Forest Research
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Trees and Forestry on Archaeological sites in the UK:

A review document

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Summary

This document is a part of an ongoing review into impacts of tree growth and woodland management practices on archaeological sites in Great Britain. It is not a policy document, but is designed to outline many of the issues and promote discussion and research on the subject matter.

Approximately 11 % of Great Britain is covered by woodland or forest, and it is Government policy to see this expand significantly. It is inevitable that proposals for new tree cover will involve land with archaeological potential. Equally, many archaeological sites already exist in wooded environments and advice is often needed by landowners on their management.

The Forestry Commission is committed to the conservation of important archaeological sites (not just scheduled monuments) in accordance with the UK Forestry Standard. This discussion document is part of the Forestry Commission's ongoing commitment to increasing knowledge and awareness and takes a new look at some of the past and present issues of tree growth and management on archaeological sites.

Very little direct research has been carried out on tree/archaeology interactions, but the damaging effects of cultivation techniques such as deep ploughing, ripping and drainage are well known. However, many archaeologists believe that in some circumstances, some form of continued tree cover may be an appropriate management option.

Many of the issues arising from archaeology under woodland management have been grouped into three main categories, each forming a separate chapter of this document:

- The impacts of new plantings on land that has not had recent woodland cover
- the effects that tree retention and therefore growth and management will have on archaeological evidence
- site management issues following tree removal

This document **does not** recommend tree planting or retention at the expense of important sites or their archaeological/aesthetic settings, but reviews current knowledge, identifies areas where little is known, and suggests topics for research. This will allow more informed management decisions to be made.

Due to the diverse nature of both the remains and the environment in which they occur, it is recommended that the management practice for any site is determined by its individual merits. On appropriate sites, some tree cover may be a practical option for both the landowner and the archaeologist.

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Chapter 1

Introduction

1.1. Background to document

Archaeological features are an important part of our cultural heritage and the tools to understanding human history and development. In England alone, there is an average density of 2.25 archaeological monuments per km^2 (Darvill and Fulton, 1998). Considering there are currently some 27,130 km^2 (2.7 million ha) of land in Great Britain under woodland management[i] it is inevitable that a significant part will contain sites of archaeological importance. These are recognised as a valuable resource by the Forestry Commission whose policy states that sites of importance should be conserved (Forestry Commission, 1995).

Any archaeological evidence is part of a dynamic environment and its management can be a complex issue. Often, the first difficulty for a woodland manager is to identify any relevant features. While many are mapped or recorded, locating them on the ground may be problematic. The development of a practical survey programme for woodlands as both a major challenge and priority for the next few years (Yarnell, 1999) and has led to some specific studies such as those in the Forest of Dean and Northants Forest District.

In many woodland areas, active tree removal has occurred as the preferred method of archaeological site preservation and is often appropriate (Crow and Yarnell, 2002). However, where former woodland management has been withdrawn from large areas, scrub, gorse (*Ulex europaeus*) and bracken (*Pteridium aquilinum*) may invade and pose as great a threat (See Chapter 4). "The value of woodland for the long-term preservation of archaeological monuments is not well known, and at best only partly investigated" (Darvill and Fulton, 1998). Nonetheless, on many sites tree removal has been both appropriate and successfully carried out.

1.2. Forests of History- The types of archaeological remains found within Britain's woods and forests are very diverse and for the purpose of this introduction, they have been broadly grouped together after Bannister (1998):

- EXTANT FEATURES - including many types of **earthwork**, **cairns**, **standing stones**, **buildings** and **industrial remains**,

- SUBSURFACE FEATURES - including **post-holes**, **buried soils, palaeoenvironmental deposits** and **occupation layers**,
- SCATTERS - including **pottery**, **flint** and other **mineral workings** (often marked as "antiquarian find" on old stock maps).

Many features such as saw pits and charcoal platforms are directly related to the history of their surrounding woodland which, when managed sympathetically, provides the correct context and enhances their value. Conversely, other monuments have no relationship with any surrounding woodland environments. Examples of the latter include military camps and burial mounds. The terms archaeology "of woodland" and "in woodland" are often used to distinguish them. The Forestry Commission is committed to conserving both.

Extant features

By their very nature, the most common known features are those above ground, of which earthworks and burial mounds are the most abundant. Earthworks vary greatly, from hillforts and Roman roads to simple boundary ditches, drainage systems and banks. There are many types of smaller earthwork in British woodlands, but they are often subtle and less obvious. Most are not legally protected, many unmapped, and others frequently unrecognised as archaeological features. Bannister (1998) gives the example of a long ditch and parallel bank, and questions whether such a feature is a parish boundary, a field bank, a wood bank, a lynchet, part of a drainage or ridge and furrow system. If the latter, is it modern or medieval? In some parts of the country, earthworks of similar dimensions may have been created through 20th century (or earlier) military manoeuvres or forest operations. Thus, even to an experienced archaeologist, correct identification of such earthworks can be problematic.

