, guideline 5) instruct forest planners to "[a]void establishing new forests on soils with peat exceeding 50cm in depth and on sites that would compromise the hydrology of adjacent bog or wetland habitats." Nevertheless, this guidance still leaves shallow peat deposits vulnerable to woodland-induced dewatering, especially where they have not been accurately mapped by prior survey (either remote or ground-truthed).

Fig 28: Diagram/photo of dewatered peat (©Henry Chapman)

6.3.8 *Erosion:* tree roots actively reinforce loose soils, particularly on slopes, through both tensile strength as well as frictional and/or adhesional properties. This is especially true for fine roots (ie, those <2mm in diameter) which form a wide-spreading root mat within the soil. Conversely, coarser roots (>2mm diameter) frequently do not penetrate deep enough to fully prevent mass wasting events, although deeper taproots can act in a stabilising manner akin to that of soil nails or construction piles (Ghestem *et al.* 2011: Table 1; Reubens *et al.* 2007, 386, 393; Stokes *et al.* 2009). Where coarse roots do penetrate the underlying bedrock they can anchor the overlying soil profile and dissipate soil-borne water pressure, though in some cases transferred water pressure may itself cause fragmentation and potential rock falls (Ghestem *et al.* 2011, 874). However, rocky ground, fragipans and high groundwater tables all typically restrict root growth and the consequent effectiveness of slope stabilisation (Reubens *et al.* 2007, 387). Some species, like the non-native stone pine (eg, *Pinus pinea*), are particularly poor at penetrating hard bedrock and will preferentially form a layer of high root density within the overlying soft sediment that can exacerbate the shear forces affecting potential slip surfaces (Ghestem *et al*. 2011, 874).

See Fig 29: Diagrams of tree roots' impact on erosion and slope stability (adapted from Stokes *et al*. 2009)

6.3.9 Although as noted above the increased porosity and improved drainage induced by extensive tree rooting will generally reduce water pressures within soil pores and thus mitigate against mass wasting, high pressures can also form where preferential flow channels converge, collapse or abruptly terminate at critical zones, as may occur when roots die off or form spongey masses. In such cases the risk of localised slope failure may be increased, especially if combined with other tree-related stressors such as the transmission of dynamic forces to the soil mantle during high winds (Ghestem *et al*. 2011: Table 1; Stokes *et al*. 2009, 13-14).

6.3.10 Specific incidences of mass wasting aside, there is an exponential relationship between increased root mass and decreased waterborne erosion, primarily through reductions in surface runoff caused by increased infiltration and the creation of a rougher ground surface which reduces the volume and velocity of surface water flow. These effects are particularly impactful in reducing rill and ephemeral gully erosion, whilst above-ground canopy cover is likewise effectual in mitigating splash and inter-rill erosive processes (Ghestem *et al*. 2011: Table 1; Gyssles *et al*. 2005; Reubens *et al*. 2007, 387; Young 2004, 179-180). These processes apply on rocky ground, or that with a very thin soil mantle and have even been noted in urban settings (Colville *et al*. 2020).

6.3.11 *Mechanical displacement:* during active growth roots can exert axial and radial pressures as high as 1.45 and 0.91 megapascals (MPa), wedging and displacing soil, and in some cases permitting the penetration and splitting of suitably soft and/or already fractured bedrock. Splitting bedrock in this manner in turn accelerates weathering processes by exposing larger surface areas to chemical attack and allowing the greater infiltration of both air and water (Gabet and Mudd 2010; Phillips and Marion 2006; Stokes *et al*. 2009, 16). As local water availability changes on a seasonal basis, so tree roots will also shrink and swell, causing fluctuations in exerted pressure within both cracked rocks and softer sediments (Navarro *et al*. 2009).

6.3.12 Tree roots can also ingress masonry structures in a manner similar to naturally rocky ground. This is particularly true of trees with strangler characteristics, such as the various strangler fig species present throughout east and southeast Asia (Jim and Chen 2010). Whilst such tree species are rare within the UK and essentially limited to singular exotic specimens, many associated woodland species such as clematis and ivy have similar effects. Freely seeding ruderals such as sycamore (*Acer pseudoplatanus*) and ash are also likely to lodge within masonry structures, where their water and nutrient requirements will remain relatively slight throughout their initial growth as young saplings.

6.3.13 Uprooting events such as tree throws can be particularly disruptive of underlying sediments, in some cases removing large quantities of soil as well as mining rock fragments from the deeper subsoil and bringing them to the

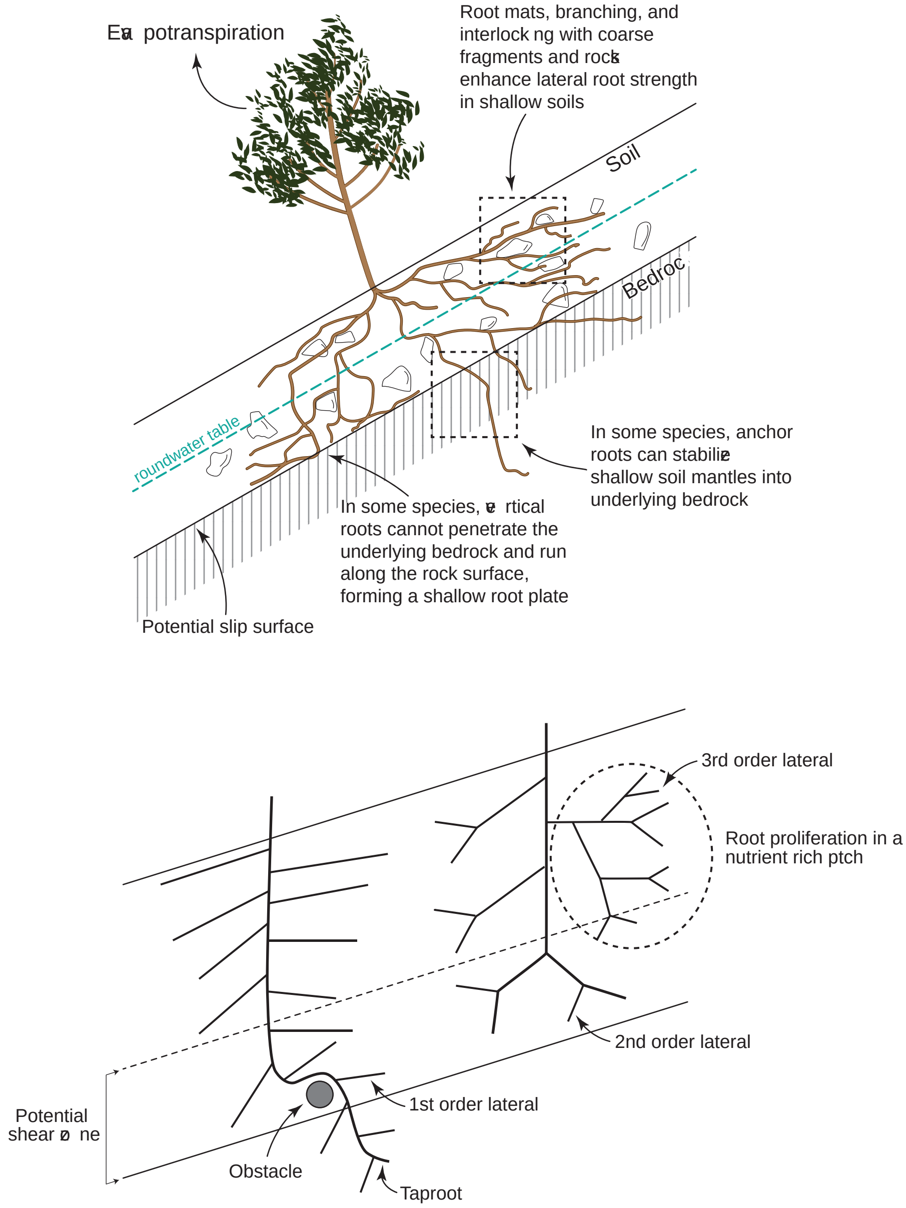
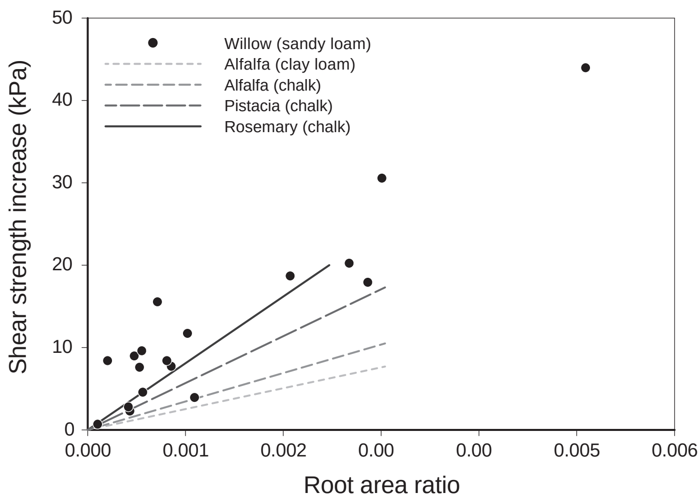


Figure 29: Diagrams on erosion and slope stability



surface (Phillips and Marion 2006). The force of these events can be severe, with some uprooted trees being recorded lifting boulders weighing as much as four tons (Gabet and Mudd 2010). As noted above, such depressions are typically as wide as the central root plate (typically 2-3m for mature trees) and as deep as the coarsest roots (generally <1m) (Phillips and Marion 2006, 234). Such destructive events are more likely to occur in single species plantations than mixed woodlands (Griess *et al.* 2012), as well as sloped and/or rocky areas where a combination of poor rooting and other factors have resulted in unstable shear surfaces (Reubens *et al.* 2007, 385).

See Fig 30: Diagram of tree throw from the Drayton Cursus, Oxfordshire (©George Lambrick)

6.3.14 A less well-known effect occurs when standing trees die *in situ* and leave smaller rotted-out stump holes in their place. These holes are generally the same size as the basal flare of the original trunk, and as deep as the principal tap/heart roots. Such holes will then infill through a combination of slumping from the surrounding sediments and/or top-down ingress of surface matter. Some differences have been noted between hardwoods (eg, *Quercus* spp.) and conifers (especially *Pinus* spp.) with regard to these features. Typically, the surface root growth of the former will laterally displace rocky inclusions and promote their later deposition within stump holes, whilst the sub-surface roots of the latter cause greater vertical displacement of both soil and rocky inclusions through basal mounding (Phillips and Marion 2006).

6.3.15 *Biomantle dynamism:* many of the more active components of tree root growth (and death) all contribute to the non-uniform dynamism of the soil biomantle, with total forest floor turnover in wet temperate environments operating on as short as a 100-year cycle (Phillips and Marion 2006, 233, 245). There is also evidence from studies on poplars that as atmospheric CO^2 increases so root biomass and fine root turnover markedly increase (Brunner and Godbold 2007), thus increasing the biomechanical dynamism of tree roots and further adding to soil carbon stocks. Even seemingly destructive episodes such as tree throws and other uprooting events can influence the spread of soils through time, particularly on slopes where the exposure of underlying sediments/bedrock layers creates renewed cycles of weathering and pedogenesis (Gabet and Mudd 2010).

Chemical effects

6.3.16 *Acidification:* all tree species secrete metabolites to the rhizophere *via* root exudates to modify specific soil properties, most notably by modifying its pH using amino acids to solubilize nutrients into assimilable forms (Smith 1976; Vives-Peris *et al.* 2020). However, a far greater acidifying effect results from the decomposition of fallen litter on the forest floor. In almost all cases this leads to a decrease in soil pH when under woodland cover, although atmospheric deposition and acidic rainfall (itself further affected by leaf drip and stemflow) are also highly influential factors (de Schrijver *et al.* 2012; Miles 1986, 55). The resultant combined acidification effect correlates to an increase in free hydrogen ions typically caused by changes in the concentrations of exchangeable soil Ca^{2+} and Al^{3+}, generally equating to a decrease in Ca^{2+} and increase in Al^{3+} (de Schrijver *et al.* 2012, 1132).

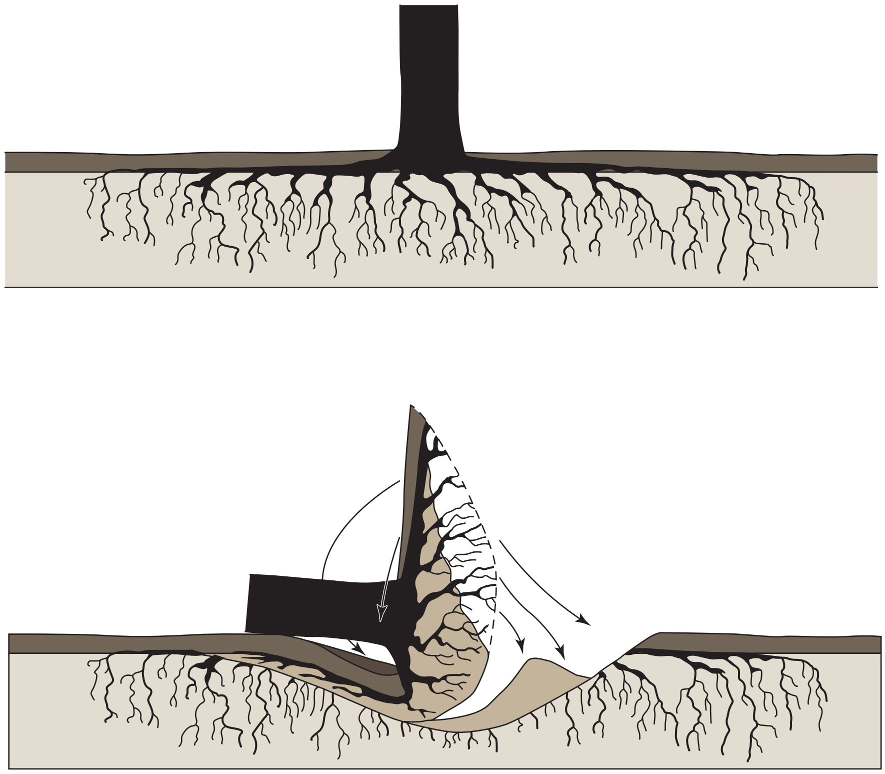


Figure 30: Diagram of tree throw from the Drayton Cursus, Oxfordshire

6.3.17 The degree of acidification varies greatly according to the dominant tree species present, with Norway spruce producing particularly highly acidified soils (Binkley and Giardina 1998, 95; Miles 1986, 56). Studies of broadleaved woodland in Belgium have noted greater soil acidification under oak, alder and ash than lime and plum *(Prunus* spp) with oak and alder having a respectively ten- and twenty-times greater effect than ash. Acidification of deeper soil layers also occurred faster under alder and oak than lime, plum or ash, although the effect lessened with increased depth stratification of the soil profile when compared with the more highly bioturbated, non-differentiated soils prevalent under the latter species (de Schrijver *et al.* 2012, 1132-1137). It is also important to note that acidification progresses much faster within freshly weathered soils than those under long-term vegetative cover (trees or otherwise), and is significantly reduced where soils are well buffered, for instance by high concentrations of calcareous clays (Miles 1986, 55).

6.3.18 *Nutrient cycling:* woodland topsoils are generally more efficient in carbon/nutrient cycling than non-wooded soils, exhibiting greater levels of nitrogen fixing and uptake from deeper soil horizons (Young 2004, 180). The preferential uptake of water and mineral nutrients can also lead to the depletion or accumulation of specific ions within the topsoil, particularly phosphorus and potassium in the former case, and sodium and calcium in the latter (Gyssles *et al.* 2005, 196). The role of different tree species is again highly variable, especially when considered in interaction with different soil/regolith types (Frouz *et al.* 2013). However, studies suggest that root exudation rates and carbon fluxes are generally higher under deciduous tree species than conifers, as are the related factors of microbial biomass, enzyme activity and net nitrogen (N) mineralisation rate, all of which result in more rapid carbon (C) and nutrient recycling (Binkley and Giardina 1998; Wang *et al.* 2021). That said, some conifers do seem to promote N availability much more than others, particularly larch and white pine (Binkley and Giardina 1998, 95).

6.3.19 As with soil pH, changes in nutrient availability and cycling are largely tied to the effects of decomposing leaf litter more than root activity *per se*. As such, the generally low C:N ratio litter of deciduous trees tends to form thick organo-mineral A horizons under narrow/absent organic Oe horizons, whilst higher C:N litter of conifers produce the opposite effect (Frouz *et al.* 2013). The mull humus typically formed from rapidly decomposing deciduous leaf litter is also generally held to be more fertile than the thick mats of undecomposed mor humus prevalent under conifers, though this correlation is far from absolute (Binkley and Giardina 1998, 95). In the case of commercial forestry operations, the application of artificial fertilisers will also affect soil nutrient levels, both directly and through subsequent litter fall (Anderson 2001, 2).

Biological effects

6.3.20 *Decomposer organisms:* two thirds of all forest litter input is derived from the death of fine roots and mycorrhizal fibres, with only one third deriving from leaf matter. As discussed above, the input of organic material (both above- and below-surface) from different species will result in varying ratios of both organic chemicals and mineral nutrients within the developing O/A-horizon, having knock-on effects on the presence and size of the populations of specific decomposer organisms (Miles 1986, 55). Such organisms range from microbial lifeforms, through a great range of fungi, to larger invertebrate fauna such as beetles and earthworms. Generally speaking, litter is more easily decomposed when it exhibits a low C:N ratio and high chlorophyll content, as is typical for broadleaved trees (Frouz *et al.* 2013, 93). It is for this reason that mull humus is more prevalent within deciduous forests, and mor humus within coniferous ones.

6.3.21 *Bioturbation:* many organisms contribute to the bioturbation of soil profiles under tree cover, from tiny insects through to comparatively large vertebrates such as badgers. However, it is the various species of burrowing earthworms which probably have the single greatest effect on biologically driven soil mixing in temperate climates (Edwards 2009). A greater abundance of earthworms within the topsoil results in increased thickening of the A-horizon, whilst the incorporation of organic matter within pores and soil aggregates slows within-soil decomposition rates, resulting in higher microbial biomass but lowered respiration. Without this process, loose litter remains on the ground surface for far longer and eventually enters the soil either as dissolved matter or very small fragments settling within near-surface void spaces (Frouz *et al.* 2013, 93). In addition to fixing higher levels of carbon within the sedimentary matrix, the incorporation of humified organic matter within soil aggregates leads to more highly developed soil pore structures and improved water retention properties (Reubens *et al.* 2007, 386; Young 2004, 179-180). The presence of plentiful burrowing earthworms also counteracts acidification by accelerating the circulation of base cations (de Schrijver *et al.* 2012, 1137-1138).

Fig 31: Worm-induced lines at Botolph Bridge, Peterborough, U.K. Note the strong sorting at the bottom of the profile, and a weak line of stones on their way down in the middle. Modern activity has scattered another layer on the current surface which will start sinking rapidly as long as casting continues (Cambridgeshire County Council Archaeological Field Unit).

6.3.22 Conversely, a dearth of earthworms will retard surface decomposition rates and lead to the build-up of forest floor Oe-horizons, in turn increasing sub-surface acidification as cations are held back from active circulation within the soil and organic acids leach down-profile. As most earthworm species prefer low C:N and lignin:N leaf litter and relatively calcium-rich substrates, and dislike the presence of concentrated tannic acids, so their numbers tend to be markedly reduced under conifers than in broadleaved woodland. This factor is a major contributor to the thickened litter mats commonly observed within coniferous plantations (Frouz *et al.* 2013; Miles 1986, 56-57). Soils underlying old growth deciduous forests have also been found to exhibit up to a seven-fold increase in worm populations relative to intensively managed farmland. However, variation do also exist for soils underlying deciduous trees. For instance, both ash and *Prunus*-dominated woodland produce higher quality (low C:N) litter layers, which are in turn subject to faster decomposition and earthworm recycling than in stands where oak and alder are the dominant species (de Schrijver *et al.* 2012, 1135-1138).