Subsurface features

These are less well-known features and many are undetectable without specialist survey equipment or extensive excavations. This is emphasized by projects such as "The Monuments at Risk Survey of England" (Darvill and Fulton, 1998), which concentrated on distinctive above ground features. However, this survey report anticipated the need for work in other areas and states that "the emphasis on monuments as the focus of interest will consequently decline". Barclay (1992_a) also compared some archaeological sites with icebergs, as "much more lies below the surface than is immediately apparent". For example, post-holes and buried

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[i] Total Forestry Commission and Private woodland as of March 2000 (Forestry Commission, 2001)

soils are often only visible through subtle changes in soil. Others, such as building foundations or filled ditches may be visible from the air as crop marks in arable fields. Such features are difficult to locate under woodland. It is therefore reasonable to assume that in the past, many subsurface features will have been inadvertently cultivated and planted.

Buried artefacts are included in this group due to their incorporation into the soil profile. In addition to artefacts, the term “ecofacts” is sometimes used as an abbreviation for palaeoenvironmental indicators. Both terms are used within this document.

Scatters

These are objects lying on or near the soil surface and may indicate a former land use, temporary or permanent occupation or industrial sites. Most Palaeolithic and Mesolithic sites do not contain any extant or subsurface features and are only known through artefact scatters. A major part of this type of archaeology is in the interpretation of the distribution patterns which in turn identify areas of former activity (Allen, 1991). While tree growth may have little direct impact on scatters, forest operations such as cultivation will have a more significant impact. Where artefacts lay buried, root growth, as with any bioturbation, can move small remains below ground potentially altering their interpretation.

The groupings used above are very general and more specific terms will be used in this document where appropriate.

Chapter 2

Establishment of new woodlands

2.1. Site preparation

The silvicultural practice used to establish woodland or forest cover will vary with the site conditions. Before any woodland cover can be established, some cultivation may be required to promote optimum root growth. Drainage, topography, fertility, previous land use and soil type all influence the choice of tree species and any necessary site preparation.

The most frequently reported mechanism of damage to archaeological features is ploughing and has resulted in several studies of agricultural landscapes. For forestry, this has been most widespread in the uplands to create a raised weed-free planting position, particularly on wetter sites. A plough is designed to move soil vertically then horizontally, forming a ridge of soil with mixed horizons that increases drainage and aeration, thus aiding root development (Crowther *et al*., 1991; Hart, 1991). On drier soils or where restocking is occurring, the use of scarifiers or mounders is preferred. These also provide improved planting conditions but with less ground disturbance[ii].

Most British trees are unable to grow in soils that are permanently waterlogged and drainage may be necessary, especially in the uplands where poorly drained gleys and peaty soils are common. Deep ploughing is less common today and discouraged by the Forestry Commission's *Forests and Water Guidelines* (2000). With the increased ability of woodland managers to diversify and select trees for nature conservation, site aesthetics, community woodlands or other non-commercial benefits, species may now be selected that suit the unaltered site.

Archaeological considerations - process involving substantial ground disturbance have the potential to cause damage to any archaeological remains buried near the surface. For this reason, the Forestry Commission's *Forests and Archaeology Guidelines* (1995) state that no area identified for archaeological conservation should be ploughed, ripped or scarified. On some larger sites such as field systems or cairnfields that may cover several hectares, some degree of tree cover may be acceptable. Here, whether any sub-surface archaeological evidence exists is likely to be unknown without geophysical survey or trial excavation.

[ii] Mounders are more commonly used on poorly drained soils, whereas scarifiers are used on well-drained soils (Crowther *et al.*, 1991).

Typically, such excavations are of less than five percent of the total land area and may miss important archaeological evidence. Geophysical surveys can become expensive on large areas of land, their results may be inconclusive and still require excavations.

Site drainage raises concerns over the loss of any organic remains that are typically well preserved in the anaerobic conditions of waterlogged soils and peats. Drainage will have a greater effect on soil water content compared to tree growth. However, before any decisions can be made over the management of such a site, information on the depth and extent of archaeological evidence and water table depths should be sought. The possibility of vertical plastic membranes to retain the water in the immediate area of the remains may also be considered. For example, at Stonea Camp in Cambridgeshire, membranes of this type have been inserted to a depth of 2 m to slow down the desiccation caused by water movement downslope (Taylor, 1994). If global temperatures continue to increase, and climatic extremes become more common, action of this kind and other water management methods may become more commonplace. The archaeological importance of waterlogged and peat covered areas is recognised by the Forestry Commission (Patterson and Anderson, 2000). River valleys and floodplains have provided desirable settlement locations since prehistory and many may have a high archaeological potential. Any expansion of floodplain forestry or wet woodlands may therefore have implications for the buried archaeological resource.

2.2. Planting and tending

Whilst tree planting can be mechanised, it is still predominantly a manual task and involves relatively minor soil disturbance. Direct sowing is of seed is less common and most young trees are derived from nursery-grown stock where they have been subjected to undercutting or transplanting. One of the primary functions of both these processes is to remove any taproots and stimulate more lateral growth (Aldhous and Mason, 1994). Deliberate planting may therefore be less detrimental than natural regeneration on sites with deeper archaeological deposits. Competition from weeds can be a major problem when establishing young trees and the most common method of control is the application of herbicides in the immediate vicinity of each young tree. Manual weeding is relatively expensive and mechanical methods are often ineffective as the weeds are cut and not pulled from the ground (Hart, 1991). Additionally, establishment on poor soils may require fertilizer applications (Taylor, 1991), commonly in mineral form, but occasionally as organic wastes, such as sewage sludge and cake sludge.

Archaeological considerations- significant physical damage to archaeological sites through the direct action of tree planting is unlikely to occur as the ground disturbance is minimal. Any chemical effects on buried remains due to the application of either herbicide or fertiliser is difficult to summarise as their chemical compositions vary considerably. Of the mineral fertilisers, rock phosphate (Apatite) is the most commonly applied. This is very similar in chemical composition to bone and teeth and its application may even be beneficial in the preservation of such remains (Crow, 2002). Potassium salts (chloride or sulphate) are both highly soluble and are unlikely to exist for a long period in a well-drained soil. Nitrogen is applied in the form of ammonium nitrate or urea, and such compounds are known to acidify soil. Urea is the more commonly used, but none of the fertilisers are applied in large amounts in forestry. Nitrogenous compounds are again readily broken down in the soil.

Herbicides also vary in composition and products that are more species selective are constantly being developed. They are usually organic based molecules that interrupt enzyme function and block metabolic pathways. Some such as “Glyphosate” are contact herbicides that are inactivated by soil contact and quickly broken down. Others applied in pellet form to the soil have a longer lifespan. Some of these compounds are acidic and may be corrosive to some archaeological evidence, but are applied at low concentrations per unit area.

2.3. **Species selection**

Where trees are to be planted upon or near an archaeological site, the choice of species will be an important issue, but may be restricted by the environmental conditions. Trees produce roots to provide support, water, nutrients and act as a food storage organ. Root distribution can be extensive and inevitably, subsoil archaeological evidence can be at risk. The interactions of roots with archaeological resource depends on many factors such as the type of evidence, soil, woodland density, management tree age and species. Genetic influences on rooting habit do exist, but the dominant effect on rooting structure will be environmentally based. Opportunities to examine the entire root systems of mature trees are rare, however storms such as those in 1987 produced many windthrown trees that allowed root plate dimensions to be surveyed by the Royal Botanical Gardens at Kew (Figure 2.1).

A summary of the root plate data is shown Appendix 2.

Dobson and Moffat (1993) made some generalisations on the rooting characteristics of major woodland species (Table 1.1.). Characteristics were studied for different species of natural regeneration, grown on well aerated sandy soils and grouped into three different types[iii].

- taproot, where a strong main root descends vertically from the underside of the trunk.
- surface roots, where large horizontal lateral roots extend below the surface, from which smaller roots descend vertically.
- heart root, where large and small roots descend from the trunk diagonally into the soil.

Table 1.1. Rooting information and relative water demands (see p. 25) for some common tree species.

Species	**Typical root architecture**	**Typical root depth (m)**	**Mechanical root penetration**	**Water requirements** 1=lowest 6=highest
Ash	Surface	1.1	Medium	2-4
Aspen	Surface	1.3	High	4-6
Birch	Heart	1.8	Medium	1-2
Beech	Heart	1.3	Low	2-3
Common alder	Heart/surface	2.0	High	2
Corsican pine	Tap	-	Medium	1
Douglas fir	Heart	2.0	High	1-2
English oak	Tap	1.5	High	3-6
Eucalyptus	-	-	-	5-6
European larch	Heart	2.0	High	1
Hornbeam	Heart	1.6	Medium	2
Japanese larch	Heart	-	Medium	1
Lime	Heart	1.3	Low	3-4
Norway maple	Heart	1.0	-	2-3
Norway spruce	Surface	2.0	Low	1
Poplar	-	-	-	4-6
Red oak	Heart	1.6	Medium	3-6
Scots pine	Tap	2.1	High	1
Sessile oak	Tap	1.5	High	3-6
Silver fir	Tap	2.0	High	1
Sycamore	Heart	1.3	Low	2-3
White pine	Surface	1.7	Low	1

(Data adapted from from Dobson and Moffat, 1993; McCombie, 1993 and Biddle, 1998).

[iii] Naturally grown trees and not established from undercut nursery stock.

Figure 2.1. Storm blown tree showing root plate typical of that found during the Kew survey.

Jones (1998) suggested that the use of species that favour a more vertical root system, such as oak, may be beneficial in the stabilisation of earth banks whereas surface rooting trees may minimise surface soil erosion or be used to avoid deeper archaeology.

Table 1.1. and Appendix 2 can only be used as a guide to species, because the environmental conditions upon a site will strongly influence the choice, and the subsequent rooting system.

CHAPTER 3.

Retention of woodland cover on archaeological sites and its management.

Considerable changes have been made in forestry practice since the deep ploughing referred to by Jackson (1978). The Forestry Commission was originally established to form a national timber reserve, but today multipurpose forestry allows more flexibility in management.

While woodland may be tolerated on some archaeological sites, the retention of tree cover may also be desirable for its own historical value. For example where archaeological evidence is directly associated with past woodland management or sites occur in areas of ancient woodlands. With sensitive management, tree cover upon or surrounding suitable types of archaeological site could provide long term, low cost, physical protection. Forests have prevented the destruction of archaeological sites from intensive agriculture or commercial development (Darvill, 1987; Macinnes, 1997), and archaeological and forestry literature refer to well preserved remains[iv] under woodland. Examples include:-

> "… many sites recorded on the Ordnance Survey second edition County series 25 inch maps, dating from 1912-1928, which had been written-off by modern O.S. fieldworkers as destroyed by afforestation (and hence omitted from modern maps) survived as originally shown, albeit planted over with trees. These monuments could be rediscovered"…. "Although often noted as a destructive agency, the early forest plantings, undertaken before the use of deep ploughing, have actually preserved many archaeological landscapes which would have otherwise almost certainly have been lost to agricultural improvements and intensification". (Lee, 1995).
>
> Following joint site inspections by Forest Enterprise and English Heritage, one site was described "The monument is in the main covered with ash natural regeneration of varying ages, some ash coppice of considerable age also exists. The tree cover has not caused any significant damage". (Wansdyke monument-Forestry Commission, 1998_c).