6.3.23 In summary, even though in dense forests tree roots typically comprise less than 1% of the volume of the uppermost 1m of the soil profile (Paton 1995, 64-65), the effect of trees on that profile can be significant. As itemised above, such effects are often varied and multi-factorial and can have differential impacts on the underlying sediments depending on how those factors combine in specific times and places. In many cases these relationships can engender strong feedback loops which drive further trajectories of bio-sedimentary change (Binkley and Giardina 1998, 89). As such, it important to stress that any assessment of trees' effect on soils needs to follow a case-by-case and science-led approach to both site and species (Binkley and Menyailo 2005; Miles 1986). It is equally important to consider how such effects may change throughout the ecological lifespan of a given tree stand (Miles 1986, 57).

6.3.24 Nonetheless, there is substantial evidence that both conifers and broadleaved trees are capable of altering soil properties, especially where those soils are well-drained and poorly buffered (as in many deep, predominantly sandy substrates). Moreover, conifers have generally been shown to promote greater surface organic matter accumulation and increased sedimentary acidification than is commonly evident in deciduous woodlands. Over time this can lead to increased podzolisation of the soil profile, in which overall bulk density and base saturation levels decrease, whilst infiltration capacity increases and organically bound nitrogen and phosphorus are leached down-profile. Such effects are generally hard to reverse, though increased bioturbation under changed planting regimes (including natural succession by birch and aspen) may mitigate the adverse effects by physically mixing the A- and B-horizons (Miles 1986, 56-60). Under native broadleaved woodland, acidification and attendant soil chemical changes are generally less marked, and further mitigated by the added incorporation of organic matter within the A-horizon by larger earthworm populations. This incorporation of organic matter further improves soil structure and its potential for moisture retention, which in combination with extensive rooting architectures can (though not necessarily) significantly lessen soil erosion, especially on sloping topographies.

Left: Root systems, Hampton Court Palace, London © Oxford Archaeology

7. Impact Analysis: Roots and Archaeology

This section presents an overall impact analysis of tree roots on archaeological resources. The evidence assessed derives from the research and stakeholder engagement project stage, with additional data collated from the stakeholder engagement and consultation exercises, desk-based data research, and specific case studies.

7 IMPACT ANALYSIS: ROOTS AND ARCHAEOLOGY

7.1 Impact Assessment

7.1.1 Although the review of existing literature in Section 3 identified a relative paucity of prior studies on the specific effect of tree roots on archaeological sites/deposits, the more botanically and pedologically focussed discussions of tree rooting in Sections 4 and 6 permit several further inferences to be made.

7.1.2 This section presents an overall impact analysis of tree roots on archaeological resources. The evidence assessed derives from the research and stakeholder engagement project stage, with additional data collated from the stakeholder engagement and consultation exercises, desk-based data research, and specific case studies.

7.2 Potential Impacts

7.2.1 The first means by which roots can impact archaeology is by their (and related factors') potential effects on stratigraphic integrity. Although roots will certainly penetrate archaeological features and buried structures as a part of their normal development, such processes are gradual and unlikely to cause significant degrees of soil mixing on their own, although specific incidences are certainly known (see below). However, the presence of trees, particularly broadleaved species, may increase the number and density of below-ground faunal populations, many of which are highly effective bioturbators. In the case of larger burrowing animals such as badgers or rabbits, the impact on archaeological assets is likely to be individually high but relatively discrete. In other words, although burrow networks may penetrate multiple stratigraphic layers and displace archaeological materials as surface upcast, those burrows are unlikely to lead to the total turnover of the horizons in which they are situated, and if subjected to archaeological excavation are typically easily recognisable even when infilled (Clarke 2014; Dalland and Carter 1998; Pelletier *et al*. 2017). Conversely, smaller invertebrates, through their far greater numbers will have a much larger effect on soil mixing, in particular the turnover of the whole matrix as opposed to the reordering of discrete areas (cf Davidson 2002).

7.2.2 As discussed above (Section 6.3.21), the most impactful bioturbating soil fauna are earthworms. In terms of archaeological stratigraphy, the activity of deeper burrowing species will lead to the steady intermixing of context horizons through time, and the blurring of their respective stratigraphic boundaries. In some cases, this can destroy buried soils and more ephemeral stratigraphic variations within discrete features. Earthworm species that are more common within the upper topsoil will then steadily bury larger inclusions such as stones and archaeological artefacts through the gradual build-up of their surface upcasts, whilst some species prevalent within mull-humus soils (as present in broadleaved woodlands) will produce small surface cairns of stones and other detritus. Experiments and field observations alike have shown both processes capable of significantly displacing archaeological material, with micromorphological methods in particular adept at identifying earthworm activity within *in situ* archaeological deposits (Canti 2017; Canti 2005, 31-37; Piron *et al*. 2012; West *et al*. 1991). That said, it is important to note that the great majority of earthworm activity (encompassing both apigeic and endogeic species) is confined to the top c 30cm of the soil profile, ie, the topsoil and immediately underlying subsoil horizon (Canti 2003, 139). Conversely, deep-burrowing anecic species such as *Lumbricus terretris* will establish large, semi-permanent vertical burrows up to several metres in depth. Though also responsible for soil mixing on a vertical plane, the frequent re-use of these burrows means that their influence is typically much slower paced than those of near-surface species (Canti 2003: 136).

7.2.3 The induced movement of inclusions throughout the soil profile can lead to issues with the dating of specific deposits, due both to general soil mixing and the specific transport of fine clastic material (both organic and inorganic) to line earthworm aestivation chambers up to 2m below ground This is particularly true with regards to the radiocarbon dating of charred seeds and other plant material, where erroneous dates may be produced from otherwise seemingly secure contexts (Canti 2003, 142-143; Canti 2005, 37-39). That said, such chambers typically comprise only a minute fraction of the surrounding sedimentary matrix (Martin Bell pers. comm. 2024), whilst the displacement of intrusive material has also been noted within sites characterised by perennially waterlogged or loose, sandy soils where worms are far fewer in number (eg, Brown *et al.* 2023; Champness 2007). In such cases, mechanical rooting is itself more likely to have been the principal causal factor in sedimentary mixture.

7.2.4 As afforested soils, particularly those under predominantly deciduous tree cover, are liable to marked increases in earthworm activity when compared to arable land (though their greatest abundances are typically recorded from field margins and hedgerows, cf Natural England 2014), so the potential impact on loose sediment archaeological features from worm-induced bioturbation can likewise be elevated. However, such effects are greatest on shallowly buried features and buried soils (Canti 2003, 1467), which themselves are already highly prone to disruption via faunal activity and/or mechanical disturbance on land not yet converted to woodland. Moreover, as discussed in Section 6.3.21, elevated earthworm populations under woodland can also have many positive effects such as improving soil structure and moisture retention, which are often also positive in terms of archaeological preservation. Research by van Nest (2002) has also demonstrated how earthworms can directly contribute to the improved preservation of archaeological sites over extended time periods by more deeply burying them under thicker protective biomantle horizons. Needless-to-say, the potential effects on archaeological assets must also be set against earthworms' positive roles within net biodiversity gain (Fragaso *et al.* 1997; Plaas *et al.* 2019) and carbon sequestration processes (Don *et al.* 2008; Thomas *et al.* 2020; Zhang *et al.* 2013).

7.2.5 Tree roots are also likely to directly impact archaeological assets characterised by loose and / or rocky material, including both below- and above-ground masonry structures. On the one hand, roots penetrating rocks and / or masonry can exert considerable force, especially when exploiting existing fractures or following similar weak points such as mortared joints. In some cases, these can degrade the structural integrity of the materials concerned, and even cause incidences of collapse. Likewise, earth shrinkage and seasonal fluctuations near to historic buildings with shallow and/or otherwise compromised foundations can exacerbate issues with subsidence. Conversely, once in place, roots penetrating masonry structures can also effectively replace the previous mortar as a structurally binding agent, as noted in several of the key stakeholder interviews discussed in Section 5. Moreover, tree roots have been found in many if not most incidences to have a positive effect in decreasing soil erosion and concomitantly increasing slope stability in areas otherwise prone to mass wastage events. For archaeological sites located on steep, fragile slopes, or which themselves feature sloped deposits vulnerable to erosion (eg, henge monuments, barrows, hillforts and linear banks), the stabilisation of those slopes through the presence of tree cover would thus lead to increased preservation of the archaeology concerned.

Fig 32: Exposed tree root systems on outer bank of Avebury henge (©Peter Crow)

Fig 33: Root-affected historic building/structure at Chilworth Gunpowder Mill (©Oxford Archaeology)

Fig 34: Rooted filled post-medieval grave at Paradise Square, Oxford (©Oxford Archaeology)

7.2.6 The root types most effective at stabilising slopes are coarser roots which grow to increased depths and/or can penetrate the underlying bedrock. In such cases these larger roots may cause greater within-profile displacement of sediment within archaeological features than would otherwise result from shallower or finer root networks. Conversely, shallow lateral rooting across slopes, especially in thin soils overlying potential sub-surface shear planes, is more likely to contribute to slope failure through adding greater mass-induced stress to shear surfaces without anchors penetrating underlying layers. Uprooting events in such environments are likewise much more likely, especially during strong winds, with the resultant tree throws potentially up-casting large portions of the underlying substrate. Even on level ground, tree throws will remain more common amongst shallowly rooted species. This is exacerbated in instances where single species predominate, as is particularly common within coniferous plantations where rooting networks are relatively simple, and the lack of a developed understory does little to reduce wind speeds. The incidence rate of uprooting events is also likely to increase where trees have been planted and staked as relatively mature saplings, and where disease and/or pests have weakened otherwise healthy trees.

7.2.7 In addition to the immediate incidence of soil displacement caused by a tree throw, as the roots and other vegetative material decays so sedimentary material will fall back into the depression left behind, and surrounding deposits will simultaneously slump into the steadily infilling cavity. In cases where the underlying deposits were archaeological in nature, this process is liable to mix different elements of the underlying stratigraphy. Artefactual inclusions are particularly liable to such mixing, potentially creating significant churned, multi-phase/period lenses within otherwise strongly seriated assemblages (Gruškovnjak 2020; Norman 2003). Both tree throws and small stump holes can also be potentially mistaken for archaeological features in themselves, especially the latter given their more discrete pit-like appearance (cf Macphail and Goldberg 1999). However, whilst later pedogenic processes may obscure the original character of the infilling material (derived from either lateral slumping and/or top-down ingress, cf Phillips and Marion 2006), careful excavation of such features remains likely to be able to identify them for what they are (cf Langhor 1993; Norman 2003); although it should also be noted that there is evidence that Mesolithic and early Neolithic populations in particular made cultural use of these otherwise 'natural' features or three-throws (cf Evans *et al.* 1999).

Fig 35: Photos of archaeological tree throw at Drayton Cursus, Oxfordshire (©George Lambrick)

Fig 36: Tree-throw of a shallow rooted tree at Nine Ladies, Derbyshire (©Forestry Commission)

7.2.8 The hydrological effects of trees and tree rooting may have significant impacts on the preservation of archaeology and related heritage assets. Nowhere is this more concern than in the dewatering effects of commercial afforestation across peats and other waterlogged deposits. As recorded in some detail for waterlogged Neolithic wooden trackways in Somerset (Brunning *et al.* 2000; Cox *et al.* 2001), the extraction of groundwater by trees even outside the official site boundary can have serious consequences by locally reduced moisture levels and increased aerobic fungal/bacterial populations, often in conjunction with other dewatering factors such as agricultural drainage, quarrying and peat cutting. These effects are likely to be exacerbated for commercial plantations. In such contexts trees are often deliberately spaced close together to promote upright stem growth and increase overall timber productivity, such that higher tree numbers create denser root networks and withdraw more soil moisture than would typically occur under natural woodland or forest succession (Johnson 1998). Regardless of the scale of dewatering, it represents a major risk to the integrity of waterlogged (and formally waterlogged) archaeological sites, not just in terms of the primary archaeological material but also valuable palaeo-environmental sequences (Cox *et al.* 2001). It is worth noting that waterlogged soils are not ideal for many tree species or woodland types. Certainly, some species tolerate waterlogged soils; wet woodland can be created and is a valuable habitat type, and using woodland creation to "slow the flow" as part of natural flood management may be desirable for other environmental and social reasons.

7.2.9 Outside of these specific environments, the influence of trees in lowering or raising groundwater levels (water-table and aquifers) compared to soil moisture levels remains relatively understudied, such that the potential archaeological implications are likewise mostly conjectural. That said, tree cover across drier, freer-draining substrates has been generally shown to improve the water absorption and retention properties of the underlying soil. This is particularly true of deciduous woodland soils, where the integration of humified organic matter within the A-horizon topsoil improves its water-holding potential to a degree far greater than that observed under coniferous plantations. In addition to increasing soil stability and preventing sedimentary loss through waterborne surface erosion, such processes can contribute to less severe seasonal changes in both topsoil moisture and underlying groundwater levels. This is a particularly important consideration for the preservation of archaeological materials, as fluctuating sub-surface water-levels will initiate cyclic oxidation-reduction (redox) reactions in which aerobic and anaerobic conditions repeatedly succeed each other, greatly accelerating the decomposition of organic remains and exacerbating the solute precipitation of mineralised features such as iron pans (Douterelo *et al.* 2009; Huisman *et al.* 2008; Martens *et al.* 2012). The stabilisation of soil hydrological regimes under at least some forms of woodland cover is thus likely to be of benefit to the preservation of any archaeological remains contained therein.

7.2.10 The final principal means by which trees can potentially affect archaeological preservation is through changed soil chemistry, particularly lowered pH (ie, increased acidification). Calcitic archaeological materials are particularly sensitive to chemical dissolution through exposure to even weak acids, particularly human and animal bone (Kibblewhite *et al.* 2015; Nielsen-Marsh *et* *al.* 2007). Whilst acidic solutions can result in excellent degrees of organic preservation this is almost only the case if they occur under strictly anaerobic conditions, as most readily supplied by perennial waterlogging within peat deposits (see discussion in Section 3). Acidification on drained or more seasonally waterlogged soils will conversely accelerate organic decomposition (Kibblewhite *et al.* 2015) and will prove especially damaging on sites where recent dewatering has seen a decline in year-round saturation. Such effects are most likely to occur in instances where peatlands have been deliberately afforested with commercially grown conifers, which as discussed above will both increase acidification and reduce soil moisture levels. Wetland (or previous wetland) edge environments are similarly vulnerable, as such locales often form archaeological 'hotspots', and may be similarly affected by the acidifying and/or dewatering effects of adjacent dryland conifer plantations (Buckland 1993; Douterelo *et al.* 2010).

7.2.11 In comparison, pH changes on fully dryland sites are likely to be less impactful on archaeological remains, particularly where base- and/or clay-rich soils provide a considerable buffering effect. Likewise, the well-developed mull humus and A-horizon topsoils prevalent within broadleaved woodlands also present a buffer to increased acidification, especially deeper within the soil profile, even where species such as oak produce relatively highly acidifying forest floor litter layers. Where underlying soils are particularly deep, loose and well-drained, acidification can again increase markedly under tree cover, though again conifers will typically have a greater effect than comparatively acid-tolerant deciduous species such as birch and aspen. Whilst afforestation in such cases may well increase the rate at which the underlying soil profile undergoes progressive podsolization, such environments are generally poor candidates for high levels of organic preservation within archaeological deposits regardless.

7.2.12 Importantly, different kinds of archaeological assets will be affected by trees and tree rooting in varying ways. For instance, and as outlined above, 'positive' features such as masonry structures are far more likely to be impacted by mechanical stress loading caused by root ingress, which in many cases will cause extensive fracturing and potential displacement of the original structure. That said, once ingress has been made then such roots can also serve to stabilise the remaining masonry, with larger scale collapse only being initiated if the roots subsequently die and rot away, forming a network of large unstable cavities within the host structure.

7.2.13 Conversely, negative features such as infilled pits and ditches are more susceptible to rooting throughout their constituent matrices, many of which are significantly organically enriched relative to the surrounding 'natural' sediment. As noted in Section 6 of this report, whilst there is no known mechanism whereby tree roots will actively grow towards more fertile soils, if already situated within such substrates many species will trend towards increased root proliferation and overall extent. However, roots will actively seek out water sources following the principle of hydrotrophism, which may include targeting organic-rich deposits which exhibit enhanced water retention properties. In both cases, tree rooting is likely to proliferate within archaeological features, particularly those which present preferential growth conditions such as increased fertility or soil moisture, or even more friable and better-drained deposits within otherwise heavy and/or waterlogged substrates. As discussed above, whilst rooting may itself impact stratigraphic integrity within such deposits, the knock-on effects of, for instance, increased earthworm activity, will markedly increase the consequences of it. Moreover, whilst direct mechanical stress may be less influential on sedimentary deposits than structural ones, rooting can also directly affect artefacts and environmental materials (especially bone) within those deposits through root etching and/or active penetration (cf Matthiesen *et al.* 2020). In situations where the archaeology is particularly sensitive, for instance where bone has already been softened from the effect of weakly acidic groundwater, then extensive rooting is likely to have considerable adverse impacts.

7.2.14 Although rooting depths are variable across species, it remains the case that most of all tree roots occur within the upper metre of the soil profile. As such, both 'positive' and 'negative' archaeological features will be at far lesser risk of impact by tree rooting if they lie within deeply buried strata, particular those below a metre's depth from the ground surface. Such situations are typically more frequent within lowland landscapes, particularly along the base of major river valleys where many centuries (if not millennia) of floodplain alluvium have gradually built up. Examples of such landscapes include the Lower Thames Estuary and the Avon Levels. Concurrently, shallowly buried archaeological deposits more susceptible to impacts from tree rooting are more typical of upland contexts where soil mantles are generally thinner, but also where archaeological features are only shallowly buried within otherwise deep sedimentary profiles, for example the Roman sequences uncovered at London Gateway (Biddulph *et al.* 2021).

7.2.15 As explored further through the stakeholder responses discussed in Section 5 of this report, there are also ways in which active tree planting can impact archaeology which are not directly tied to the biologically induced effects of the trees themselves. For instance, mechanised forestry operations are liable to cause significant levels of ground disturbance using heavy plant and other machinery, most notably those associated with both felling and mass planting (Johnson 1998). On the other hand, planting new woodlands may convert land parcels from uses even more destructive of archaeological assets, for instance arable fields subject to disturbance from deep ploughing and acidification through the application of industrially produced fertilisers (cf Goulding 2016; Vogt and Kretschmer 2019). Similarly, converting land previously closed to the public (as under active cultivation) to woodland could result in a greater quantity and variety of archaeological sites becoming accessible to more people. Such potential impacts are considered in greater detail in the following section.

7.3 Discussion of Impacts

7.3.1 Although trees (especially their roots) have the potential in many cases to impact above- and below-ground archaeological remains, the above discussion also makes clear that this is not always the case. For instance, trees can prove highly effective in stabilising positive features such as banks or earthworks otherwise susceptible to sedimentary erosion, and likewise whole archaeological sites where they are situated on steep and/or unstable slopes. As discussed in Section 3, recent research projects making use of LiDAR have identified many instances where extensive swathes of the historic landscape have been beneficially preserved within existing woodland. Moreover, as most of all tree roots are situated within the upper metre of their respective sedimentary substrates, so both their direct impacts and those of associated factors (eg, litterfall acidification, earthworm bioturbation) are likewise concentrated within this relatively shallow sub-surface zone. Accordingly, any archaeological deposits buried lower than c 1m are unlikely to be subject to significant adverse impacts from overlying tree/woodland cover. The major exception in this regard is that of dewatering, as lowered moisture levels higher within the soil profile will also affect moisture levels (including groundwater fluctuations) at greater depth. That said, for many archaeological deposits, changes in soil moisture may not be that impactful depending on the preservation conditions already prevalent at the site (see further discussion in Section 9: Evaluative Framework). Moreover, not all woodland creation will necessarily result in significant dewatering or increased fluctuations in extant groundwater levels.

7.3.2 Moreover, as identified in several other sections of this report (see especially 3 and 5) there are numerous other potential benefits to integrating archaeological assets within new woodland creation schemes. The first of these concerns the role of woodland in supporting the protection of archaeological sites within active site management plans. As mentioned above, trees can play a crucial role in reducing surface weathering and erosive run-off regimes, but they have also been reported to shade out bracken and scrub growth that is itself detrimental to archaeological preservation (cf Gerrard 2014; 2016). Reductions in scrub cover is also likely to benefit public access to sites previously covered with dense vegetation. Relatedly, where woodland creation is taking place on land previously removed from public access (eg, arable fields), so any sites within them will again benefit from increased accessibility for local communities and other countryside users. Such benefits are again considered within the evaluative framework laid out in Section 9. Finally, in ringfencing land for long-term woodland creation, so any archaeological resources within that land may be protected from far more damaging land-use practices, such as arable agriculture or future development. The following Section 8 explores this last issue in greater detail.

Left: Ploughsoil test pits, Lincolnshire © Oxford Archaeology

8. Comparing impacts

The study considers how new afforestation programmes may affect the preservation of archaeological assets that are potentially already degraded because of previous land management regimes. For instance, where sustained periods of deep ploughing have already resulted in significant disturbance to sub-surface features, any additional disturbance from tree rooting after active afforestation is likely to be negligible in comparison. Indeed, while the data does not currently exist to verify this claim it is highly likely that converting land previously under arable cultivation, especially that subject to deep ploughing, into woodland will result in a net benefit to archaeological preservation irrespective of any deleterious effects of tree rooting.

8 COMPARING THE IMPACTS OF WOODLAND WITH OTHER LAND USES

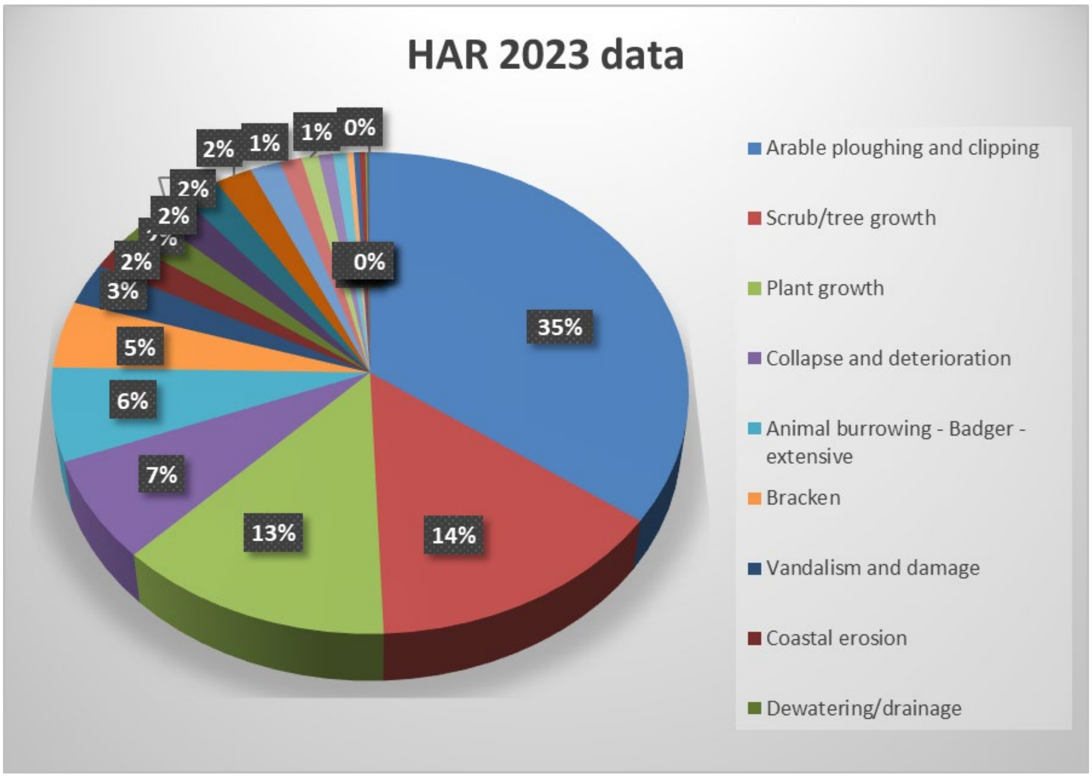
8.1 Introduction

8.1.1 In the absence of a national land-use policy, individual policies have been, or are being, developed to govern individual issues involved in rural land use (eg tourism, agriculture, rural employment, depopulation and forestry). Ideally, these issues would be dealt with under an umbrella forum, but the development of an all-embracing land use might be too impractical to achieve. One of the difficulties with developing individual policies for land use is that they will often come into conflict with each other, with grant structures and with issues which have not been fully considered within the policy. Forestry policy has largely been dictated by an annual planting target and a grant system designed to achieve that level of planting. Protection of Heritage assets forms one of the cornerstones of the UK Forestry Standards (UKFS) but takes a different approach to the impacts covered under National Planning Policy Framework (NPPF), especially in terms of requirement for pre-surveys and fieldwork.

8.2 Other land uses

8.2.1 To draw any meaningful conclusion about the impact of root systems and therefore tree-planting, we also need to compare these impacts with other land uses. As in most of these cases we are talking about afforestation of land currently being used for other land uses like arable agriculture, pasture, orchards, floodplain and upland environments.

Table 6: HAR stated risk breakdown 2023



8.2.2 Cultivation damage continues to be the single most significant reason for placing monuments on the Heritage at Risk Register (HAR; see Fig 6). In 2023, 669 monuments (35% of those on HAR) were directly threatened by cultivation - 589 by ploughing and 80 by arable clipping. Compared with 10 years ago in 2013, this number was much higher with 43% threatened by cultivation – 1,571 by ploughing and 405 by arable clipping. The percentage of monuments affected by root disturbance has been steadily increasing partly as a response to the greater recording of tree root impact and partly in response to the success in reducing the number of monuments affected by plough disturbance. It should also be noted that many of these scheduled monuments have been within woodland for hundreds of years and in some most cases are typically in far better condition than parts/neighbouring monuments under arable land.

8.2.3 Most archaeological investigation work occurs through the planning process (NPPF) through proposed urban development or land-use change. This partly reflects the much greater impacts of commercial developments over the perceived threats from Forestry. Except for a few community or research excavations, much of this work is undertaken by archaeological contractors paid through the commercial development of the site. No such immediate commercial benefits currently come through the planting of new woodland, which could fund archaeological fieldwork. The current model also reflects the greater impact of commercial development compared to those of new areas of woodland planting.

8.3 Impacts of arable agriculture

8.3.1 During the Ripping up History campaign of 2003 - which sought to persuade government that there was a greater need to incentivise farmers to appropriately manage archaeology subject to arable agriculture, and in parallel to reform the Ancient Monuments (Class Consents) Order 1994 - it was apparent that existing Historic England (then English Heritage) datasets, such as the Record of Scheduled Monuments, contained little reliable information on the extent to which monuments were affected by cultivation. This was the first major obstacle to taking a more strategic approach to the management of such sites and was overcome through the Scheduled Monuments at Risk initiative which was completed nationally in 2008. However, both Scheduled Monuments at Risk (and now HAR) were based upon the precautionary principle and automatically identified any monument under cultivation as being “at risk”. In parallel, in their response to Ripping Up History DCMS tasked Historic England with undertaking preparatory work to enable reform of Class 1 Consent by exchanging the general ‘one size fits all’ consent for agricultural operations with individual SMCs tailored to the individual circumstances of each monument.

8.3.2 As a part of this research, the Trials Project (OA 2010) provided an improved, scientific, understanding of the effects of tillage and other agricultural operations on surface and sub-surface archaeology. A key result of the project (funded jointly by Defra) was to indicate that, rather than cultivation always being incompatible with the management of a monument, in most cases sites could remain under cultivation without being at risk of significant degradation or material loss, as long as the method of cultivation was itself appropriately modified (ie, mitigated). These findings were further supported by the results of the COSMIC and COSMIC 2 and 3 pilots (OA 2014; see further below), which field-tested a series of risk assessment methodologies in the East Midlands region. Whilst in many ways COSMIC represented the culmination of this work, in key respects it will also form the starting point for further site management-based research over the coming years.

8.3.3 The study identified that most arable impacts occur during the initial stages of transitions in established land-use, eg, pasture to arable, or changes within planting regimes, whilst after a period the impacts were seen to level off and establish a new equilibrium. Episodes of greater impact or damage were seen to occur following changes within this sedimentary environmental either through soil loss through erosion or harvesting, deeper ploughing or poor soil management. Most periods of greater damage were through a lack of understanding and through poor/lack of management.

8.3.4 The Cosmic and Trials research did not consider or include the risks of root disturbance or forestry on archaeological remains. At the time, cultivation was seen as the biggest risk factor to archaeology that needed to be urgently addressed. As has been highlighted in Section 3, no comprehensive research has yet been undertaken looking at the effects of tree rooting or planting in a similarly comparative fashion. Where localised or specific studies have been undertaken, they have indicated that forestry and root systems do not represent any greater threat to archaeology than ploughing. Moreover, where good management practices are being followed, or under certain circumstances such as hillslopes / earthworks vulnerable to surface erosion, tree cover can offer significant benefits. In such cases, it is the long-term deployment of appropriate land management practices which comprise the key factors determining the level of preservation afforded.

8.3.5 Concomitantly, it is also necessary to consider how new afforestation programmes may affect the preservation of archaeological assets that are potentially already degraded because of previous land management regimes. For instance, where sustained periods of deep ploughing have already resulted in significant disturbance to sub-surface features, any additional disturbance from tree rooting after active afforestation is likely to be negligible in comparison. Indeed, while the data does not currently exist to verify this claim (though see propositions for ground truthing in Section 9 of this report), it is highly likely that converting land previously under arable cultivation, especially that subject to deep ploughing, into woodland will result in a net benefit to archaeological preservation irrespective of any deleterious effects of tree rooting. Conversely, the potential benefits/drawbacks on archaeological preservation of pasture *versus* woodland are liable to be more finely balanced, and dependent on both local management regimes as well as the type of archaeological asset concerned (masonry structures, earthworks, sub-surface features, etc). Such issues are considered further in Section 9 below.

Left: Root system, Chipperfield, Hertfordshire © Oxford Archaeology

9. Evaluative framework

This section focuses on rooting depth over the architecture type of the rooting system, as such types are a) morphologically highly variable, b) often non-exclusive within species, and c) typically relatively shallow regardless of type, exceptions under specific soil conditions. In tune with many recent discussions of tree planting, whether related to archaeology or not, the key emphasis of this report is that of the 'right tree, right place' (cf Caneva 1999).

9 EVALUATIVE FRAMEWORK: TREE SPECIES, SITES AND SOIL TYPES

9.1 Framework

9.1.1 Collation of the data from the archaeological projects reported within the Section 3 literature review, combined with the findings drawn from Sections 4 and 7 and the stakeholder-derived data summarised in Section 5, has identified several potential impacts that trees and tree roots can have on both above- and below-ground archaeological assets. The stakeholder interviews further highlighted the need to situate these impacts within an evaluative framework suitable for use by both heritage and forestry professionals. This final report section aims to provide such an evaluative framework, although it must be noted that this framework presents only provisional guidance and should be read in conjunction with official policy documents including the UKFS and Historic England's own guidelines.

9.1.2 Table 7 provides a summary of factors that should be considered when assessing the potential impact of tree planting on different kinds of archaeological resources in a range of depositional contexts. Tables 8-9 then summarises the typical rooting depth, water demands, and degree of mechanical root penetration exhibited by a selection of tree species commonly planted within the UK, which should be referred to in conjunction with the preceding Table 7.

9.1.3 For the purposes of this evaluative framework, it was decided to focus on rooting depth over the architecture type of the rooting system *per se*, as such types are a) morphologically highly variable, b) often non-exclusive within species, and c) typically relatively shallow regardless of type, exceptions under specific soil conditions notwithstanding (see discussion in Section 4). It should also be noted that the species listed in Tables 8-10 are not a definite list of all trees commonly planted within UK woodlands, but merely those for which the relevant data is currently available.

Table 7: Archaeological resource types and considerations for tree planting

Archaeological factors		Considerations for tree planting
Type of archaeological feature	Earthworks	Earthworks are generally less liable to disturbance by tree rooting than other archaeological features due to their typically massive nature. Instead, the primary threat they face is that of sedimentary erosion, in which case tree planting may serve to mitigate run-off and stabilise sloped banks/mounds. In cases where the earthworks are relatively internally homogenous (eg, the ramparts of an Iron Age hill fort), then more deeply rooted tree species are unlikely to disturb important internal stratigraphy, whilst providing better anchoring of the overall slope than shallower rooting systems. Conversely, where internal stratigraphy is more vulnerable to disturbance (eg, Neolithic/Bronze Age barrows), then more

		shallowly rooted species may be preferable due to their comparatively lesser impact at depth.
	Structures, eg, walls	Where walls, floors or other *in situ* structural remains are present then all tree roots are likely to adversely affect the archaeological resource by means of mechanical displacement. Where structural remains are buried below ground, and/or located in close spatial proximity to woodland, then tree species with a high degree of mechanical root penetration are likely to have a greater adverse impact than those with typically less forceful rooting habits.
	Surface artefact scatters	Surface scatters, particularly lithics, are especially vulnerable to spatial displacement both through direct rooting and surrounding sedimentary deformation. All trees are liable to cause such effects, but particularly those with surface-type rooting habits (eg, ash, aspen, common alder and Norway spruce).
	Buried artefact scatters	*In situ* artefact scatters buried within sub-surface horizons are equally liable to spatial displacement both through direct rooting and surrounding sedimentary deformation. All tree roots have the potential to impact such assemblages, the primary mitigating factor being the depth at which the artefacts are buried *contra* the depth of the roots themselves.
	Buried sedimentary features	Infilled ditches, pits, post-holes, etc., are all liable to impact by tree rooting, though the degree to which this occurs will vary according to both tree species and sedimentary context. Bioturbation through both direct rooting and associated vectors (such as earthworm activity) is more likely to affect features and stratified deposits rich in organic matter and other nutrients, such as those commonly associated with occupation horizons. Tree species with particularly acidifying effects (principally conifers) are also more likely to degrade the organic archaeological inclusions contained within such features. Conversely, relatively sterile features, such as ditched field boundaries, are less liable to adverse disturbance from either mechanical root ingress or altered pH conditions.
Depth of overburden	Shallow	Shallowly buried archaeological deposits are at far greater risk of disturbance from tree rooting than those at greater depth and are likewise more vulnerable to the upper-profile impacts of woodland-associated factors such as sustained earthworm activity. In such cases,

		comparatively shallow rooted tree species are less likely to disturb the underlying archaeological horizons whilst growing *in situ* but are more likely to create tree throws than those with deeper roots.
	Deep	When archaeological strata are deeply buried, as under thick alluvial and/or colluvial deposits, tree planting up-profile is unlikely to affect the archaeology itself, even in the case of waterlogged or other sensitive material. If the overburden is more than 4m thick, then even very deeply rooted tree species are unlikely to have notable adverse effects.
Preservation conditions	Waterlogged	Waterlogged sites present excellent conditions for the preservation of organic archaeological remains and associated palaeo-environmental data but are extremely sensitive to damage *via* dewatering and increased soil aeration. Any tree species planted on/adjacent to such sites, even those with relatively low water demands, are likely to exacerbate dewatering via transpiration and lowered groundwater tables, and thus severely damage the archaeological resource. Such effects often exacerbate those caused by other dewatering vectors, such as agricultural field drains or nearby quarrying activities.
	Partially waterlogged	Partially waterlogged sites include those which have already undergone some degree of dewatering, or those which contain more discrete waterlogged features such as wells or palaeochannels within otherwise drier environments. In such cases, tree species with higher water demands are likely to have a higher adverse impact on archaeological preservation than those with lower water demands. Tree species (principally conifers) with particularly acidifying effects are also more likely to degrade organic archaeological remains where they are situated within lowered and/or fluctuating groundwater tables.
	Dry	Most organic remains are likely to suffer poor preservation within already dry sedimentary environments. In such cases, additional dewatering from trees is unlikely to cause any additional adverse effects with regards to soil moisture content. However, tree species with acidifying effects (particularly conifers) are likely to cause the increased degradation of archaeological materials which typically preserve well

		within neutral-alkaline substrates, such as human and animal bone.
Landscape/topographic setting	Hillsides and other slopes	Where archaeological sites are situated on steep and/or unstable slopes, increased tree planting may have positive effects in terms of slope stabilisation and decreased sedimentary erosion. Species with deeper roots, and potentially higher degrees of mechanical root penetration, are likely to prove most effective in binding vulnerable soils to the underlying substrate, reducing surface run-off, and improving the moisture retention properties of the soil itself. Where the archaeological remains are also sensitive to penetrative rooting, then tree planting to stabilise the surrounding slopes may be preferable to direct planting across the site itself.
	Floodplains and river margins	Tree planting across partially and/or seasonally waterlogged environments such as floodplains and riparian corridors is likely to focus on species tolerant of saturated soils, such as black poplar, common alder and various willows. In these cases, rooting habits are likely to be shallower than in more well-drained conditions, but will still affect the underlying substrate through mechanical disturbance and groundwater extraction. Potential dewatering effects (particularly during drier seasons) should thus be considered in line with its potential impact on any underlying archaeology.
	Wetland edges	Partially/seasonally drier land fringing contemporary wetland areas typically comprise archaeological 'hot spots' likely to contain large quantities of previously unidentified archaeological remains, including well-preserved organic material where waterlogging is more persistent. In such cases tree planting may cause/exacerbate dewatering effects that would adversely affect anoxic preservation conditions, both across the drier edging land and within the adjacent wetland itself.

Table 8: Typical rooting depth of select tree species

<table>
<tr><th>Typical rooting depth</th><th>Example tree species</th><th>Advantages for archaeological preservation</th><th>Disadvantages for archaeological preservation</th></tr>
<tr><td>Shallow (<1.5m)</td><td>Beech, field maple, grand fir, noble fir, Norway maple</td><td>Reduced impact on archaeological deposits at depth.</td><td>Increased risk of tree throws or other uprooting events.</td></tr>
<tr><td>Medium (c 1.5m)</td><td>Ash, aspen, hornbeam, red oak, sessile oak, small-leaved lime, sycamore, western hemlock, western red cedar, wild cherry</td><td colspan="2">Generally balanced risk of impact on archaeological deposits at depth vs. likelihood of tree throws or other uprooting events, though dependent on site-specific variables such as depth of overburden, topography, ground conditions, etc.</td></tr>
<tr><td>Medium to deep (c 1.5-2m)</td><td>Corsican pine, downy birch, European larch, common alder, common walnut, Douglas fir, lodgepole pine, Norway spruce, pedunculate oak, Scots pine, silver fir, Sitka spruce, sweet chestnut, white poplar</td><td>Reduced risk of tree throws or other uprooting events.</td><td>Increased impact on archaeological deposits at depth.</td></tr>
<tr><td>Deep (c 2-3m)</td><td>Japanese larch, white willow, crab apple</td><td>Additionally reduced risk of tree throws or other uprooting events.</td><td>Additionally increased impact on archaeological deposits at depth.</td></tr>
</table>

9.1.4 It should be noted that tree species will root to greater depths when growing within fertile loamy soils, particularly pedunculate oak (up to depths of c. 4m). Some species are also adapted to exhibit deeper rooting within deep, highly permeable soils to reach low-lying groundwater sources, including aspen and sweet chestnut but particularly European larch and Scots pine.