Figure 3.1. shows a section of a tree covered hillfort where the well preserved form of the ramparts is often attributed to the long-term tree cover. However, what is not known is how

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[iv] It is recognised that these references deal with monument form, and that impacts below ground have often not been investigated.

such land management has affected and below ground remains. This chapter will examine the various ways in which tree growth could influence the preservation of archaeological evidence.

Figure 3.1. A well-preserved monument? – rampart and ditch section of a tree covered hillfort

3.1. Published examples of tree induced archaeological damage.

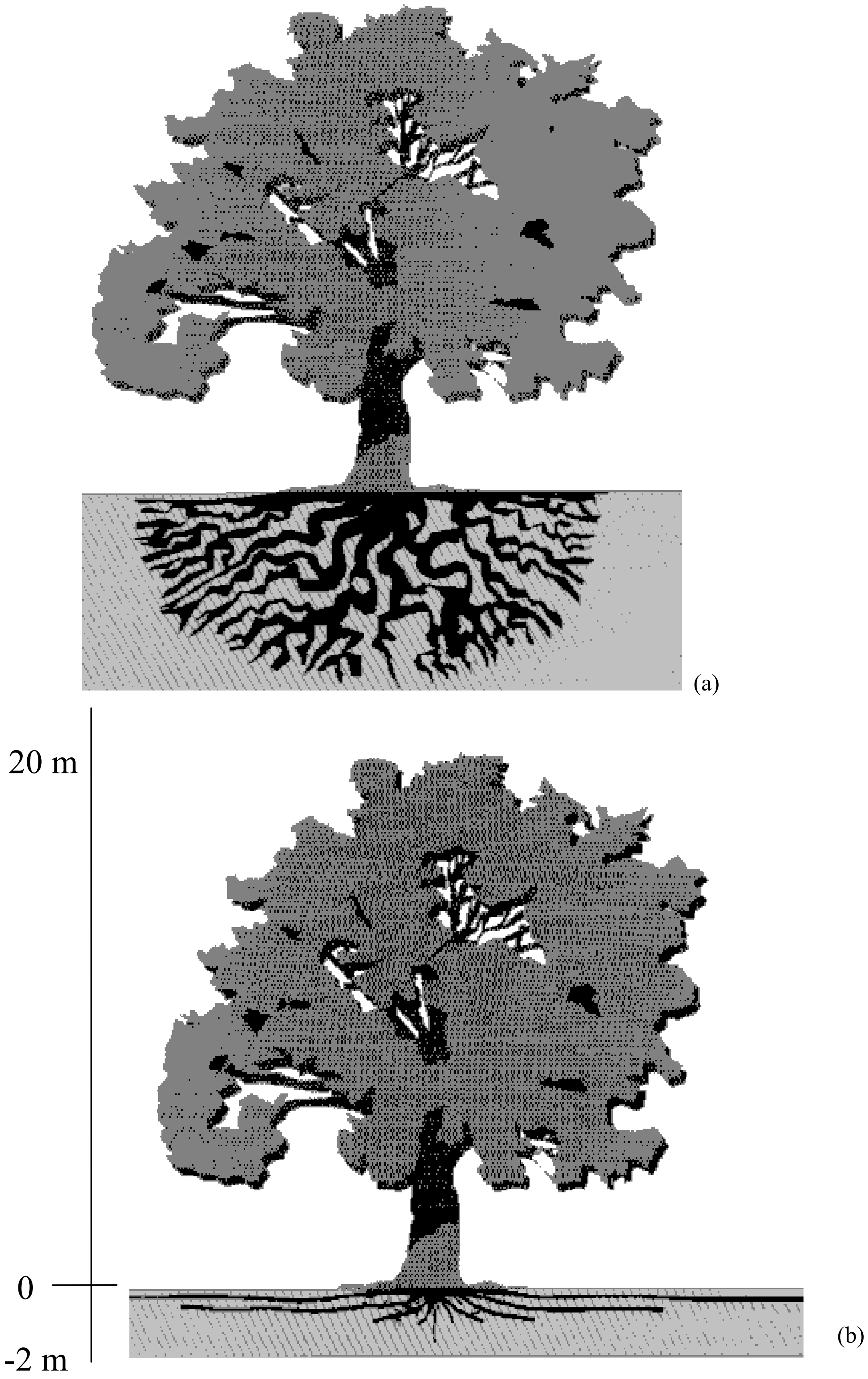
While the archaeological literature contains examples of site damage through forest operations (Jackson, 1978), there are few that give detail on the direct impacts of tree growth. Tree roots are rarely recorded during archaeological excavations and few references are made to them in published reports. For example, the Iron Age hillfort at Danebury in Hampshire, has had extensive woodland cover and excavations occurred annually on the monument between 1969 and 1988 (Cunliffe and Poole, 1991). At the time of the Cunliffe and Poole report, 0.9 ha (17% of the fort interior) remained covered with mature beech. By 1988, 3.1 ha (57.3 % of the interior) had been excavated. Six volumes have been produced to form the Danebury Report (Cunliffe, 1995) but references relating to tree growth or cover are very few. 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. The woodland management plan at the time (1969) envisaged a period of felling and timber removal. Concerns were expressed within volume one, over the trafficking required through the original Iron Age entrance to enable timber extraction. During the reporting of subsequent excavations, little more was mentioned on how roots impacted on the archaeological evidence or its interpretation.