Table 9: Relative water demands of select tree species

Water demands	Example tree species
Low	Common alder, Corsican pine, Douglas fir, downy birch, European larch, hornbeam, Japanese larch, Norway spruce, Scots pine, silver fir
Low to medium	Ash, beech, Norway maple, sycamore
Medium	Small-leaved lime
Medium to high	Aspen, pedunculate oak, red oak, sessile oak, white poplar

9.1.5 Similarly, although beech has relatively low water demands, it is also highly intolerant of overly dry or drought-prone soils. In conjunction with its typically shallow root system this can result in higher rates of structural failure, including uprooting, when under drought-related stress.

Table 10: Relative degree of mechanical root penetration of select tree species

Degree of mechanical root penetration	Example tree species
Low	Beech, Norway spruce, small-leaved lime, sycamore
Medium	Ash, Corsican pine, downy birch, hornbeam, Japanese larch, red oak
High	Aspen, common alder, Douglas fir, European larch, pedunculate oak, Scots pine, sessile oak, silver fir

9.1.6 In tune with many recent discussions of tree planting, whether related to archaeology or not, the key emphasis of this report is that of 'right tree, right place' (cf Caneva 1999). This guiding principle precludes any simplistic determinations such as 'shallow roots = good, deep roots = bad' or 'broadleaf trees are better than conifers', and will need to be considered in all future discussions when balancing the need to protect heritage assets with that of woodland creation and expanding sustainable forestry operations. Achieving this balance may prove particularly complex within areas of high archaeological sensitivity, such as thin soiled upland environments with typically ephemeral archaeological records, which also form priority areas for future tree planting (cf Wickham-Jones *et al.* 2020). In many cases it will also need to be considered if, although tree planting may have some adverse effects on local archaeological assets, afforestation is of overall benefit to archaeological preservation in terms of removing land from more damaging land-use practices (eg, deep ploughing under intensive arable agricultural regimes) or improving public access. Where archaeological sites are already under tree cover, it may also prove of greater benefit to leave existing trees *in situ* than to cause further damage by trying to remove them (cf Johnson 2008). Finally, although the deliberate planting of exotic specimen trees is unlikely to form part of many woodland creation projects, it will comprise an active element of ongoing landscape management for many historic parks and gardens (Historic England 2020).

9.1.7 Most archaeological sites are not scheduled and here the long-term fate of any archaeological evidence is largely dependent on the landowner and forest manager. Regardless of management practice, all known archaeological sites should be recorded on all maps and brought to the attention of any contractors working in the area. The interviews conducted for this project reported many incidents where monuments and unscheduled remains suffered damage from a wide range of minor forest operations due to a lack of awareness amongst, or information available to, the responsible contractors. The lack of long-term management and adoption of good manager practices were some of the main determining factors where damage to archaeological assets were reported.

Within the Forestry Commission itself, all scheduled monuments on its land are recorded on a GIS and each has its own management plan in place. Nonetheless, consideration of unknown / unmapped archaeological assets in areas where there is potential for their presence remains an issue.

9.1.8 In some cases, especially across the predominantly agricultural lowland plains of southern Britain, decades of large-scale open area excavations induced by extensive housebuilding and infrastructural development programmes have uncovered abundant archaeology at a landscape scale. For some areas, as across parts of Cambridgeshire, this has resulted in a form of 'knowledge plateau' with regards to topics such as Iron Age and Roman settlement patterns (Aldred *et al.* 2023). In areas like these, the conversion of selected land parcels to woodland, even if directly impactful on specific archaeological assets, may not necessarily detract from our understanding of those assets at a more regional scale. This situation is further conditioned by the typical implementation of archaeological mitigation works, whereby only 10-20% of the exposed sub-surface features will be subjected to full excavation, and in the case of a standard evaluation only c 5-3% of the total site area will be actively trenched (Hey 2006; Hey and Lacey 2001). This sample-based approach to archaeological recovery and subsequent interpretation means that in almost all cases mitigation does not prevent the damage or outright destruction of all archaeological remains known to be present at a given site. Accordingly, any potentially adverse impacts of new tree planting will likewise affect archaeological deposits of which the majority would never have been excavated in any case. That said, this does not preclude the need for active consideration of those effects on the 10-20% of archaeological features that would, in theory, form the focus of any deliberate intervention.

9.1.9 Altogether, increased tree planting will certainly present challenges for the future management of the UK's heritage assets. However, it also encompasses a range of opportunities, not just with regards to certain technical aspects of archaeological preservation but also in expanding people's imaginative engagement with the jointly historic and biotic landscapes in which they live (cf Farstadvoll 2019). For both challenges and opportunities to be addressed effectively, there is a need for increased open communication and active collaboration amongst different actors and agencies within both heritage and forestry sectors (cf Historic England 2020; see especially discussion of stakeholder responses in Section 5 of this report). Good-faith communication will be key to addressing many complex issues, from the preservation of gazetted *vs.* currently unrecorded archaeological sites within proposed new woodlands, to the potential mitigation procedures to be implemented during forestry operations such as planting and harvesting, and the agreement of ongoing woodland management programmes to address the proliferation of saplings and/or death of mature trees across buffered sites.

9.1.10 This report has also highlighted how little is known with regards to the potential impacts of trees and tree roots on diverse types of archaeological deposits. For instance, there are currently only a very few published reports on the dewatering effects caused by trees on/adjacent to wetland/former wetland environments (cf Holden *et al.* 2006), and none on how the potentially acidifying effects of different types of woodland cover compare with, for instance, the application of agri-chemicals on arable fields or improved pastureland. There is also very little published data currently available for the typical rooting habits (including average depths) of many tree species common to England (cf Appendix I of this report), nor how these respond to differing soil conditions and other environmental factors. The predictive power of the evaluative framework resulting from this report would be greatly strengthened were it to be updated with such data, particularly if that data were spatially defined. It would then be possible to predictively map the relationships between tree species/woodland types, their rooting habits subject to different environmental variables, and the potential impact (both positive and negative) of tree cover on the varied archaeological assets of a given area. In the meantime, it is hoped that the evaluative framework developed here proves a useful tool for both forestry and heritage professionals during the ongoing process of balancing the need for increased woodland creation across England with that of safeguarding our archaeological heritage.

Left: Trees on and by the King's Barrow, Stone Henge World Heritage Site © Oxford Archaeology

10. Proposed Project Design: Ground truthing framework

More data is required on the impacts of tree roots on sensitive archaeological remains. Issues of dewatering, water quality, chemical changes, biological changes and mechanical impacts need to be addressed by further fieldwork testing.

10 PROPOSED PROJECT DESIGN: GROUND TRUTHING FRAMEWORK

10.1 Introduction

10.1.1 The report identified the following gaps in current knowledge and provides a potential road map for future fieldwork testing:

- More data is required on the impacts of tree roots on sensitive archaeological remains associated with wetland habitats. Issues of dewatering, water quality, chemical changes, biological changes and mechanical impacts need to be addressed by further fieldwork testing.
- The long-term management of extensive earthworks also needs to be addressed in terms of the potential to increase woodland cover on areas currently managed by periodic shrub clearance across open areas. The costs of maintaining large areas of grassland are proving to be economically challenging for some monuments, and research is needed to indicate whether woodland may be a viable alternative to continued shrub/bracken management over monuments currently under rough pasture.
- A comparative study of archaeological remains needs to be undertaken for a 'type site' where the archaeology is under different land uses and management regimes. This would ideally comprise a site that is covered by both woodland and arable cultivation, which would provide an opportunity for directly comparing the relative impacts of different root systems on a given set of archaeological remains.

10.1.2 The three study areas (a waterlogged site, an earthwork monument partly under trees and site partly under arable cultivation) could be used to test a range of difference variables like soil type, tree species, soil depth, root structure, water quality and archaeological impact. This would help to provide the data that is urgently needed to address the current gaps within the research dataset.

10.1.3 It is recommended the work should be undertaken by a research group including an archaeological contractor (to record archaeological fieldwork impacts), soil science/ecological research body (possibly a university) to undertake soil testing and would also include involvement of local forestry and heritage professionals.

10.1.4 The aim of the research would be to fill the current data gaps within the research and to provide specific data on different tree root systems, under the different environmental variables and record their archaeological impacts.

10.2 Aims

10.2.1 The specific aims and objectives of the ground truthing project are as follows:

- to develop the most cost-effective and non-invasive way of mapping and recording different root systems;
- to be able to ground-truth that method to ensure accurate representation of root systems;
- to excavate, record and assess tree root growth impact on archaeological remains;

- to determine the condition and state of preservation of any archaeological remains under woodland, including chemical or long-term preservation issues;
- to ascertain what types of impact(s) can be identified by tree roots on archaeological remains;
- to ascertain if certain tree species cause more impacts than others to archaeological remains;
- to ascertain if certain types of archaeological remains are more susceptible to tree root impacts than others.

10.3 Methodology

10.3.1 The first stage would be to identify and gain permission for the three study areas in which to cover the variables that have been identified. The following methodology has been proposed for a non-intrusive method for mapping root systems and ground-truthing these results. Also, a programme of fieldwork test pits and sampling to assess impact and preservation levels of archaeological and palaeoenvironmental remains under these different root systems.

Non-invasive methodology for mapping roots – GPR survey

10.3.2 The mapping of different root structures of various tree species and soil depths / types would be instrumental in providing real data on the impacts of different roots structures. The preconceptions of root structure and impacts need to be challenged and tested based on those represented in schematic examples. This study has identified that the root structures can vary significantly based on various environmental variables. Also, although most heritage professionals perceive root growth on archaeological sites as negative impacts, the observational and present limited research datasets available would suggest mostly localised and limited disturbance being recorded during the consultant process.

10.3.3 Several kinds of non-destructive methods (radioactive tracers, combining soil water content and sap flow) have been used to estimate the extent and depth of root systems of forest trees (Woods 1969, Hruska *et al*. 1999, Cermák and Kucera 1990). The limitation of these methods is that they provide little or no resolution of root structure. Ground-penetrating radar (GPR) has proved useful in several archaeological studies (Cammarano and Piro 1997) including some studies that focused on tree roots (Butner *et al*. 2001; Papamarinopoulos *et al*. 2008). Pilot studies on dry soils on both oak (Hruska *et al*. 1999), and pine and willow (*Stokes et al*. 2002) have already successfully mapped large root systems using GPR.

10.3.4 A similar approach could be used to map different root systems and test them against the different environmental variables. The ground-penetrating radar system is non-invasive and allows relatively rapid and repeated measurements of the distribution of coarse root systems of trees. GPR could therefore offer a cost-effective of surveying a variety of root systems, whilst protecting the tree and provide a means for targeting test pitting to ground truth these results.

10.3.5 The GPR measurement could be performed with a portable signal transmitter and receiver-type GPR system using a signal frequency of 450 MHz, which allows horizontal as well as vertical distances to be distinguished with a precision of 5cm (2 in.). Roots with a diameter greater than 2cm (0.8 in.) can be identified down to a depth of 2.5m (8.2 ft). The instrument would be gradually moved over the soil surface along specified grid lines, and vertical "slices" of soil measured.

10.3.6 However, Butner *et al.* (2001) found that GPR resolution for detecting roots was best in dry sandy soils but seriously degraded in soils with high water and/or clay contents. They also found that wet soils weakened the correlation between root biomass and GPR index and that thick litter layer on the soil surface degraded the ability of GPR to delineate roots. Therefore, not all the proposed investigation areas in terms of wetland areas and clay soils may be measured using this method, and alternative approaches should be considered with the help of specialists in this field.

Test pitting methodology

10.3.7 In order to ground-truth the root structures identified by the GPS survey, hand or vacuum excavation test pits will be used to remove the soil around a root system and record the structure. The area of the site will be selected based upon the environmental variables being tested and where archaeological remains are either thought to occur or had been recorded by previous surveys.

10.3.8 The test pits will be between 1-2m in width and diameter and will facilitate access in order to be able to record any archaeological remains and provide a stratigraphic section. The test pits will not exceed a maximum depth of 1-1.5m from the current ground level, for safety and logistical reasons. All test pits will be backfilled once recording has been completed and will not be left overnight without any further safety provisions being put in place. Any deeper investigation of water-levels will be undertaken with a hand auger using suitable heads.

10.3.9 Sample sections will be located using either a GPS unit or total station. Coordinates relative to Ordnance Survey and Ordnance Datum will be obtained for each sampling location.

10.3.10 All roots present in the subsoil will be first classified (species, root type), counted, measured and recorded on the site tree/vegetation species, soils and rooting (TSR) pro forma sheets for analysis. *In situ* roots will be drawn on plans and/or sections, as well as photographed (Photogrammetry). Where larger or stronger roots continue into test pits these will be retained and protected. The finer feeder roots will be removed in consultation with advice from an arborealist without detrimentally affecting the tree. Larger roots will be retained and protected in the ground.

10.3.11 A pro forma sheet will be used to record the root system, where present, per stratigraphic unit (ie topsoil, natural etc) or archaeological context (ie layer, fill etc). The pro forma will be used to record the following for each test pit:

- Classification section for tree and vegetation species.
- Classification section for root types. To include root systems (ie taproot, heart root, surface root).

- Root growth description section. To include lateral and horizontal growth patterns; general growth depth, ie in an upper or lower deposit etc; and root growth density/proliferation, ie occurrence of root mass etc.
- Root count section. The number of roots found in each deposit to be counted and totalled. The root count for each species and/or root type will also be recorded, where identified.
- Root measurement section. The thickness and length of roots will be recorded as well as the (average) root measurements for each species and/or root type, where identified. If roots continue into trench sections and cannot be measured in totality, this will be noted.
- Soils description section. To include soil type and condition; what species and/or types of roots are present in the soil, where identified.
- Impact assessment section. Identified impact(s) of roots on the deposit or archaeological evidence will be recorded, ie truncation, artefact displacement etc. If no impact is identified, this will also be recorded.
- Free text section. For further observations and notes.

10.3.12 Following removal of the topsoil and subsoil deposits, the roots recording and planning processes will be implemented in any archaeological horizons and natural deposits/ features encountered where roots are present, down to the natural geology or the maximum test pit, whichever is reached first.

10.3.13 Stratigraphic and archaeological remains will be recorded using standard archaeological procedures including drawn sections and plans, with digital photography. All work will be carried out in accordance with The Chartered Institute for Archaeologists' Code of Conduct, Standard for Archaeological Field Evaluation, and Universal Guidance for Archaeological Field Evaluation (2023).

10.3.14 All suitable permissions will be in place before excavating the test pits within the canopy of a living tree and areas of ancient woodland. The aim would be to ensure no trees or large root systems are harmed by this process.

Sampling and testing

10.3.15 Samples will be taken throughout the soil and subsoil profile to compare environmental conditions, like water levels and quality, soil pH, type and depth and structure. Collaboration with a specialist soil science university would help to test for any changes in the sedimentary environment and soil biology caused by the root system.

10.3.16 Archaeological samples to test for the preservation of environmental indicators like charred plant remains, bone, pollen and waterlogged remains will also be taken. Soil micro-morphology samples will be taken to look at the impacts of root system on the archaeological stratigraphy and any remains.

Reporting

10.3.17 The results for the three different study areas will be used to provide a more comprehensive study of different tree root systems, the factors that affect them and what they can mean for archaeological preservation.

10.3.18 A draft copy of the report will be issued to the client/project funder/collaborating bodies for comment and review prior to being finalised. Based on the results, a research article will also be submitted to a relevant specialist journal.

10.3.19 The study would be guided by a steering group committee comprising of key specialists in the Forest Committee, Historic England and academia.

10.3.20 Digital copies of the completed report in Adobe Acrobat (.pdf) format will be provided to the client/project funder/collaborating bodies and the relevant County Council(s) and Historic Environment Records (HERs).

Left: Thornborough Henges, North Yorkshire © Rose Ferraby

11. Conclusions and Recommendations

Current approaches to tree planting in areas of archaeological interest are largely built upon anecdotal evidence that derives from 'worst case scenarios' where tree roots have significantly damaged archaeology. For most areas of new tree planting, impacts are likely to be limited and not especially detrimental to the overall interpretation of a given archaeological site. Accordingly, the presence of archaeology should not necessarily be seen or used as a block to new tree planting schemes, but rather a factor that needs to be considered and balanced alongside other ecological and environmental factors on a site-by-site basis.

11 Conclusions and Recommendations

11.1.1 Tree roots have been shown to have both positive and negative impacts on heritage assets. Further field-based research into the relationship between tree roots and archaeological remains in a range of different settings is needed urgently. Current approaches to tree planting in areas of archaeological interest are largely built upon anecdotal evidence that derives from 'worst case scenarios' where tree roots have significantly damaged archaeology. The evidence is often contradictory and thus not straightforward to interpret or to build upon policy-wise. Direct investigations into the relationship between tree roots and archaeology are rare. Where these have been undertaken, the findings are often complex and not conducive to being more widely applied. The character of the relationship between tree roots and archaeology, including the degree of damage caused, depends on a range of specific factors, and requires further field-led research.

11.1.2 For many heritage professionals, their negative perception of tree roots in relation to archaeology is largely a historical one, related to concerns over areas of unknown archaeology, or when dealing with the secondary impacts of woodland management practices (for example, the use of heavy machinery). This view has been reinforced by the current lack of detailed empirical research or fieldwork into the impacts of roots on archaeological remains. Based on the results of this study and the limited research and observational data that is currently available, however, tree roots are not necessarily any more damaging to heritage assets than other types of land use. Indeed, trees can contribute positively to archaeology.

11.1.3 Tree planting, using the right combination of deep- or shallow-rooted species, can help to actively stabilise slopes, prevent soil erosion, curb other, more damaging land use activities (such as deep ploughing), discourage anti-social behaviour, and otherwise protect sites, especially up-standing earthworks. Woodland cover has in several cases been shown to be a long-term protector of archaeological monuments and landscapes when compared to sites under arable cultivation, even when these are left as protected islands within ploughed fields.

11.1.4 Woodland settings enhance peoples' experiences of archaeological sites. Incorporation of known archaeological sites within planting schemes typically allows better public access compared to other land uses, particularly arable cultivation. This increased accessibility (with appropriate management) could allow visitors to attain a better 'sense of place' and provide stronger links between the public's engagement with cultural heritage assets and the wider landscape. Thornborough Henges in North Yorkshire is one example where the one wooded henge is notable better preserved than the other two (Figures 37 and 38). All three henges are now part of a long-term managed landscape by English Heritage, sometime called the 'Stonehenge of the North', they provide a cultural landscape where people can gather and connect with their past.

Figure 37: Aerial view of Thornborough Henges, North Yorkshire (© Historic England ref: NMR_17393_06)

Figure 38: Wooded landscape of part of Thornborough Henges, North Yorkshire (© Rose Ferraby)

11.1.5 It has also been recognised that past tree removal across many archaeological sites has had detrimental impacts on the archaeology due to the increasing costs of weed or scrub management. Where data does exist, it suggests that the dense, fine root systems of bracken and other shrubs could have more of an impact on buried archaeology than the roots of trees themselves, especially on shallowly buried or especially sensitive remains.

11.1.6 There is clear evidence that tree roots do sometimes damage archaeology by displacing and diminishing the preservation of artefacts and ecofacts, blurring stratigraphic relationships, altering the burial environment, and making areas inaccessible for further archaeological study. However, these impacts are primarily localised with disturbance often limited to a depth of *c.* 0.6-1m and an area of *c.* 2-3m around the tree bowl itself. There is an enhanced risk of subsidence for historic structures located within this zone, as well as an increased probability of mechanical damage to artefacts, disturbance of stratigraphic relationships and chemical and biological damage to organic materials.

11.1.7 The depth and extent of this disturbance will depend on various environmental factors, including tree species, soil type and depth, local hydrology and bedrock density. This project has, however, demonstrated the paucity of published data specific to rooting types and depths across tree species, particularly in relation to other variables such as soil type, depth, and so on. Moreover, many of the limited studies conducted thus far have been focussed on very specific environments and tree species across Europe, not all of which are directly relevant to UK landscapes. Any predictive mapping that is conducted based on this data would only be possible on a small (eg county/district) scale, and only with enhanced data input, for example the relationship between woodland type, tree rooting habit, soil type, presence and type of archaeology and potential impacts on that archaeology.

11.1.8 There was a consensus that our most sensitive and highly valued archaeological sites and monuments should remain under managed pasture or natural grassland, as this is still seen as the most benign and protective form of land use for continued archaeological preservation. In these cases, however, archaeological preservation should be considered alongside other, equally important, factors such as biodiversity, habitat creation and carbon capture, especially where long-term grassland management is either prohibitively expensive or simply impractical, or the site concerned is already partly wooded or at risk of damage from other land uses.

11.1.9 For most areas of new tree planting, impacts are likely to be limited and not especially detrimental to the overall interpretation of a given archaeological site. On some sites, the possibility of tree cover as an alternative means of archaeological site preservation may be tolerated, if not actively encouraged, with management practices such as coppicing employed to lessen the risks of any detrimental impacts. Mixed approaches to any given site are also likely to give the best results. For instance, deeper rooting tree species can help to stabilise the banks of earthworks on Iron Age hillforts, whereas shallow-rooting trees or grass cover could be considered for the more sheltered inner areas where tree throw is less likely to occur. Areas of modern disturbance, previous excavations, or generally less sensitive archaeology could then be considered for mixed planting with less species-specific consideration.

11.1.10 Woodland creation has already successfully incorporated many archaeological sites and monuments within programmes of long-term land management, where a monument or site has been actively managed for 10-20 years. In certain situations, it has been shown that woodland creation has had better outcomes for archaeological preservation than other land uses, especially where issues of soil erosion, slope stability and the long-term protection of earthworks are particularly heightened. The HAR reports indicate that many monuments are often at risk through decay or deterioration due to lack of any management plans, which would ideally include such strategies as shrub or bracken clearing, coppicing or pollarding, deterring burrowing animals and protecting against vandalism or other anti-social behaviours.

11.1.11 The creation of new woodland on former ploughed fields, heath land or other land uses will help the UK to reach its much-needed biodiversity, carbon capture and environmental goals. The preservation of archaeological remains and sites has its part to play in this process and needs to be balanced and considered as part of these wider environmental targets. Selecting the right sites, with the right tree planting schemes, has been shown to offer benefits to the long-term protection and management of archaeological sites. Accordingly, the presence of archaeology should not necessarily be seen or used as a block to new tree planting schemes, but rather a factor that needs to be considered and balanced alongside other ecological and environmental factors on a site-by-site basis.

11.1.12 Nevertheless, tree planting will not be appropriate for all situations, particularly where there are sensitive, discrete, or especially well-preserved archaeological deposits. For example, discrete early prehistoric sites, burials, waterlogged sites, and certain types of structural remains are all at enhanced risk from rooting. In environments where superficially buried waterlogged organic and/or other palaeoenvironmental remains are thought to be present, tree planting would not be appropriate since these remains would be highly susceptible to damage from both hydrological and chemical changes as well as physical disturbances.

11.1.13 It is appreciated that planting and ongoing woodland management schemes can only factor in and protect archaeological remains where they are already known and are therefore less effective at protecting areas of as-yet un-surveyed archaeology. Many of the heritage professionals interviewed for this project were more concerned about the effects of forest operations on unknown archaeology, specifically types of archaeological sites that are typically not identified by geophysical surveys, as well as a general lack of provision for archaeological pre-surveys to be undertaken ahead of woodland creation. They also raised concerns about a perceived lack of early consultation, including a failure to share management plans or EIAs. If rectified, this could address some of the concerns in terms of planting regimes, harvesting methodologies, and the management of areas of known or potential archaeological value.

11.1.14 The current arrangements for how heritage and forestry professionals collaborate on new planting schemes needs to be improved. Better communication of management practices and plans, along with greater consultation in woodland schemes, would help to alleviate many of these concerns among heritage professionals and related stakeholders, who commented that engagement only occurred very late in the process and that management plans were not always provided. In addition, it was generally felt that there was a reluctance to undertake archaeological survey work ahead of planting. At present, local historic environment services (LHES) should be consulted by applicants for information and advice during "Stage 1" of Woodland Creation Planning Grant applications, and by applicants ahead of submitting England Woodland Creation Offer applications. Under standalone afforestation, EIAs would typically require an applicant to submit a consultation response or evidence from the LHES when they apply. If an application is found not to be UKFS compliant, the application is returned to the applicant. As such, heritage is increasingly being seen as an integral part of woodland planning, to be dealt with early in the process. However, further work may need to be undertaken to ensure that such regulations are properly fulfilled in all instances and can be improved upon where possible or appropriate.

11.1.15 Recent analysis suggests that almost four in five sites on the National Heritage List for England will face higher levels of risk by the second half of the 21st century, with climate-driven hazards intensifying the impact of background environmental processes such as weathering and erosion. In this light, the concept of ‘adaptive release’ – the idea that, in undertaking urgent nature restoration measures, it is sometimes necessary to manage positively the dynamic transformation of heritage assets rather than to stick fixedly to outdated conservation measures built on a thin evidence base (DeSilvey et al. 2021) – presents a useful working framework for developing future policies for tree planting in areas of archaeological interest. This approach recognises both the huge environmental and social value of historic environment assets and the urgency of measures, like tree planting, designed to tackle our current environmental emergency. Most importantly, the concept of 'adaptive release' promotes close collaborative working between historic and natural environment practitioners and academic researchers in order to ensure that environmental measures are realised positively, thoughtfully and effectively.

11.1.16 Approaches to tree planting in areas of known archaeological interest are already changing. New 'sensitivity mapping' methods, incorporating Historic Environment Record (HER) and LiDAR data are being developed which will help practitioners to identify the location of archaeological features and to determine their broad significance (Last and Kidd 2023). It seems that identifying the right sites as well as the right tree species will be key to future progress, with access to the most up-to-date, high quality heritage mapping and early consultation essential to overall success (cf Sunley and Robertson 2023). There needs to be a future mechanism for updating archaeological evidence into sensitivity mapping on a much more regular basis, as the Forestry Commission's National Historic Environment Datasets for Woodland Creation project is currently pursuing (Last 2023). More systematic and targeted research on the impact of tree roots and woodland management on archaeological remains would help to address many concerns on the part of both heritage and forestry sectors.

11.1.17 Consideration of landscapes less suitable for woodland creation will also be needed, and datasets based on Historic Landscape Characterisation (HLC) data could help to identify historic landscape types that should be avoided when considering future afforestation (cf Aldred and Fairclough 2003; Last and Kidd 2023). This avenue is being actively explored by the Forestry Commission as part of their 'National historic environment datasets for woodland creation project'. Working in collaboration with partners will be key to ensuring these datasets are fit for purpose and can be used to guide appropriate woodland creation.

12 Communication Strategy

12.1 Communication

12.1.1 Stakeholder engagement and proactive communications emerged as an integral part of the project from its inception. In their "Tree roots and archaeology research project design" paper, Edward Peveler and Jessica Turner (2023) acknowledged that the relations between the heritage and forestry sectors are marked by lack of reciprocal understanding that hinder collaboration.

12.1.2 Oxford Archaeology identified proactive communications about the project and stakeholder engagement as a key instrument to bridge the gap between the two sectors and to expand the evidence base through gathering the experiences of professionals. The project team agreed to use digital communications (blog posts and social media) to mark key stages of the project and issue public calls for action; it then planned to issue a questionnaire and conduct one-on-one interviews to gather information and evidence from key stakeholders selected based on their experience and knowledge of the topic.

12.2 Digital content

12.2.1 A blog post was published by Oxford Archaeology that illustrated the project, its aims and methodology, and encouraged people from both the heritage and forestry sectors to get in touch with the project team. To maximise its reach, the post was widely shared on all of Oxford Archaeology's and Forestry Commission's social media profiles. Particular attention was dedicated to LinkedIn as a very common platform used by many forestry and heritage professionals and organisations.

12.2.2 The post was read by 900 visitors to the website, while the LinkedIn post produced over 300 engagements (comments and shares) and reached a total audience of 11,800 people, in the UK and across Europe. Additionally, following the posts, several people contacted the project team via email to offer their contributions and volunteer to be interviewed.

12.2.3 The expressions of interest resulting from the blog and social media posts supplemented the list of target stakeholders, produced and agreed by Oxford Archaeology and the Forestry Commission, that would be sent the questionnaire or invited to be interviewed.

12.3 Targeted engagement

12.3.1 The questionnaire, designed to collect information about the interaction of tree roots and archaeology based on the practical experience of professionals in both the heritage and forestry sectors, was sent to a group of 60 stakeholders selected by both Oxford Archaeology and Forestry Commission. A target of 20 responses was set and met.

12.3.2 Eleven stakeholders were interviewed by Oxford Archaeology. The group of interviewees was progressively selected based on the evidence already acquired and the gaps in information that had emerged from the literature review and during the regular discussions with the Forestry Commission team. The interviews were aimed at providing key stakeholders with wider freedom to share their experiences and thoughts.

12.3.3 This led to some extremely interesting insights that often reached beyond the topic of tree roots and archaeology. Several individuals reiterated the view of Peveler and Turner (2023) that lack of understanding between the two sectors hinders collaboration; they also provided examples of how this issue could be overcome and expressed the hope that this project could generate a step change in the collaboration between heritage and forestry.

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APPENDIX A TREE SPECIES, PREFERRED HABITATS AND ENVIRONMENTAL TOLERANCES

A.1 Table A.1 below reproduces the available data on many common tree species within the UK, including naturalised species and non-natives commonly planted in significant numbers for their timber value. Though many of the assessments of rooting depth remain somewhat conjectural, an attempt has been made to highlight where possible how certain species respond to different soil conditions, as well as their general preferences regarding soil types and other environmental variables.

A.2 Table A.2: General rooting habits of common UK tree species (both native and introduced) The data is drawn from Crow (2005: Table 1), Crow and Moffat (2005: Table 1), Forest Research (2024), and Hotchkiss and Herbert (2022).

A.3 Table A.3: then itemises the principal tree species that currently occur within different woodland communities within the UK. Those communities are broadly defined following the schema of Hotchkiss and Herbert (2022) – acid upland, base-rich upland, wet upland, acid lowland, base-rich lowland, and wet lowland. 'Upland' and 'lowland' are here approximately divided along the 300m contour, and 'wet' woodland defined as that occurring in areas of either particularly high rainfall (principally western Britian's Atlantic temperate rainforests) and/or perennially high groundwater tables (eg, fen-edge alder carr).

Table A.1 General rooting habits of common UK tree species (both native and introduced)

N.B. total rooting depth is inclusive of fine root network in addition to principal coarse root architecture. Where entry is blank, no reliable data is currently available.

Species	Native status	Dominant rooting architecture type	Typical rooting depth (m)	Degree of mechanical root penetration	Water demands	Preferred soil conditions	Effect of soil type variability on rooting habits
Alder buckthorn (*Frangula alnus*)	Locally native					Prefers moist, generally more acidic soils. Intolerant of drought-prone or permanently waterlogged sites.	

Ash (*Fraxinus excelsior*)	Native	Surface	1.5	Medium	Low to medium	Prefers neutral to alkaline soils. Intolerant of deep, highly permeable soils, shallow soils over rock, and partially waterlogged soils, and especially so of fully waterlogged peaty substrates.	Rooting can extend down to 2m in fertile, loamy soils, and possibly also in deep, more highly permeable soils.
Aspen (*Populus tremula*)	Native	Surface	1.5	High	Medium to high	Tolerant of a range of conditions (dry to slightly wet, nutrient poor to rich), though prefers moist clay or sandy soils. Intolerant of deep, highly permeable soils and waterlogged peaty substrates.	Rooting depth is <2m in fertile, loamy soils and soils with moisture-retentive upper horizons, and <2.5m where present on deep, highly permeable soils. Rooting is typically limited to <1m in thin soils over rocky substrates.
Beech (*Fagus sylvatica*)	Locally native	Heart	1-1.3	Low	Low to medium	Tolerant of both acid and base-rich soils, typically on free draining lowland sites. Intolerant of drained organic-rich soils and deep, highly permeable soils, and especially so of waterlogged peaty substrates. Sensitive to drought.	Rooting depth is <2m in fertile, loamy soils and soils with moisture-retentive upper horizons. Rooting is typically limited to <1m in thin soils over rocky substrates.
Bird cherry (*Prunus padus*)	Locally native					Prefers moist, base-rich substrates, particularly near watercourses. Tolerant of thin soils over rock. Intolerant of	

						drought-prone and highly acidic soils.	
Black poplar (*Populus nigra*)	Native					Prefers moist riparian soils, particularly seasonally flooded and/or waterlogged soils alongside lowland rivers.	
Blackthorn (*Prunus spinosa*)	Native					Prefers base-rich, drier soils, though will also grow on neutral to slightly acid substrates. Intolerant of very damp soils.	
Common alder (*Alnus glutinosa*)	Native	Heart/surface	2.0	High	Low	Prefers moist to very wet riparian soils of a wide pH range, including locally damp soils in otherwise drier areas. Intolerant of highly calcareous soils and deep, highly permeable soils.	Rooting can extend down to 2.5m in fertile, loamy soils, but is typically limited to <1.5m in thin soils over rocky or impervious substrates, or when subjected to prolonged waterlogging.
Common pear (*Pyrus communis / P. pyraster*)	Naturalised	Tap				Tolerant of a wide range of soil pH and moisture levels, though prefers neutral to base-rich substrates and is intolerant of highly acidic soils.	
Common/English walnut (*Juglans regia*)	Non-native,		2.0			Intolerant of calcareous soils, deep, highly permeable soils, soil profiles featuring	Rooting depth is <4m in fertile, loamy soils, and (where present) <2.5m in

	locally naturalised					impervious subsoils, and drained organic-rich substrates, and especially so of waterlogged peaty substrates.	deep, highly permeable soils. Rooting is typically limited to <1.5m in thin soils over rock.
Corsican pine (*Pinus nigra var. maritima*)	Non-native	Tap	1.5-2.0	Medium	Low	Prefers acidic, freely draining, dry sandy soils. Intolerant of overly moist or compacted soils, and especially so of waterlogged peaty substrates. Generally intolerant of calcareous soils unless well drained.	Rooting depth can extend to <2.5m in deep, highly permeable soils, but is typically limited to <1m in soils with impervious substrates and/or wet lower horizons.
Crab apple (*Malus sylvestris*)	Native		2.0-3.0			Tolerate of a wide range of soil conditions and pH, but prefers deep, relatively moist and fertile soils. Intolerant of calcareous soils and waterlogged peaty substrates.	Rooting depth can extend to <4m in fertile, loamy soils, but is typically limited to <2m in thin soils over rocky or impervious substrates.
Crack willow (*Salix fragilis*)	Possibly native					Prefers seasonally flooded or permanently damp lowland riparian and floodplain sites, particularly those with base-rich soils and permanently high groundwater tables.	
Douglas fir (*Pseudotsuga menziesii*)	Non-native	Heart	2.0	High	Low	Prefers acidic, freely draining soils subject to relatively high rainfall. Intolerant of deep, highly permeable soils, shallow	Rooting depth can extend down to 3m in fertile, loamy soils, and possibly also where present on

						soils over rock and partially waterlogged soils, and especially so of calcareous soils and waterlogged peaty substrates.	deep, more highly permeable soils. Rooting is typically limited to <1.5m where present on soils with wet lower horizons.
Downy birch (*Betula pubescens*)	Native	Heart	1.5-1.8	Medium	Low	Prefers damp, typically neutral to acid soils, including freer-draining soils subject to relatively high rainfall. Intolerant of calcareous and deep, highly permeable soils.	Rooting can extend down to 2m in fertile, loamy soils and where present on deep, highly permeable soils. Rooting is typically limited to <1m in thin soils over rocky substrates and impervious subsoils, and <0.5m on waterlogged peaty substrates.
English yew (*Taxus baccata*)	Native					Prefers base-rich substrates, including very calcareous soils over chalk or limestone. Intolerant of more acidic, rocky soils.	
Elder (*Sambucus nigra*)	Native					Prefers base-rich soils.	
European larch (*Larix decidua*)	Non-native	Heart	1.5-2.0	High	Low	Prefers relatively moist but free-draining, neutral to slightly acidic soils. Highly intolerant of overly compacted or waterlogged soils, including peaty substrates.	Rooting can extend down to 2.5m in fertile, loamy soils, and 4m in deep, highly permeable soils.

Field maple (*Acer campestre*)	Native		1.0			Tolerant of a wide range of soil conditions, though prefers neutral to base-rich soils. Relatively intolerant of deep, highly permeable soils, shallow soils over rock or impervious subsoils, overly acidic soils, or drained organic-rich substrates, and especially so of waterlogged peaty substrates.	Rooting depth rarely exceeds 1m regardless of soil conditions.
Goat willow (*Salix caprea*)	Native					Prefers moist, typically base-rich soils. Less tolerant of frequent waterlogging/constant saturation than other willow species.	
Grey willow (*Salix cinerea*)	Native					Prefers very wet and waterlogged soils. Will also tolerate drier soils in areas with relatively high rainfall.	
Grand fir (*Abies grandis*)	Non-native		1.0m			Prefers deep, neutral to acid, relatively free draining soils in areas with high rainfall. Will tolerate lower rainfall on more moisture retentive soils. Intolerant of deep, highly permeable or other dry soils, and especially so of calcareous soils and	Rooting depth can extend to 1.5m in fertile, loamy soils and soils with wet lower horizons.

						waterlogged peaty substrates.	
Hawthorn (*Crataegus monogyna / C. laevigata*)	Native					Tolerates a wide range of soil conditions but prefers neutral heavier clay or loamy soils.	
Hazel (*Corylus avellana*)	Native					Tolerant of a wide range of pH conditions, from base-rich to slightly acidic. Prefers moist soils but will also tolerate some drier and/or shallower rocky soils. Intolerant of waterlogged soils.	
Holly (*Ilex aquafolium*)	Native					Prefers well-drained neutral to acidic soils.	
Hornbeam (*Carpinus betulus*)	Locally native	Heart	1.5	Medium	Low	Prefers neutral to acidic but relatively fertile, sandy-to loamy clay soils, including clay-with-flints. Intolerant of calcareous soils, infertile, highly permeable soils, and especially so of waterlogged peaty substrates.	Rooting can extend down to 2m in fertile, loamy soils, and where present on deep, highly permeable soils. Rooting is typically limited to <1m on shallow soils over rock or impervious subsoils.
Horse chestnut (*Aesculus hippocastanum*)	Naturalised					Prefers moist, well drained soils, though will tolerate wide range of soils, including both sandy substrates and wet clays.	