Tree roots were encountered during the excavations but no systematic recordings were made (Cunliffe pers. comm.). However, 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 20 cm 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 2-3 m in diameter, to a depth of 0.6-1.0 m.

The aim of the Danebury project was to study, interpret and record the archaeology of the site and not examine the rooting habit of mature beech trees. It is therefore not surprising that published references to the roots were few. The field observations provide useful information and clearly, any archaeological evidence located within shallow deposits and in close proximity to a mature tree is at risk of disturbance or damage. One report was commissioned to look specifically at the impacts of forestry on a fort, settlement and field system at Tamshiel Rig, in the Scottish Borders (Cressey, 1996). This joint Historic Scotland and Forestry Commission funded project analysed the effects of the cultivation methods used prior to afforestation, and the subsequent rooting impacts. Cressey found that root activity had effected some archaeological evidence but the extent of damage was clearly dependent on the proximity to the trees. The report concluded that the worst site damage was caused during cultivation, and that root induced problems were more local. The risk to near surface archaeological evidence directly from tree roots is therefore also related to the stand density (the number of trees per hectare). Comparable findings were reported by a similar study of a settlement at Glen Brein, Inverness-shire (Hanley and Wordworth, 1997). The effect of forest cover on archaeological remains depends upon many variables and both reports identified the need for further research on a wider range of tree species, soil types and archaeological evidence.

Figure 3.2.

The commonly held idea of a tree’s root system (a) and a more realistic representation (b).



3.2. The effects of tree roots on soil structure and stability

Roots provide a tree with structural support, water, nutrients and act as a food storage organ. They may inevitably threaten subsoil archaeology that is situated close to the stem. However, a common misconception is that the volume of root underground reflects that of the trunk and branches above (Dobson, 1995) (see Figure 3.2a). Typically, trees have relatively shallow but wide-spread root systems (Dobson and Moffat, 1993; Dobson, 1995). It is unusual for roots to penetrate to a depth greater than 2 m, with 80-90 % found within the top 60 cm of the soil profile. Of the 4511 wind thrown trees surveyed by Cutler, Gasson and Farmer (1990) after the 1987 October storm, only 2.4 % were found to have tap roots (much of this figure was attributed to the American hickories (*Carya* species), a species that favours tap root development). However, it is possible that any trees with deeper roots were less affected by the 1987 storm and thus excluded from the survey. Summary data from the storm survey are given in Appendix 2. A more accurate representation of tree roots can be seen in Figure 3.2b.

A study of a range of plant species and soils by Bauhus and Messier (1999) indicated a difference in the rooting habit of conifers compared to deciduous trees, understorey shrubs and herbs. In disturbed soil, they found that conifer root architecture showed a relatively shallow root system comprised of slow growing, coarse roots. In contrast, deciduous trees, shrubs and herbs colonized favourable soil environments to a larger extent maintaining highly ramified but finer roots to exploit a greater soil volume. While there are some species-specific rooting characteristics, the primary influences on rooting habit are those of silvicultural practice and soil conditions (environmental). Dobson and Moffat (1993) classified these environmental issues into four groups:

- Mechanical resistance - Roots are unable to grow far into soil horizons with a high bulk density. In addition to layers of bedrock or excessive stoniness, fine sands, ironpans and many clays may also compact to resist root penetration.
- Aeration - Virtually all common tree species found within Britain have roots that need oxygen to respire. For most tree species, when the oxygen falls below 10-15 % in a soil, root growth is inhibited and stops completely at 3-5 %. Such conditions occur when oxygen in the soil is replaced by more soil (compaction), water or other gasses such as carbon dioxide, hydrogen sulphide or methane.
- Fertility – Infertile soils with a low fertility produce root systems which are long, poorly branched and shallow, whereas fertile sites produce more vigorous, well branched roots that may descend deeper into the soil. Roots proliferate in areas especially rich in nitrogen and phosphorus which tend to be the upper organic-rich soil horizons.

- Moisture.- Waterlogged soils results in poor gas exchange thus depleting the soil of oxygen and will eventually lead to anaerobic conditions and subsequent root death. Excess water usually results in the formation of a shallow root system. Drought conditions have also produced some trees with shallow roots and this is believed to increase interception of any moisture near the soil surface. If there is a deeper sub-surface supply of water, roots may well exploit it providing the soil conditions are suitable at that depth for root penetration and respiration.

Archaeological considerations - many buried archaeological remains have a high nutrient content and constitute attractive loci for biological activity (Goldberg and Macphail, 1989). These will inevitably become exploited (under favourable environmental conditions) by soil fauna and the roots of any plant species, leading to possible physical displacement or chemical alteration. The physical and chemical properties of both the archaeological evidence and the surrounding soil will have a large influence on the degree of exploitation. Examples of issues regarding root distribution and soil stability are given below:

- Concerns have been expressed over a tree's ability to seek moisture-retaining deposits under a rubble or chalk capped barrow and invade the important cultural and paleo-environmental horizon (Allen, pers. comm. (Wessex Archaeology)). One example of rooting preference was seen at Boscombe Down, Amesbury, where Romano-British wells, comprising of vertical shafts cut into rock 3-4 m deep were lined by a root mat several centimetres thick. This was not seen to be detrimental to the feature, nor seriously to the artefacts (Allen, pers. comm.). This site occurred over a chalk bedrock which is freely draining, difficult for roots to penetrate and typically covered only by a thin rendzina soil. Under such conditions it may not be surprising that the roots have favoured the wells as they may offer an increased moisture availability and allow better anchorage for the tree above. The site conditions have had a major influence on the development of the tree root system. While hydrotropism (positive root growth towards a source of water) may have contributed to the example above, no corresponding tropism is known to exist for nutrients and thus nutrient rich archaeological deposits will not "attract" roots. However, if such a deposit is randomly encountered by the roots from any type of plant, they are likely to proliferate and exploit it, especially if surrounded by a less fertile soil environment.

- Jones (1998) referred to trees causing a load at the top of earthwork slopes resulting in the banks mechanical failure. However, he continued to recommend woodland as a stable form of ground cover providing appropriate species and management are considered.

  > "Many sites now under grass cover have been wooded at some stage in their land management history and they have better overall surface condition from this stabilizing cover of former woodland. Today we admire the condition of a particular earthwork but fail to recognise that this is historically due to a former woodland". (Jones, 1998).

Due to logistical problems, biological studies of mature tree root systems that have not been upheaved are few and restricted to only some species and soil types. Most of the data collected on root dimensions is therefore derived from windblown or mechanically lifted root plates. Although few roots were found to extend beyond 1.5 m depth, archaeological evidence typically occurs within this depth, and where important, tree planting is not recommended. Tree cover inevitably complicates both archaeological surveys and excavations and this combined with a range of other reasons has resulted in relatively fewer studies in wooded areas compared to other rural environments. Therefore, published observations of root occurrence during archaeological excavations are few, and a systematic recording of their presence, extent and impact would be advantageous.

3.3. The physical and chemical effects of roots on buried remains

Buried archaeological remains are diverse in their chemical composition. Some are of organic origin e.g. bone, shell, pollen, plant debris and animal remains, others are of mineral origin for example flint, ceramics, glass, metal workings and masonry. Similarly, the sizes of any remains can vary from buried landscapes and soils, occupation layers and foundations to microscopic diatoms and pollen grains. Different environmental conditions favour the preservation of different types. Waterlogged soils will preserve many types of organic and environmental evidence, bone and shell are better protected by alkaline soils and pollen by acidic conditions (Evans and O'Connor 1999). The composition of glass has altered considerably since the Roman period and different types and production methods can influence the rates of weathering (Freestone, 2001). Equally, many of the chemicals used to add colours to glass may be more susceptible to degradation (Cox and Pollard, 1981; Pollard and Heron, 1996). The composition of metal artefacts also varies from single elements to complex alloys and their longevity below ground will be determined by the metals, their corrosion products and the chemistry of the surrounding soil environment (Gerwin and

Baumhauer, 2000; McNeil and Selwyn, 2001). Due to these complexities, more work is required on the preservations of metals (Edwards, 1996; Kars, 1998).

In Britain, pottery has been made since at least the Neolithic, manufactured from heated clays that are in turn made from groups of sheet like silicate minerals. The different ratios in which these occur can be used to provenance the raw material (Sullivan and Malville, 1993; Pollard and Heron, 1996). During earthenware production, clays are fired producing changes to their chemical bonds typically resulting in more chemically stable and structurally stronger products than the original clay (Herz and Garrison, 1998). Nonetheless, they are still susceptible to gradual breakdown in many soil environments. Ceramics fired at temperatures below 700°C may contain reversible bonds and will slowly revert to the original clay minerals (Kingery, 1974). These ceramics are therefore likely to decompose more rapidly. The temperature at which ceramics are fired also relates to the porosity of the final material. Lower temperatures produce a more porous ceramic which allows greater soil water percolation and increases the susceptibility to weathering (Freestone, 2001). Additionally, any non-silicate minerals such as anhydrite or shell fragments used as a temper may rapidly decompose in the soil environment compromising the structural integrity of the ceramic (Firman, 1991). The longevity of any archaeological resource is determined by the many current site variables (Banwart, 1996), but also past and current land use and the nature and size of the evidence.

While literature on the chemical alteration of archaeological evidence through root activity is limited, there are many publications concerning the weathering of soil minerals and the influence of root exudates and associated microbiological activity. Ranger *et al.* (1990) found changes in the structure of reference minerals buried at various depths within different soils that could be attributed to both the soil horizon and the surface vegetation. Similar results have been found by Crow, 1998 and Augusto *et al.*, 2001. Others have reported on increased mineral weathering due to dissolution by ectomycorrhizal activity (Paris *et al.*, 1995) and hyphal penetration of mineral flakes (Leyval and Berthelin, 1991). While some mineral weathering has been attributed directly to root exudates (Leyval and Berthelin, 1991; Courchesne and Gobran, 1997), Ochs *et al.* (1993) found no increase in weathering from humic substances or exudates and suggested that such compounds may inhibit mineral dissolution. These different findings emphasize the complexity of mineral weathering rates that are dependent upon soil type, temperature, horizon chemistry, water content, microbial activity, vegetation type and root exudates. However, like archaeological evidence, the mineral longevity is primarily influenced by its own chemical composition.