Japanese larch (*Larix kaempferi*)	Non-native	Heart	2.0-2.5	Medium	Low	Prefers acidic, nutrient poor soils in areas of relatively high rainfall. Intolerant of waterlogged peaty substrates and very deep, highly permeable soils.	Rooting typically limited to under 1.5m on shallow soils over rock, and (where present) <1m on waterlogged peaty substrates.
Juniper (*Juniperus communis*)	Locally native					Prefers drier, free-draining soils of low fertility, ranging from base-rich to acidic rocky substrates.	
Large-leaved lime (*Tilia platyphyllos*)	Locally native					Prefers calcareous lowland soils, will tolerate some more acidic substrates.	
Lodgepole pine (*Pinus contorta*)	Non-native		1.5-2.0			Tolerant of a wide range of typically acidic, nutrient poor soils from podzols to peats. Intolerant of calcareous soils.	Rooting can extend down to 2m in fertile, loamy soils, drained organic-rich substrates, and soils with wet lower horizons. Rooting is typically limited to <1.0m in soils with impervious subsoils and/or moisture retentive upper horizons, and to <0.5m on waterlogged peaty substrates.
Noble fir (*Abies procera*)	Non-native		1.0			Tolerant of a wide range of conditions, though prefers moist soils in areas subject to cool climates	Rooting can extend down to 1.5m in partially waterlogged soils.

						and relatively high rainfall. Intolerant of calcareous soils, deep, highly permeable or other dry soils, and both drained and fully waterlogged organic-rich substrates.	
Norway maple (*Acer platanoides*)	None-native	Heart	1.0		Low to medium	Tolerant of a wide range of soil conditions but prefers deep, relatively free-draining neutral to base-rich soils. Intolerant of more acidic soils or waterlogged peaty substrates.	
Norway spruce (*Picea abies*)	Non-native	Surface	2.0	Low	Low	Prefers moist, relatively free-draining soils. Tolerant of a range of pH levels except where nutrient levels are very low (typically on more acidic substrates). Intolerant of both deep, highly permeable or other dry soils and waterlogged peaty substrates.	Rooting is typically restricted to the upper 1.5m in drained organic-rich horizons and partially waterlogged soils, and where present in waterlogged peaty horizons, and to <0.5m in shallow soils over rock.
Pedunculate/English oak (*Quercus robur*)	Native	Tap	1.5-2.0	High	Medium to high	Tolerant of a wide range of soil conditions, particularly neutral heavy soils in lowland areas. Intolerant of overly acidic- or base-rich soils and deep, highly permeable soils, and especially so of	Rooting can extend down to 2.5m in drained organic-rich substrates, and 4m in fertile, loamy soils. Rooting is typically limited to <1m in

						waterlogged peaty substrates.	shallow soils over rock.
Purging buckthorn (*Rhamnus cathartica*)	Native					Prefers calcareous lowland soils, typically free-draining though will tolerate some wetter base-rich soils.	
Red oak (*Quercus rubra*)	Non-native	Heart	1.6	Medium	Medium to high	Prefers moderately dry to moist, typically slightly acidic soils of poor to medium nutrient status, particularly acidic sandy loams.	
Rowan (*Sorbus acuparia*)	Native					Tolerant of a wide range of soil conditions, though prefers moderately moist to moderately dry, neutral to somewhat acid soils. Intolerant of heavy or highly waterlogged soils.	
Scots pine (*Pinus sylvestris*)	Locally native	Tap	2.0	High	Low	Prefers neutral to acid-rich, low fertility, freely drained soils. Prefers drier substrates but will slowly colonise waterlogged peats. Tolerant of more base-rich soils if relatively thin, typically those overlying rocky substrates. Generally intolerant of fertile, loamy soils, calcareous soils, and both partially and fully waterlogged substrates.	Rooting can extend down to 3m in deep, highly permeable soils. Rooting is typically restricted to <1.5m in drained organic rich substrates and <1m in shallow soils over rock.

Sessile oak (*Quercus petraea*)	Native	Tap	1.5	High	Medium to high	Prefers relatively infertile, neutral to acidic soils.	
Sitka spruce (*Picea sitchensis*)	Non-native		1.5-2.0			Prefers soils of poor to medium nutrient status, either in areas of high rainfall or where soils are more moisture retentive. Tolerant of drained peats and gleys. Intolerant of calcareous soils and deep, highly permeable or other dry soils.	Rooting typically limited to under 1m in soils with wet lower horizons, and <0.5m in shallow soils over rock.
Silver birch (*Betula pendula*)	Native					Prefers drier, free-draining acidic to base-rich soils. Less tolerant of waterlogged soils than downy birch.	
Silver fir (*Abies alba*)	Non-native	Tap	2.0	High	Low	Prefers neutral to acidic, intermediate to moist soils subject to relatively high rainfall. Tolerant of deeper (ie, partially buffered) soils overlying limestones and other calcareous substrates. Highly intolerant of both deep, highly permeable or other very dry soils and waterlogged peaty substrates.	
Small-leaved lime (*Tilia cordata*)	Native	Heart	1.3-1.5	Low	Medium	Tolerant of a wide range of soil conditions, from freely draining to heavier clays, but prefers neutral to slightly acidic soils over	Rooting depth can extend down to 2m in deep, highly permeable soils and soils with moisture

						fairly calcareous geologies. Intolerant of waterlogged peaty substrates.	retentive upper horizons, but is typically limited to <1m in shallow soils over rock or impervious subsoils.
Spindle (*Euonymus europaeus*)	Locally native					Prefers free draining calcareous lowland soils, especially those overlying limestone/chalk.	
Sweet chestnut (*Castanea sativa*)	Naturalised		2.0			Prefers moist but free-draining soils. Tolerant of range of pH conditions, except very alkaline soils. Intolerant of deep, highly permeable or other dry soils as well as partially waterlogged soils, and especially so of fully waterlogged peaty substrates.	Where present rooting can extend down to 2.5m in deep, highly permeable soils, but is typically limited to <1.0m in shallow soils over rock.
Sycamore (*Acer pseudoplatanus*)	Naturalised	Heart	1.5	Low	Low to medium	Tolerant of a wide range of soil conditions except the most acidic and/or infertile. Intolerant of deep, highly permeable soils, thin soils over rock, and waterlogged peaty substrates.	Where present rooting can extend down to 2m in deep, highly permeable soils, but is typically limited to <1m in soil profiles featuring impervious subsoils.
Western hemlock (*Tsuga heterophylla*)	Non-native		1.5			Prefers neutral to acidic, slightly dry to moist soils subject to relatively high rainfall. Intolerant of deep, highly permeable or other	Where present rooting can extend down to 2m in deep, highly permeable soils, but is typically

						very dry soils, and especially so of waterlogged peaty substrates.	limited to <1m in soil profiles featuring impervious subsoils.
Western red cedar (*Thuja plicata*)	Non-native		1.5			Prefers moderate to high fertility, neutral to acid soils subject to relatively high rainfall. Will tolerate lower rainfall if soil is more moisture retentive. Tolerant of calcareous soils if grown under light shelter. Intolerant of deep, highly permeable soils, thin soils over rock, and waterlogged peaty substrates.	Rooting can extend down to 2m in fertile, loamy soils and drained organic-rich substrates. Rooting is typically limited to <1m in soils with wet lower horizons and, where present, waterlogged peaty substrates.
Whitebeam (*Sorbus aria*)	Locally native					Prefers very base-rich lowland soils, typically overlying limestone/chalk.	
White poplar (*Populus alba*)	Naturalised		2.0		Medium to high	Prefers moist soils, typically in riparian or floodplain locations. Intolerant of deep, highly permeable soils, thin soils over rock, and both drained and waterlogged organic-rich substrates.	Rooting can extend down to 3m in soils with moisture retaining upper horizons.
White willow (*Salix alba*)	Naturalised		2.0-2.5m			Prefers moist to wet lowland soils, including seasonally flooded and permanently waterlogged sites. Tolerates a wide range of pH, except highly calcareous substrates.	Rooting typically limited to <1m in thin soils over rock.

						Intolerant of dry conditions, including deep, highly permeable soils.	
Wild cherry (*Prunus avium*)	Native		1.5			Prefers deep, fertile, relatively moist lowland soils. Tolerant of a wide range of pH conditions. Intolerant of deep, highly permeable or otherwise drought-prone soils, thin and/or infertile soils and waterlogged soils, including peaty substrates.	Rooting can extend down to 2m in fertile, loamy soils and drained organic-rich substrates, and to 2.5m in soils with moisture retentive upper horizons.
Wild service tree (*Sorbus torminalis*)	Locally native					Tolerant of a wide range of soil conditions, including some neutral or slightly acidic soils, but prefers clayey soils overlying base-rich soils.	
Wych elm (*Ulmus glabra / U. scabra*)	Native					Prefers neutral to base-rich, relatively moist soils.	

Table A.2 Probable rooting depth ranges for selected tree species. After Crow 2005, Table 1

Tree species	Soil types*							
	Loose, deep well-drained soils	Shallow soils over rock	Intermediate loamy soils	Impervious subsoils	Soils with moisture retaining upper horizons	Soils with wet lower horizons	Organic rich soils	
	1	2	3	4	5	6	7a Drained	7b Waterlogged
Alder (*Alnus glutinosa*) *unlikely if soils are calcareous		<1.0m root depth	<2.5m root depth	<1.5m root depth	<2.0m root depth	<2.0m root depth	<2.0m root depth	<1.5m root depth
	Not ideal & growth may be impeded (site variable)	Values conjectural		Values conjectural		Values conjectural	Values conjectural	Values conjectural
Apple (*Malus sylvestris*) *unlikely if soils are calcareous	<3.0m root depth	<1.5m root depth	<4.0m root depth	<2.0m root depth	<3.0m root depth	<2.0m root depth	<2.5m root depth	< 1.5m root depth
		Values conjectural		Values conjectural		Values conjectural	Values conjectural	Not ideal for growth but some values published
Ash (*Fraxinus excelsior*)	<2.0m root depth		<2.0m root depth		<1.5m root depth	<1.5m root depth	<1.5m root depth	
	Not ideal for growth but some values published	Not ideal & growth may be impeded (site variable)		Not ideal & growth may be impeded (site variable)	Not ideal for growth but some values published	Not ideal for growth but some values published	Values conjectural	Conditions not recommended for growth

Aspen (*Populus tremula*) *unlikely if soils are calcareous	<2.5m root depth	<1.0m root depth	<2.0m root depth	<1.5m root depth	<2.0m root depth	<1.5m root depth	<1.5m root depth	<1.0m root depth
	Not ideal for growth but some values published	Values conjectural					Values conjectural	Not ideal for growth but some values published
Beech (*Fagus sylvatica*)		<1.0m root depth	<2.0m root depth	<1.5m root depth	<2.0m root depth	<1.5m root depth		
	Not ideal & growth may be impeded (site variable)	Values conjectural		Values conjectural	Values conjectural	Values conjectural	Not ideal & growth may be impeded (site variable)	Conditions not recommended for growth
Corsican pine (*Pinus nigra* var. *maritima*)	<2.5m root depth	<1.5m root depth	<2.0m root depth	<1.0m root depth	<1.0m root depth	<2.0m root depth	<2.0m root depth	
		Values conjectural				Values conjectural	Values conjectural	Conditions not recommended for growth
Douglas fir (*Pseudotsuga menziesii*) *unlikely if soils are calcareous	<3.0m root depth		<3.0m root depth	<2.0m root depth	<2.0m root depth	<1.5m root depth	<2.0m root depth	
	Not ideal for growth but some values published	Not ideal & growth may be impeded (site variable)		Not ideal for growth but some values published	Not ideal for growth but some values published	Not ideal for growth but some values published	Values conjectural	Conditions not recommended for growth

Downy birch (*Betula pubescens*) *unlikely if soils are calcareous	<2.0m root depth	<1.0m root depth	<2.0m root depth	<1.0m root depth	<1.5m root depth	<1.5m root depth	<1.5m root depth	<0.5m root depth
	Not ideal for growth but some values published	Values conjectural		Values conjectural	Values conjectural	Values conjectural	Values conjectural	Values conjectural
European larch (*Larix decidua*)	<4.0m root depth	<1.5m root depth	<2.5m root depth	<1.5m root depth			<1.5m root depth	
		Values conjectural		Values conjectural	Not ideal & growth may be impeded (site variable)	Not ideal & growth may be impeded (site variable)	Values conjectural	Not ideal & growth may be impeded (site variable)
Field maple (*Acer campestre*)			<1.0m root depth		<1.0m root depth	<1.0m root depth		
	Not ideal & growth may be impeded (site variable)	Not ideal & growth may be impeded (site variable)		Not ideal & growth may be impeded (site variable)	Values conjectural	Values conjectural	Not ideal & growth may be impeded (site variable)	Conditions not recommended for growth
Grand fir (*Abies grandis*) *unlikely if soils are calcareous		<1.0m root depth	<1.5m root depth	<1.0m root depth	<1.0m root depth	<1.5m root depth	<1.0m root depth	< 1.0m root depth
	Not ideal & growth may be impeded (site variable)	Values conjectural		Values conjectural				Not ideal for growth but some values published

Hornbeam (*Carpinus betulus*) *unlikely if soils are calcareous	<2.0m root depth	<1.0m root depth	<2.0m root depth	<1.0m root depth	<1.5m root depth	<1.5m root depth	<1.5m root depth	
	Not ideal for growth but some values published	Values conjectural		Values conjectural			Values conjectural	Conditions not recommended for growth
Japanese larch (*Larix kaempferi*) *unlikely if soils are calcareous		<1.5m root depth	<2.5m root depth	<2.5m root depth	<2.5m root depth	<2.0m root depth	<2.0m root depth	<1.0m root depth
	Not ideal & growth may be impeded (site variable)	Values conjectural	Values conjectural		Values conjectural	Values conjectural	Values conjectural	Not ideal for growth but some values published
Lime, small-leaved (*Tilia cordata*)	<2.0m root depth	<1.0m root depth	<1.5m root depth	<1.0m root depth	<2.0m root depth	<1.5m root depth	<1.5m root depth	
	Values conjectural	Values conjectural		Values conjectural	Values conjectural	Values conjectural	Values conjectural	Conditions not recommended for growth
Lodgepole pine (*Pinus contorta*) *unlikely if soils are calcareous	<1.5m root depth	<1.5m root depth	<2.0m root depth	<1.0m root depth	<1.0m root depth	<2.0m root depth	<2.0m root depth	<0.5m root depth
		Values conjectural				Values conjectural		
Noble fir (*Abies procera*) *unlikely if soils are calcareous		<1.0m root depth	<1.0m root depth	<1.0m root depth	<1.5m root depth	<1.5m root depth	<1.0m root depth	<1.0m root depth
	Not ideal & growth may be impeded	Values conjectural	Values conjectural	Values conjectural	Values conjectural	Values conjectural	Not ideal for growth but some values published	Not ideal for growth but some values published

	(site variable)							
Norway spruce (*Picea abies*)	<2.0m root depth	<0.5m root depth	<2.0m root depth	<1.0m root depth	<1.0m root depth	<1.5m root depth	<1.5m root depth	<1.0m root depth
	Not ideal for growth but some values published	Values conjectural		Values conjectural		Values conjectural	Values conjectural	Not ideal for growth but some values published
Pedunculate oak (*Quercus robur*) *unlikely if soils are calcareous	<2.0m root depth	<1.0m root depth	<4.0m root depth	<2.0m root depth	<1.5m root depth	<1.5m root depth	<2.5m root depth	
	Not ideal for growth but some values published			Values conjectural			Values conjectural	Conditions not recommended for growth
Scots pine (*Pinus sylvestris*) *unlikely if soils are calcareous	<3.0m root depth	<1.0m root depth	<2.0m root depth	<2.0m root depth			<1.5m root depth	
				Not ideal for growth but some values published	Conditions not recommended for growth	Conditions not recommended for growth	Values conjectural	Conditions not recommended for growth
Sitka spruce (*Picea sitchensis*) *unlikely if soils are calcareous	<2.0m root depth	<0.5m root depth	<2.0m root depth	<1.5m root depth	<2.0m root depth	<1.0m root depth	<1.5m root depth	<0.5m root depth
	Not ideal for growth but some							

	values published							
Sweet chestnut (*Castanea sativa*) *unlikely if soils are calcareous	<2.5m root depth	<1.0m root depth	<2.0m root depth				<2.0m root depth	
	Not ideal for growth but some values published	Values conjectural		Not ideal & growth may be impeded (site variable)	Not ideal & growth may be impeded (site variable)	Not ideal & growth may be impeded (site variable)	Values conjectural	Conditions not recommended for growth
Sycamore (*Acer pseudoplatanus*)	<2.0m root depth		<1.5m root depth	<1.0m root depth	<1.5m root depth	<1.5m root depth	<1.5m root depth	
	Not ideal for growth but some values published	Not ideal & growth may be impeded (site variable)		Values conjectural	Values conjectural	Values conjectural	Values conjectural	Not ideal & growth may be impeded (site variable)
Walnut (*Juglans regia*) *unlikely if soils are calcareous	<2.5m root depth	<1.5m root depth	<4.0m root depth		<2.0m root depth	<2.0m root depth		
	Not ideal for growth but some values published	Values conjectural		Not ideal & growth may be impeded (site variable)		Values conjectural	Not ideal & growth may be impeded (site variable)	Conditions not recommended for growth
Western hemlock (*Tsuga heterophylla*)	<2.0m root depth		<1.5m root depth	<1.0m root depth	<1.5m root depth	<1.5m root depth	<1.5m root depth	

*unlikely if soils are calcareous	Not ideal for growth but some values published	Not ideal & growth may be impeded (site variable)		Values conjectural		Values conjectural	Values conjectural	Conditions not recommended for growth
	<1.5m root depth		<2.0m root depth	<1.5m root depth	<1.5m root depth	<1.0m root depth	<2.0m root depth	<1.0m root depth
Western red cedar (*Thuja plicata*)	Not ideal for growth but some values published	Not ideal & growth may be impeded (site variable)	Values conjectural	Values conjectural			Values conjectural	Not ideal for growth but some values published
			<2.0m root depth	<2.0m root depth	<3.0m root depth	<2.0m root depth		
White poplar (*Populus alba*) *unlikely if soils are calcareous	Not ideal & growth may be impeded (site variable)	Not ideal & growth may be impeded (site variable)		Values conjectural		Values conjectural	Not ideal & growth may be impeded (site variable)	Not ideal & growth may be impeded (site variable)
		<1.0m root depth	<2.5m root depth	<2.0m root depth	<2.5m root depth	<2.0m root depth	<2.5m root depth	<2.0m root depth
White willow (*Salix alba*) *unlikely if soils are calcareous	Not ideal for growth but some values published	Values conjectural	Values conjectural	Values conjectural	Values conjectural		Values conjectural	Values conjectural
			<2.0m root depth	<1.5m root depth	<2.5m root depth	<1.5m root depth	<2.0m root depth	<1.5m root depth

Wild cherry (*Prunus avium*)	Not ideal & growth may be impeded (site variable)	Not ideal & growth may be impeded (site variable)		Values conjectural	Values conjectural	Values conjectural	Values conjectural	Not ideal for growth but some values published

- Root depth = probable rooting depth range for mature trees

**Further soil types information (Crow 2005, 5):*

1 **Loose, deep well-drained soils.** Some sands with large pore spaces are most likely to promote greater root depths as they are well aerated & may provide less resistance to root penetration. Examples include Littoral soils.