Archaeological consideration - During the excavations of the Romano-British wells at Boscombe Down, some species of snail known to be post-Medieval were present in an earlier deposit. These recent intrusions are presumed to be the result of tree rooting action (Allen, pers. comm.). This led to a concern over the integrity of the context in which the palaeoenvironmental indicators at the site were found. However, this site is located over chalk and likely to have a large worm population. Such faunal activity must also be considered as a possible mechanism for any loss of context integrity (see chapter 4). Allen also refers to sites such as Rock Common and Grimes Graves where occasional flint fragments have become incorporated into growing tree roots and require extraction from the root. Subsequent root growth following flint inclusion will inevitably result in displacement and complications with interpretation.

Larger remains such as masonry are less likely to be moved. When a root encounters an obstruction, it will attempt to grow around it. If holes are found (e.g. in a dry stone wall foundation), the roots may penetrate. Roots will grow along the path of least resistance and this can be clearly seen in Figure 3.3, where the roots of a hawthorn have grown between the individual tesserae of a mosaic floor. At Waverley Abbey (Surrey), an old yew tree has grown over a section of ruined wall (Figure 3.4). Adjacent wall is lower and it may be argued that the tree roots have protected and increased the walls stability resulting in a greater height under the trunk. However, should the tree be uprooted, physical damage to the wall is likely to be severe. This tree has stood here for a considerable length of time, although its age and relationship with the wall are a point of debate (Beavan-Jones, 2002). With careful management to reduce the risk of windthrow, the yew should continue to coexist with the wall for many years to come. Walls exist in two environments, (above and below ground) and their longevity will differ in each. Below ground, soil chemistry, water content and the burial depth will also be relevant to the wall’s longevity and how the roots interact will again be influenced by the chemical composition of the stones and any cementing agent used. Chemical weathering of stone by roots has been seen at a Bronze Age granite roundhouse on Dartmoor. This was seen as a brown stain with accompanying loss of feldspar integrity where the granite was in contact with bracken rhizomes (Gerrard, pers. comm. (Dartmoor bracken project)).

Figure 3.3. Hawthorn roots growing over and between tesserae (underlying a 15 cm thick agricultural soil).

Figure 3.4. Ancient yew tree growing over ruined walls of Waverley Abbey.

Artefacts are at risk from chemical dissolution but the rates will be determined by their solubility and the soil horizon chemistry (Crow, 2002). It is possible that increased input of organic acids (due to root exudates or litter decomposition) into a relatively neutral soil will be detrimental to remains such as shell or bone. More chemically stable ceramics are still susceptible to gradual breakdown in many soils, but the rates are difficult to determine. Little has been found in the literature to compare the weathering rates of the ceramics to their original clay minerals. At Overton and Wareham, the experimental earthwork project (Bell, Fowler and Hillson, 1996) consists of constructed earth banks, where artefacts were incorporated into the structure for later recovery. Subsequent retrieval and analysis has shown differences in rates of decomposition for artefacts buried in the Chalk bank and the buried turf at its base. While this work will provide valuable information for sites on Chalk (Overton) and Heathland (Wareham), it will not be possible to study interactions with trees as they are actively removed as they become established.

More research is required on a wider range of soil types to determine the effects of plant roots and their exudates on various types of archaeological evidence. Methods of root control are outlined in Chapter 4.

3.4. Influence of trees on atmospheric deposition and soil solution chemistry

Tree cover will inevitably influence a site and in addition to changing the microclimate will alter the quantities and chemistry of any wet deposition entering the ecosystem. Trees have evolved a large leaf surface area to intercept light. This, combined with the aerodynamic roughness of the canopy, also makes them efficient at removing or intercepting particles, water droplets and gaseous compounds from the atmosphere. These substances can be transferred from the atmosphere by three processes:

- Wet deposition - the most abundant in the UK, where particles and gases are dissolved into rainfall.
- Occult deposition - where particles and dissolved gases are deposited through fog, mist and cloudwater.
- Dry deposition - where particles settle and gas molecules make direct contact with plant surfaces.
-

There has been much research in recent years in the role that trees play in removing airborne pollution and is extensively reviewed by Broadmeadow and Freer-Smith (1996). Both occult and dry deposition can be increased by woodland cover. The local atmospheric chemistry being intercepted and to a lesser extent the species of tree can strongly influence the composition of the water that reaches the ground.

Archaeological considerations - How the chemistry of water passing through the canopy (throughfall (TF)) will affect above-ground remains will not only depend upon the TF chemistry but also the composition of the archaeological feature. For example, stones with a high carbonate content, such as limestone, are more susceptible to physical and chemical weathering. Damage of this type can be seen on many city buildings or on limestone tombstones. Rocks such as granite or millstone grit are common in many Neolithic or Bronze Age stone structures and are more resistant to chemical dissolution. Walderhaug (1998) found that the some forms of Norwegian Rock Art were damaged more through oxidation than acidic dissolution. He concluded that while the detrimental process was determined by the chemistry of the rock, sheltering the stone from water could reduce both chemical actions. Equally, physical processes such as freeze-thaw (chapter 4) will be hindered by a reduction in water in contact with the stone. It is noteworthy that the TF volume reaching the soil is usually less in woodland than the rainfall volume outside. The pH of the TF compared to the precipitation outside of the woodland can be either more or less acidic. This is strongly influenced by the chemistry of the local air quality, the volume of rainfall and to a lesser extent the tree species. Due to a dissolved quantity of Carbon dioxide from the atmosphere, all rainfall is mildly acidic.