2 **Shallow soils over rock.** Well drained, but bedrock occurs at less than 1m. If the rock is chalk or a similar soft rock, some local root penetration may occur. Common examples are Rendzinas & Rankers.

3 **Intermediate loamy soils.** Retain more moisture than soils 1 or 2, but still allow considerable root development. Examples include Brown Earths that can vary greatly in their constituents & water content.

4 **Impervious subsoils.** Soils with a large particle size that are restricted by an impervious layer. These soils may be seasonally waterlogged. The main example soil type is Podzols, with a cemented iron pan formed within 1m of the soil surface.

5 **Soils with moisture retaining upper horizons.** These soils are seasonally waterlogged in the top 40cm due to poor slowly permeable surface horizons. In such soils, there may be little need for deep root development. The most important soil example type are Surface-water gleys.

6 **Soils with wet lower horizons.** Examples such as Ground-water gleys occur within or over permeable materials that allow periodic waterlogging by a fluctuating water table. These waterlogged horizons may determine the root depth.

7 **Organic rich soils.** These include peat soils of varying type & origin. They are distinguished between drained & predominantly waterlogged soils.

Table A.3: Typical tree species present within different types of UK native woodland

Data drawn from Hotchkiss and Herbert (2022)

Woodland type	Typical species mix by structural woodland component		
	Groves (>70% canopy cover)	Open wooded habitats (20–70% canopy cover)	Glades (<20% canopy cover)
Acidic upland	Downy birch, hazel, holly, small-leaved lime (local), Scots pine (local), sessile oak	Aspen, bird cherry (local), downy birch, goat willow, grey willow (local), hawthorn, hazel, holly, small-leaved lime (local), rowan, Scots pine (local), sessile oak	Aspen, bird cherry (local), downy birch, goat willow, grey willow, hawthorn, hazel, holly, juniper (local), rowan, Scots pine (local), sessile oak
Base-rich upland	Ash, aspen, downy birch, hazel, holly, small-leaved lime (local), pedunculate oak (local), sessile oak, silver birch (local), wych elm, yew (local)	Alder (damp areas), ash, aspen, bird cherry (local), crab apple (local), downy birch, hazel, holly, juniper (local), small-leaved lime (local), pedunculate oak (local), rowan, Scots pine (local), sessile oak, silver birch (local), sycamore (local), wild service (local), wych elm, yew (local)	Alder (damp areas), ash, aspen, bird cherry (local), blackthorn, crab apple (local), downy birch, elder, goat willow, grey willow, hawthorn, holly, juniper (local), rowan, Scots pine (local), sessile oak, silver birch (local), sycamore (local), wild service tree (local), wych elm
Wet upland	Alder, ash, crack willow (local), downy birch, holly, Scots pine (local), sessile oak, white willow (local to some alluvial or riparian areas), wych elm	Alder, alder buckthorn (local), ash, aspen, bird cherry (local), downy birch; elder, goat willow, grey willow, holly, sessile oak	Alder, alder buckthorn (local), aspen, bird cherry (local), downy birch, elder, goat willow, grey willow, holly, sessile oak
Acidic lowland	Beech (local), downy birch (local), hazel, holly, hornbeam (local), pedunculate oak, sessile oak (local), silver birch	Aspen, beech (local), crab apple, downy birch, goat willow, grey willow, hawthorn, hazel, holly, hornbeam (local), pedunculate oak, rowan, sessile oak (local), silver birch, wild cherry	Aspen, beech (local), blackthorn, crab apple, downy birch, elder, goat willow, grey willow, hawthorn, hazel, holly, hornbeam (local), pedunculate oak, rowan, sessile oak (local), silver birch, wild cherry
Base-rich lowland	Ash, beech (local), downy birch (locally damp), field maple, hazel, hornbeam (local), large-leaved lime (local), small-leaved lime (local), hawthorn (local), pedunculate oak, sessile oak (local), silver birch, wych elm, yew	Ash, aspen, beech (local), whitebeam (local), crab apple, downy birch, field maple, grey willow, hawthorn, hazel, holly, hornbeam (local), small-leaved lime (local), hawthorn (local), pedunculate oak, purging buckthorn (local), rowan, sessile oak (local), silver birch, spindle, sycamore (local), wild cherry (local), wild service tree (local), wych elm, yew	Ash, aspen, beech (local), blackthorn, crab apple, whitebeam (local), downy birch, elder, field maple, goat willow, grey willow, hawthorn, hazel, holly, hornbeam (local), small-leaved lime (local), pedunculate oak, purging buckthorn (local), rowan, silver birch, spindle (local), sycamore (local), wild cherry (local), wild service tree (local), wych elm, yew

Wet lowland	Alder, ash, black poplar (local), crack willow, downy birch, holly, hornbeam (local), small-leaved lime (local), pedunculate oak, white willow, wych elm	Alder, alder buckthorn (local), ash, aspen, black poplar (local), crack willow, downy birch, elder, goat willow, grey willow, holly, hornbeam (local), small-leaved lime (local), pedunculate oak, white willow	Alder, almond willow, ash, aspen, black poplar (local), alder buckthorn (local), crack willow, downy birch, elder, goat willow, grey willow, holly, small-leaved lime (local), pedunculate oak, white willow

APPENDIX B CORRELATION OF UK SOIL CLASSIFICATION SYSTEMS

B.1 Despite the great impact of soil type on both the distribution and growth habits of all UK tree species, there is at present no single classificatory system for soils within the UK. There is even less available data on how the various classifications in use specifically correlate with factors such as floral biodiversity or habitat type. In an effort to provide some degree of continuity across the various sources cited within this report, Table B.1 presents a preliminary correlation of soil types as utilised by Crow (2005; ie, those principally referred to within Table A.1 of Appendix A) with those of the National Soil Map of England and Wales, the UK Soil Observatory's 'Soilscapes' mapping, and the UN's World Reference Base for Soil Resources. The full soil class definitions according to each classificatory system are provided in the text following Table B.1

B.2 It is important to note that not all soil classes are mutually exclusive in terms of their correlation with alternative classification systems, nor should the correlations outlined here be viewed as definitive associations.

Table B.1: Preliminary correlation of UK soil classification schema

Soil classification			
Crow (2005)	National Soil Map of England and Wales	Soilscapes	World Reference Base
1: Loose, deep well-drained soils	1, 6	4, 10, 11, 14	1, 10, 11, 14
2: Shallow soils over rock	3	3, 13, 19	6, 13
3: Intermediate loamy soils	5, 9	5, 6, 7, 12, 24	2, 7
4: Impervious subsoils	4, 7	17, 18, 19	9, 12
5: Soils with moisture retaining upper horizons	2, 6, 7	1, 15, 16, 23	3, 9, 10
6: Soils with wet lower horizons	8	1, 8, 9, 15, 17, 18, 19, 20, 21, 22, 23	3, 4, 12
7a: Organic rich soils (drained)	9, 10	2, 19, 23	5, 8
7b: Organic rich soils (waterlogged)	10	2, 16, 19, 23, 25, 26, 27	5, 8

UK soil class definitions: Crow (2005)

1: Loose, deep well-drained soils. Some sands with large pore spaces are most likely to promote greater root depths as they are well aerated and may provide less resistance to root penetration. Examples include Littoral soils.

2: Shallow soils over rock. Well drained, but bedrock occurs at less than 1m. If the rock is chalk or a similar soft rock, some local root penetration may occur. Common examples are Rendzinas & Rankers.

3: Intermediate loamy soils. Retain more moisture than soils 1 or 2, but still allow considerable root development. Examples include Brown Earths that can vary greatly in their constituents & water content.

4: Impervious subsoils. Soils with a large particle size that are restricted by an impervious layer. These soils may be seasonally waterlogged. The main example soil type is Podzols, with a cemented iron pan formed within 1m of the soil surface.

5: Soils with moisture retaining upper horizons. These soils are seasonally waterlogged in the top 40cm due to poor slowly permeable surface horizons. In such soils, there may be little need for deep root development. The most important soil example types are surface-water gleys.

6: Soils with wet lower horizons. Examples such as groundwater gleys occur within or over permeable materials that allow periodic waterlogging by a fluctuating water table. These waterlogged horizons may determine the root depth.

7: Organic rich soils. These include peat soils of varying type and origin. They are distinguished between drained and predominantly waterlogged soils.

UK soil class definitions: National Soil Map of England and Wales (Cranfield University 2018)

1: Terrestrial raw soils. Very recently formed material with little to no pedogenic alteration. Includes raw sands, as within coastal dune systems.

2: Raw gley soils. Mineral material which has been waterlogged since deposition, often unvegetated. Includes estuarine muds and intertidal saltings.

3: Lithomorphic soils. Shallow soils with a shallow organic/organic-enriched surface horizon. Includes rankers (over non-calcareous bedrock) and rendzinas (over chalk and other limestones).

4: Pelosols. Slowly permeable clay soils, often with marked subsoil clay enrichment. Do not display prominent subsurface mottled (i.e., gleyed) horizons.

5: Brown soils. Predominantly well drained and moderately developed soils, with predominantly brown/reddish subsurface horizons. Commonly used for agricultural purposes.

6: Podzolic soils. Soils with a black/dark brown/ochreous subsurface horizon resulting from the down-profile leaching of Fe/Al minerals and/or organic matter. Normally form under acid weathering conditions, with an unincorporated surface layer of acidified organic matter.

7: Surface-water gley soils. Seasonally waterlogged, slowly permeable soils with mottling of upper horizons.

8: Ground-water gley soils. Seasonally waterlogged soils usually occuring within/over permeable materials, with mottling of lower subsurface horizons arising from a fluctuating groundwater table.

9: Man-made soils. Any soil formed in material modified or created by human activity. Includes backfill soils, manured and/or deeply ploughed soils, and refuse deposits.

10: Peat soils. Predominantly organic soils derived from decomposed plant remains accumulated under waterlogged conditions. Includes drained soils, including those now under agricultural use.

UK soil class definitions: Soilscapes (Cranfield University 2024)

1: Saltmarsh soils. Loamy, naturally wet, lime-rich but saline, low to medium topsoil carbon. Coastal salt marsh vegetation subject to tidal flooding. Often used for rough grazing.

2: Shallow very acid peaty soils over rock. Peaty, variable drainage, very low fertility, high topsoil carbon. Rugged wet heather and grass moor with bare rock, and bog vegetation in hollows. Often used for rough grazing.

3: Shallow lime-rich soils over chalk or limestone. Loamy, freely draining, lime-rich, low to medium topsoil carbon. Herb-rich downland and limestone pastures, limestone pavements in the uplands, beech hangers and other lime-rich woodlands. Often under arable use or pasture.

4: Sand dune soils. Sandy, freely draining, lime-rich, low topsoil carbon. Sand dune vegetation ranging from pioneer dune systems through to low shrub.

5: Freely draining lime-rich loamy soils. Loamy, freely draining, lime-rich, low topsoil carbon. Herb-rich chalk and limestone pastures, lime-rich deciduous woodlands. Often under arable use with pasture at higher elevations.

6: Freely draining slightly acid loamy soils. Loamy, freely training, low fertility, low topsoil carbon. Neutral and acid pastures and deciduous woodlands, acid communities such as bracken and gorse in the uplands. Often under arable use or pasture.

7: Freely draining slightly acid but base-rich soils. Loamy, freely draining, high fertility, low topsoil carbon. Base-rich pastures and deciduous woodlands. Often under arable use or pasture.

8: Slightly acid loamy and clayey soils with impeded drainage. Loamy/some clayey, slightly impeded drainage, moderate/high fertility, low topsoil carbon. Wide range of pasture and woodland types. Often under arable use or seasonal pasturage.

9: Lime-rich loamy and clayey soils with impeded drainage. Clayey/some loamy, slightly impeded drainage, high fertility, low topsoil carbon. Base-rich pastures and classic chalky boulder clay ancient woodlands, some wetter areas and lime-rich flush vegetation. Often under arable use, some pasture.

10: Freely draining slightly acid sandy soils. Sandy, freely draining, low fertility, low topsoil carbon. Acid dry pastures, acid deciduous and coniferous woodland, potential for lowland heath. Often under arable use.

11: Freely draining sandy Breckland soils. Sandy, freely draining, mixed fertility/low to lime-rich, low topsoil carbon. Characteristic Breckland heathland communities. Often under arable use or forestry.

12: Freely draining floodplain soils. Loamy, freely draining, moderate to high fertility, low topsoil carbon. Grassland, wet carr woodlands in old river meanders. Mostly used for pasture due to flood risk, sometimes arable.

13: Freely draining acid loamy soils over rock. Loamy, freely draining, low fertility, medium topsoil carbon. Steep acid upland pastures dry heath and moor, bracken gorse and oak woodlands. Often used for rough grazing or improved pasture

14: Freely draining very acid sandy and loamy soils. Sandy/some loamy, freely draining, very low fertility, medium topsoil carbon. Mostly lowland dry heath communities. Often used for rough grazing or forestry.

15: Naturally wet very acid sandy and loamy soils. Sandy and loamy, naturally wet, very low fertility, medium soil carbon. Mixed dry and wet lowland heath communities. Often under arable and horticultural use.

16: Very acid loamy upland soils with a wet peaty surface. Peaty, surface wetness, very low fertility, high topsoil carbon. Grass and heather moor, with flush and bog communities in wetter parts. Often used for rough grazing or forestry.

17: Slowly permeable seasonally wet acid loamy and clayey soils. Loamy and clayey, impeded drainage, low fertility, medium topsoil carbon. Seasonally wet pastures and woodlands. Often under grass pasture, sometimes arable.

18: Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils. Loamy and clayey, impeded drainage, moderate fertility, low topsoil carbon. Seasonally wet pastures and woodlands. Often under grass pasture, sometimes arable.

19: Slowly permeable wet very acid upland soils with a peaty surface. Peaty or humose loamy, impeded drainage, low fertility, high topsoil carbon. Grass moor and some heather with flush and bog communities in wetter parts. Often used for rough grazing or forestry.

20: Loamy and clayey floodplain soils with naturally high groundwater. Loamy and clayey, naturally wet, moderate fertility, medium topsoil carbon. Wet flood meadows with wet carr woodlands in old river meanders. Often under grass pasture, sometimes arable.

21: Loamy and clayey soils of coastal flats with naturally high groundwater. Loamy and clayey, naturally wet, lime-rich to moderate fertility, medium topsoil carbon. Wet brackish coastal flood meadows. Often under arable use.

22: Loamy soils with naturally high groundwater. Loamy, naturally wet, low fertility, low topsoil carbon. Wet acid meadows and woodland. Often under arable use, pasture where too stony or wet.

23: Loamy and sandy soils with naturally high groundwater and a peaty surface. Peaty, naturally wet, low to high fertility, medium to high topsoil carbon. Wet meadows. Mostly under arable use.

24: Restored soils mostly from quarry and opencast spoil. Loamy, variable drainage, low to moderate fertility, low topsoil carbon. Variable habitats, including agricultural use.

25: Blanket bog peat soils. Peaty, naturally wet, very low fertility, high topsoil carbon. Wet heather moor with flush and bog communities. Often used for rough grazing or forestry.

26: Raised bog peat soils. Peaty, naturally wet, very low fertility, high topsoil carbon. Raised bog communities. Often drained for grassland pasture or sometimes arable.

27: Fen peat soils. Peaty, naturally wet, mixed fertility/very low to lime-rich, medium to high topsoil carbon. Wet fen and carr woodlands. Often drained for arable and horticultural use.

UK soil class definitions: World Reference Base (Cranfield University 2024, cf FAO 2015)

1: Arenosols. Relatively young soils or soils with little or no profile development, typically very sandy.

2: Cambisols. Relatively young soils or soils with little or moderate profile development.

3: Fluvisols. Soils influenced by water, including on floodplains and tidal marshes.

4: Gleysols. Soils influenced by groundwater.

5: Histosols. Soils with thick organic layers.

6: Leptosols. Soils with limited rooting due to shallow permafrost or stoniness.

7: Luvisols. Soils with a clay-enriched subsoil, typically displaying high base status and high-activity clay.

8: Phaeozems. Accumulation of organic matter with high base status, typically marking transition to a more humid climate.

9: Planosols. Soils with stagnating water and abrupt textural discontinuity.

10: Podzols. Soils set by Fe/Al chemistry, i.e. cheluviation and chilluviation.

11: Regosols. Relatively young soils or soils with no significant profile development.

12: Stagnosols. Soils with stagnating water and structural or moderate textural discontinuity.

13: Umbrisols. Relatively young soils or soils with little or no profile development, typically with an acidic dark topsoil.

Appendix C Tree Roots Interview Questionnaire

Tree Roots Interview Questions

Part 1: Introductory questions on expertise and professional context of interviewee:

- Please can you confirm that you have received, signed and returned the ethics clearance form for this project, and are happy for this interview to be recorded for further research purposes within the project?
- Please can you confirm that you are happy for your interview responses to be attributed under your own name for the purposes of project reporting?
- Can you briefly outline your career so far and explain how/where you developed your interest/expertise in tree rooting and/or archaeology?
- Do you have any particular expertise related to specific aspects of this project? E.g., conservation of heritage assets, botany and plant science, soil science, silvicultural practices, policy frameworks for land management, etc.

Part 2: General questions tied to project research questions:

- In your experience, what effects do tree roots have on archaeological assets?
- Are there any particular tree species that you think affect archaeological assets more than others?
- If so, why do you think this might be? E.g., total rooting depth vs type of rooting structure.

Rooting structure examples: taproot / heart / surface.

- Have you noticed any relationship between rooting tendencies and particular soil types or topographic locations/environments?

Soil type examples: loose, deep well-drained soils / shallow soils over rock / intermediate loamy soils / impervious subsoils / soils with moisture retaining upper horizons / soils with wet lower horizons / drained organic rich soils / waterlogged organic rich soils.

Topographic locations/environments: riverine floodplains / bogs, marshes and fens / highland moors / lowland dry valleys / hillsides / etc.

- In your experience, are certain types of archaeological features, structures or site types are more affected by tree rooting than others?
- If so, do you think trees preferentially root towards/away from certain types of archaeological assets? E.g., organic pit fills vs buried masonry structures.
- Relatedly, do you think certain types of archaeological assets are more resistant to rooting disturbance than others?
- Have you noticed any differences in the effects of rooting between native woodlands and commercial plantations?
- Relatedly, have you noticed any differences in the effects of rooting amongst different woodland management regimes. E.g., coppicing, woodland pasturage, rotational clear cutting, no active management, etc.
- Outside of possible rooting disturbance, what other advantages/disadvantages do you think there might be for archaeological sites under tree cover? For

instance, does tree cover increase animal burrowing? Or conversely provide better protection against soil erosion?

Part 3: More focused exploration of specific case studies:

- Please could you provide us with up to three notable examples of your experience of the interaction between tree rooting and archaeological preservation?
- For each example, please provide the name and location of the site concerned, the type of land use prevalent at the site, the specific archaeological/other heritage assets present, and the degree of cover by specific tree species/woodland types.
- For each of these examples, would you say that the effects of tree rooting on the archaeological assets were positive or negative, or both?
- For each of these examples, were any actions taken to mitigate the effect/presence of tree roots, or were any plans made for such mitigation in the future?
- For each of these examples, did you encounter any conflicts of interest between forestry and archaeological specialists or other stakeholders?
- If so, how were these resolved (or not)?

Part 4: Broader discussion of impacts/future direction of project

- What do you think are the main opportunities and challenges of planting and growing trees in areas that are also of archaeological interest?
- Which policy frameworks do you currently operate within that condition your experience of dealing with the interaction between tree roots and archaeology?
- Do you think these policy frameworks provide an adequate means for archaeologists, forestry specialists and other stakeholders to understand each other and work towards common goals?
- If not, how do you think these frameworks could be amended/expanded to better support productive cross-disciplinary partnerships within tree planting projects?
- Do you think that there are broadly predictable relationships between tree species, soil types and the preservation of heritage assets that are already generally understood by heritage and/or forestry professionals?
- If so, please explain your understanding of these relationships.
- If not, do you think better understandings of these relationships would be of benefit to heritage and forestry professionals, and if so, then how could they be most usefully presented/communicated?
- What specific aspects of the relationships between tree planting/subsequent rooting and archaeological assets do you think most urgently require further investigation?
- If you could design a targeted experiment to test the interactions between tree roots and archaeological assets, how would you approach this?

APPENDIX D ONLINE QUESTIONNAIRE

"Tree Roots and Archaeology" questionnaire

We are working with the Forestry Commission on a project that aims to collect and assess evidence of the effects of tree roots on archaeology. You can read more here https://www.oxfordarchaeology.com/news/tree-roots-and-archaeology

A very important part of the project is to carry out consultation to gather evidence and experiences from a wide selection of heritage and forestry professionals on the subject and you have been identified as a key stakeholder. The survey should take around 20 minutes to complete. The questionnaire begins with some general questions about your experience of/understanding of the effects of tree roots on archaeology. You then have the opportunity to provide more detailed information on up to three sites.

By completing the survey, you give permission for the results to be shared (in anonymised form) between relevant parties at Oxford Archaeology and the Forestry Commission, as well as for the (anonymised) results to be reported in either unpublished (e.g. web posts, talks) or published (e.g. journal) outputs.

Oxford Archaeology and the Forestry Commission may contact you for further information about your survey answers. Please provide a contact email address if you are happy to be contacted. You can unsubscribe at any time.

If you have any questions about the survey, please contact communications@oxfordarchaeology.com

* Required

Background questions

1. What is your role/affiliation in the heritage sector? *

2. Where is your role/affiliation based in the UK (country, county or city)? *

3. What is your particular association with trees/archaeology? *

- ☐ Land manager
- ☐ Forestry professional
- ☐ Archaeological/heritage professional
- ☐ Archaeological contractor
- ☐ Other

General questions

4. Please provide a brief summary of your overall opinion on how tree roots interact with archaeology (e.g. they don't affect archaeology at all)

5. Specifically, what evidence/experience do you have of tree roots affecting **buried** archaeology (i.e. underground archaeological sites)?

6. Specifically, what evidence/experience do you have of tree roots affecting **structural** archaeology (i.e. masonry; earthworks etc)?

7. In your experience, are different archaeological **site** types more or less susceptible to harm from tree roots (i.e. hillfort; cemetery; Roman settlement; medieval village etc)?

8. In your experience, are different archaeological **feature** types more or less susceptible to harm from tree roots (i.e. pits; ditches; layers/deposits etc)?

9. Have you noted that there is a predictable relationship between tree species and soil type and the impact caused to archaeology by tree roots? Please explain briefly.

10. Have you noted whether any specific tree species or soil type were particularly prone to resulting in impacts to archaeology? Please explain briefly.

11. In your experience, does the presence of trees growing on top of archaeological features provide any benefits to the preservation of that feature, relative to other land uses? Please explain briefly.

12. In your experience, have you noted an increase in animal burrowing or action on archaeological sites where there are and/or were trees? Please explain briefly.

13. Have you had cause to remove trees and have you any particular notes on the effect that the roots of the trees have had on archaeology? Please explain briefly.

14. In your experience, are type(s) of woodland management more likely to impact archaeology (i.e. actively managed woodland; woodland cropped for hard/softwood timber or in a coppice regime; woodland subject to clear-felling or continuous canopy management etc)? Please explain briefly.

15. Do you know of specific examples that illustrates the interactions between tree roots and archaeology?

- ◯ Yes
- ◯ No

Specific site or example 1

This section is an opportunity to provide more detailed information on a particular site for which you have detailed information. If you have more than one example to share, please fill in a separate section for each site (Section 4 and Section 5 additional below)

16. What is the name of the site?

17. Where is the site located?

18. Is the site located in a rural or urban context?

- ◯ Rural
- ◯ Urban
- ◯ Other

19. What type(s) of investigation/research were undertaken at the site?
(i.e. archaeological excavation, survey, research project etc)

20. Were the investigation(s) at the site a commercial or non-commercial venture?

- ◯ Commercial
- ◯ Non-Commercial
- ◯ Unsure
- ◯ Other

21. What type(s) of archaeology are present at the site?
(i.e. buried archaeology, structures, monuments etc)

22. What is the land use or natural habitat of the site?
(i.e. agricultural, new plantation, regenerating woodland ancient woodland etc)

23. If known, what species of tree(s) are present at the site?

24. If known, what species of tree(s) present at the site have impacted the archaeology?

25. What type(s) of rooting are present at the site?

- [ ] Taproot (main root descending vertically from the trunk underside)
- [ ] Heart root (roots descending diagonally from the trunk)
- [ ] Surface root (large, horizontal lateral roots extending just beneath soil surface, with smaller vertical roots)
- [ ] Unsure

26. What type(s) of rooting have impacted on the archaeology?

- [ ] Taproot (main root descending vertically from the trunk underside)
- [ ] Heart root (roots descending diagonally from the trunk)
- [ ] Surface root (large, horizontal lateral roots extending just beneath soil surface, with smaller vertical roots)
- [ ] Unsure

27. Which soil type(s) are present at the site?

- [ ] Peat
- [ ] Silts/ Sand
- [ ] Loam
- [ ] Sand/ Silt clays
- [ ] Clay
- [ ] Unsure
- [ ] Other

28. What type(s) of impact of tree rooting on archaeology were observed at the site?

- [ ] Stratigraphic impact
- [ ] Structural impact
- [ ] Artefactual (finds) impact
- [ ] Environmental remains (organics; soil micromorphology etc) impact
- [ ] Osteological (human bone) impact
- [ ] Soil impact (i.e. oxygenation; erosion etc)
- [ ] Windthrow / tree clearance / similar truncation (removal) impacts
- [ ] Animal burrowing/activity impact
- [ ] Unsure
- [ ] Other

29. In reference to the previous question, please briefly describe any examples of the impact(s) observed:

30. Were any observed rooting interactions at the site considered to have a (potentially) **positive** impact on the archaeology?

- ○ Yes
- ○ No/Unsure

31. What **positive** impact(s) were observed on site?

32. What was the **positive** impact level of tree rooting on archaeology assessed at the site, on a scale from Nil/Negligible (1)–High (4)?

- 0. Unsure
- 1. Nil/Negligible no or minimal loss of: archaeological intactness (i.e. sparse root growth on a wall); and/or the significance of the site setting (i.e. no visual impediments)
- 2. Low a short-term to medium impact which: enhances archaeological intactness (i.e. roots reducing erosion or weathering); and/or enhances or restores the setting of the site (i.e. setting views)
- 3. Medium a medium to long-term impact which: enhances archaeological intactness (i.e. roots supporting earthwork stabilisation); and/or enhances or restores the setting of the site (i.e. landscape character)
- 4. High a long-term impact which completely conserves the intactness and setting of a site

33. Why have you chosen this **positive** impact level as your response?

34. Were any observed rooting interactions at the site considered to have a (potentially) **negative** impact on the archaeology?

- Yes
- No/Unsure

35. What **negative** impact(s) were observed on site?

36. What was the **negative** impact level of tree rooting on archaeology assessed at the site, on a scale from Nil/Negligible (1)–High (4)?

- 0. Unsure
- 1. Nil/Negligible no or minimal loss of archaeological intactness (i.e. sparse root growth on a wall)
- 2. Low minor loss of archaeological intactness (i.e. reversible damage to a wall)
- 3. Medium moderate loss of archaeological intactness (i.e. partial wall collapse)
- 4. High complete loss of archaeological intactness (i.e. total wall collapse)

37. Why have you chosen this **negative** impact level as your response?

38. How were the impact(s) managed, avoided and/or mitigated on site?

39. Would you like to add one more example?

- Yes
- No

Specific site or example 2

This section is an opportunity to provide more detailed information on any particular site for which you have detailed information.

40. What is the name of the site?

41. Where is the site located?

42. Is the site located in a rural or urban context?

- ○ Rural
- ○ Urban
- ○ Other

43. What type(s) of investigation/research were undertaken at the site?
(i.e. archaeological excavation, survey, research project etc)

44. Were the investigation(s) at the site a commercial or non-commercial venture?

- ○ Commercial
- ○ Non-Commercial
- ○ Unsure
- ○ Other

45. What type(s) of archaeology are present at the site?
(i.e. buried archaeology, structures, monuments etc)

46. What is the landscape and/or natural habitat of the site?
(i.e. agricultural, new plantation, regenerating woodland ancient woodland etc)

47. If known, what species of tree(s) are present at the site?

48. If known, what species of tree(s) present at the site have impacted the archaeology?

49. What type(s) of rooting are present at the site?

- [ ] Taproot (main root descending vertically from the trunk underside)
- [ ] Heart root (roots descending diagonally from the trunk)
- [ ] Surface root (large, horizontal lateral roots extending just beneath soil surface, with smaller vertical roots)
- [ ] Unsure

50. What type(s) of rooting have impacted on the archaeology?

- [ ] Taproot (main root descending vertically from the trunk underside)
- [ ] Heart root (roots descending diagonally from the trunk)
- [ ] Surface root (large, horizontal lateral roots extending just beneath soil surface, with smaller vertical roots)
- [ ] Unsure

51. Which soil type(s) are present at the site?

- [ ] Peat
- [ ] Silts/ Sand
- [ ] Loam
- [ ] Sand/ Silt clays
- [ ] Clay
- [ ] Unsure
- [ ] Other

52. What type(s) of impact of tree rooting on archaeology were observed at the site?

- [ ] Stratigraphic impact
- [ ] Structural impact
- [ ] Artefactual (finds) impact
- [ ] Environmental remains (organics; soil micromorphology etc) impact
- [ ] Osteological (human bone) impact
- [ ] Soil impact (i.e. oxygenation; erosion etc)
- [ ] Windthrow / tree clearance / similar truncation (removal) impacts
- [ ] Animal burrowing/activity impact
- [ ] Unsure
- [ ] Other

53. In reference to the previous question, please briefly describe any examples of the impact(s) observed:

54. Were any observed rooting interactions at the site considered to have a (potentially) **positive** impact on the archaeology?

- ○ Yes
- ○ No/Unsure

55. What **positive** impact(s) were observed on site?

56. What was the **positive** impact level of tree rooting on archaeology assessed at the site, on a scale from Nil/Negligible (1)–High (4)?

- ◯ 0. Unsure
- ◯ 1. Nil/Negligible no or minimal loss of: archaeological intactness (i.e. sparse root growth on a wall); and/or the significance of the site setting (i.e. no visual impediments)
- ◯ 2. Low a short-term to medium impact which: enhances archaeological intactness (i.e. roots reducing erosion or weathering); and/or enhances or restores the setting of the site (i.e. setting views)
- ◯ 3. Medium a medium to long-term impact which: enhances archaeological intactness (i.e. roots supporting earthwork stabilisation); and/or enhances or restores the setting of the site (i.e. landscape character)
- ◯ 4. High a long-term impact which completely conserves the intactness and setting of a site

57. Why have you chosen this **positive** impact level as your response?

58. Were any observed rooting interactions at the site considered to have a (potentially) **negative** impact on the archaeology?

- ◯ Yes
- ◯ No/Unsure

59. What **negative** impact(s) were observed on site?

60. What was the **negative** impact level of tree rooting on archaeology assessed at the site, on a scale from Nil/Negligible (1)–High (4)?

- 0. Unsure
- 1. Nil/Negligible no or minimal loss of archaeological intactness (i.e. sparse root growth on a wall)
- 2. Low minor loss of archaeological intactness (i.e. reversible damage to a wall)
- 3. Medium moderate loss of archaeological intactness (i.e. partial wall collapse)
- 4. High complete loss of archaeological intactness (i.e. total wall collapse)

61. Why have you chosen this **negative** impact level as your response?

62. How were the impact(s) managed, avoided and/or mitigated on site?

63. Would you like to add one more example?

- Yes
- No

Specific site or example 3

This section is an opportunity to provide more detailed information on any particular site for which you have detailed information.

64. What is the name of the site?

65. Where is the site located?

66. Is the site located in a rural or urban context?

- Rural
- Urban
- Other

67. What type(s) of investigation/research were undertaken at the site?
(i.e. archaeological excavation, survey, research project etc)

68. Were the investigation(s) at the site a commercial or non-commercial venture?

- Commercial
- Non-Commercial
- Unsure
- Other

69. What type(s) of archaeology are present at the site?
(i.e. buried archaeology, structures, monuments etc)

70. What is the landscape and/or natural habitat of the site?
(i.e. agricultural, new plantation, regenerating woodland ancient woodland etc)

71. If known, what species of tree(s) are present at the site?

72. If known, what species of tree(s) present at the site have impacted the archaeology?

73. What type(s) of rooting are present at the site?

- [ ] Taproot (main root descending vertically from the trunk underside)
- [ ] Heart root (roots descending diagonally from the trunk)
- [ ] Surface root (large, horizontal lateral roots extending just beneath soil surface, with smaller vertical roots)
- [ ] Unsure

74. What type(s) of rooting have impacted on the archaeology?

- [ ] Taproot (main root descending vertically from the trunk underside)
- [ ] Heart root (roots descending diagonally from the trunk)
- [ ] Surface root (large, horizontal lateral roots extending just beneath soil surface, with smaller vertical roots)
- [ ] Unsure

75. Which soil type(s) are present at the site?

- [ ] Peat
- [ ] Silts/ Sand
- [ ] Loam
- [ ] Sand/ Silt clays
- [ ] Clay
- [ ] Unsure
- [ ] Other

76. What type(s) of impact of tree rooting on archaeology were observed at the site?

- [ ] Stratigraphic impact
- [ ] Structural impact
- [ ] Artefactual (finds) impact
- [ ] Environmental remains (organics; soil micromorphology etc) impact
- [ ] Osteological (human bone) impact
- [ ] Soil impact (i.e. oxygenation; erosion etc)
- [ ] Windthrow / tree clearance / similar truncation (removal) impacts
- [ ] Animal burrowing/activity impact
- [ ] Unsure
- [ ] Other

77. In reference to the previous question, please briefly describe any examples of the impact(s) observed:

78. Were any observed rooting interactions at the site considered to have a (potentially) **positive** impact on the archaeology?

- ○ Yes
- ○ No/Unsure

79. What **positive** impact(s) were observed on site?

80. What was the **positive** impact level of tree rooting on archaeology assessed at the site, on a scale from Nil/Negligible (1)–High (4)?

- ◯ 0. Unsure
- ◯ 1. Nil/Negligible no or minimal loss of: archaeological intactness (i.e. sparse root growth on a wall); and/or the significance of the site setting (i.e. no visual impediments)
- ◯ 2. Low a short-term to medium impact which: enhances archaeological intactness (i.e. roots reducing erosion or weathering); and/or enhances or restores the setting of the site (i.e. setting views)
- ◯ 3. Medium a medium to long-term impact which: enhances archaeological intactness (i.e. roots supporting earthwork stabilisation); and/or enhances or restores the setting of the site (i.e. landscape character)
- ◯ 4. High a long-term impact which completely conserves the intactness and setting of a site

81. Why have you chosen this **positive** impact level as your response?

82. Were any observed rooting interactions at the site considered to have a (potentially) **negative** impact on the archaeology?

- ◯ Yes
- ◯ No/Unsure

83. What **negative** impact(s) were observed on site?

84. What was the **negative** impact level of tree rooting on archaeology assessed at the site, on a scale from Nil/Negligible (1)–High (4)?

- ◯ 0. Unsure
- ◯ 1. Nil/Negligible no or minimal loss of archaeological intactness (i.e. sparse root growth on a wall)
- ◯ 2. Low minor loss of archaeological intactness (i.e. reversible damage to a wall)
- ◯ 3. Medium moderate loss of archaeological intactness (i.e. partial wall collapse)
- ◯ 4. High complete loss of archaeological intactness (i.e. total wall collapse)

85. Why have you chosen this **negative** impact level as your response?

86. How were the impact(s) managed, avoided and/or mitigated on site?

Section

87. Do you have any further comments, ideas or suggestions for the project?

APPENDIX E ETHICS FORM

TREE ROOTS AND ARCHAEOLOGY:
EXPERT EXPERIENCES OF INTERACTIONS BETWEEN TREE ROOTS AND ARCHAEOLOGY
Participant information and consent form

XX – [INTERVIEWER], Oxford Archaeology

Tree Roots and Archaeology is a collaborative research project between Oxford Archaeology and the Forestry Commission. We are aiming to gather current published information (in print and online) about the relationship between tree roots and archaeology, and to garner expert opinions and practical experiences of this relationship from heritage and forestry professionals. The notion that tree roots are a risk to archaeology is currently a key guiding principle in landscapes of known archaeological interest. Archaeological features are typically left as open spaces in woodland; woodland creation proposals are sometimes also rejected or reduced in scale on this basis. However, research into this topic has been piecemeal and no systematic study has been undertaken of how tree roots potentially impact upon archaeology. The project seeks to address this gap in evidence within the context of the ambitions tree planting targets for the current Environmental Improvement Plan

The research, interviews and report will be carried out by Oxford Archaeology. The project is led by Ianto Wain at Oxford Archaeology, with guidance from colleagues at the Forestry Commission and from an expert academic panel. It is funded by the Forestry Commission.

Interviews will be carried out with heritage and forestry professionals to gather information focused on the practitioners' knowledge of the relationship between tree roots and archaeology, and to gather practical examples of this relationship. The interviews follow on from an initial literature review and from a questionnaire circulated across a wider set of practitioners. Individuals from a representative set of stakeholder organisations with substantial experience of this topic were selected for interview.

Key research questions include:

- What evidence exists to show the presence of trees (and of tree roots in particular) harming buried archaeological features?
- Are different archaeological feature types more or less susceptible to harm from tree roots?
- Is there a predictable relationship between tree species and soil type and the impact caused to buried archaeology by tree roots?
- Does the presence of trees growing on top of archaeological features provide any benefits to the preservation of that feature, relative to other land uses?

The interview findings will be used alongside those from questionnaires to compile a short report summarising current perceptions and experiences of interactions between tree roots and archaeology across the forestry and heritage sectors. The report will be available in Spring 2024. The report will be used to guide future research and management in Forestry Commission settings.

Interviews will take place both online and in person, depending on the location and availability of interviewees. They will be recorded using the recording function on Microsoft Teams (or Zoom if preferred) Recordings will not be shared outside of Oxford Archaeology and will be stored securely by Oxford Archaeology until the completion of the project and publication of the report. The material will then be discarded.

Oxford Archaeology is a charitable organisation and processes personal data for the purposes of carrying out research in the public interest. We endeavour to be transparent about its processing of your personal data and this information sheet should provide a clear explanation of this. If you do have any queries about how your personal data will be processed that cannot be resolved by the research team, further information may be obtained by emailing info@oxfordarchaeology.com

1. I understand that my participation is voluntary, and that I am free to withdraw at any time without giving any reason and without my legal rights being affected.	
2. I understand the findings may be looked at by other individuals at Oxford Archaeology and the Forestry Commission.	
3. I understand that taking part involves audio and video recordings that will be used by Oxford Archaeology to compile a report for the Forestry Commission that will be in the public domain.	
4. I agree to take part in the above research.	

Name of participant **Date** **Signature**

Name of researcher taking consent **Date** **Signature**

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