TF may have an indirect influence on weathering rates through its effects on lichen colonies. Lichens grow on and into rock surfaces and utilise some of the surface minerals as a source of substrate through dissolution (Brodo, 1973). Individual species are very sensitive to their environment and therefore occur in limited habitats. Thus lichen populations have been changed by increased pollution levels (Hawksworth and Rose, 1976) or by changes in their physical environment (Broad, 1989). As the chemistry of TF has a higher ion concentration than that of rain water, it may have implications on the species of lichen found and their primary source of substrate. If nutrients can be utilised from TF, then there may be less dissolution of the substrate on which the lichens grow. All of the above implications are currently relevant to those Forest Districts examining Rock Art conservation.

How the buried archaeological resource will be affected by percolating TF will be largely dependant upon the chemistry of the surrounding soil and their interactions. The ability of a soil to neutralize any acidic inputs is termed its buffering capacity. A soil with a high carbonate content such as a rendzina is able to neutralize relatively high acidic levels whereas raw sands or peaty soils are more sensitive to acidic inputs. In some podzols, the influence of atmospheric deposition was still observed at a depth of 40 cm. Some palaeoenvironmental indicators such as molluscs are composed of calcium carbonate and are readily dissolved by an acidic environment. However, snails are usually associated with a habitat containing non-acidic soils (Harris and Harris, 1997). Oyster shells are often associated with Roman activity and their distribution is more varied. Where these occur in neutral or weakly acidic soils, the influence of TF chemistry may be greater.

Each soil horizon also has its own set of chemical properties and the preservation of buried soils or artefacts is therefore dependant not only on the soil type and horizon, but also the composition of the archaeological evidence (Crow, 2002). The chemical effects of tree-intercepted atmospheric deposition on different types of archaeological evidence would benefit from further investigation.

3.5. The effect of trees on site hydrology

Just as tree cover will influence the quality and quantity of water reaching the soil surface, so it will affect the water content within the soil. Dobson and Moffat (1993) gave four factors that may contribute to different soil moisture under woodland:

- the lower reflectivity of forests allows absorption of more incoming solar radiation, and thus increases the energy available for evaporating moisture.
- the roughness of the forest canopy. This increases air turbulence resulting in more efficient transfer of water vapour and thus evaporation.
- the ability of trees to extract water from a large volume of soil may enable them to transpire for longer during drought conditions compared to other plant types.
- the ability to retain water through interception that will evaporate without reaching the soil.

Rainfall interception rates will be affected by species and the geographic location. The increase in water use by coniferous forest compared to grassland was found to vary from 15-20 % in the wetter north-west to 5-10 % in the south-east (Dobson and Moffat, 1993). For broadleaved trees, these figures can be reduced by a further 5 %, suggesting that in the drier south-east, water consumption of broadleaved trees and grass may be similar. Grass transpiration begins early in spring whereas most deciduous tree species do not come into leaf until early summer. Equally, grass transpiration will continue long after tree leaves have fallen in the autumn. The longer growing season may therefore potentially cause the total annual water usage for grassland to be higher (Nisbet pers. comm. (Forest Research)). Biddle (1998) gives an example of a greater soil moisture deficit to a depth of 1.2 m under grass than that found under an adjacent horse chestnut (*Aesculus hippocastanum*) tree, and recent work by Forest Research found grass roots under pasture to a depth of 1.5 m (Crow, 2003). The water usage of grass or agricultural crops should not be underestimated, as they are very efficient at competing for moisture to this depth.

Trees are very sensitive to atmospheric conditions, and prolonged drying can rapidly lead to stomatal closure on the foliage. This prevents further water loss and reduces the need for water uptake, however it also inhibits photosynthesis and therefore growth. During a dry summer, a tree is more likely to "shut down" rather than sink deeper roots in search of water.

The mineral and organic composition of a soil will determine the relative quantity of water that can be held within it. Soils with a large clay content are renowned for their ability to shrink and crack whereas the structure of free draining sands and gravels will be comparatively unaffected by prolonged drying. These differences are due to nature of the minerals in the soil and their relative particle size. "Clay" minerals have a very small particle size (<2µm) and a molecular structure that forms sheets covered with many exchangeable ions. These minerals are able to both absorb water within their molecular structure and adsorb it onto sheet surfaces. Thus, there is a very large surface area enabling a significant quantity to be held. As drying occurs, the molecular sheets and individual mineral particles are forced closer together causing the shrinkage. The severity of this process will depend upon the mineral composition of the clay as they differ in their ability to both bind and loose the percolating water. Conversely, sands have a bigger particle size (60-2000 µm) and fewer surface ions able to interact with water. It is generally accepted that only soils with at least 35 % sand can be considered non-shrinkable (Biddle, 1998). When water is removed from a soil by roots or a falling water table, a vacuum is created. This loss of water from between soil particles may result in the shrinkage of some clay soils, but is usually associated with an increase in the air content between the particles. Figure 3.5 shows the relative fractions of soil particles, water and air that comprise the main textural classes.

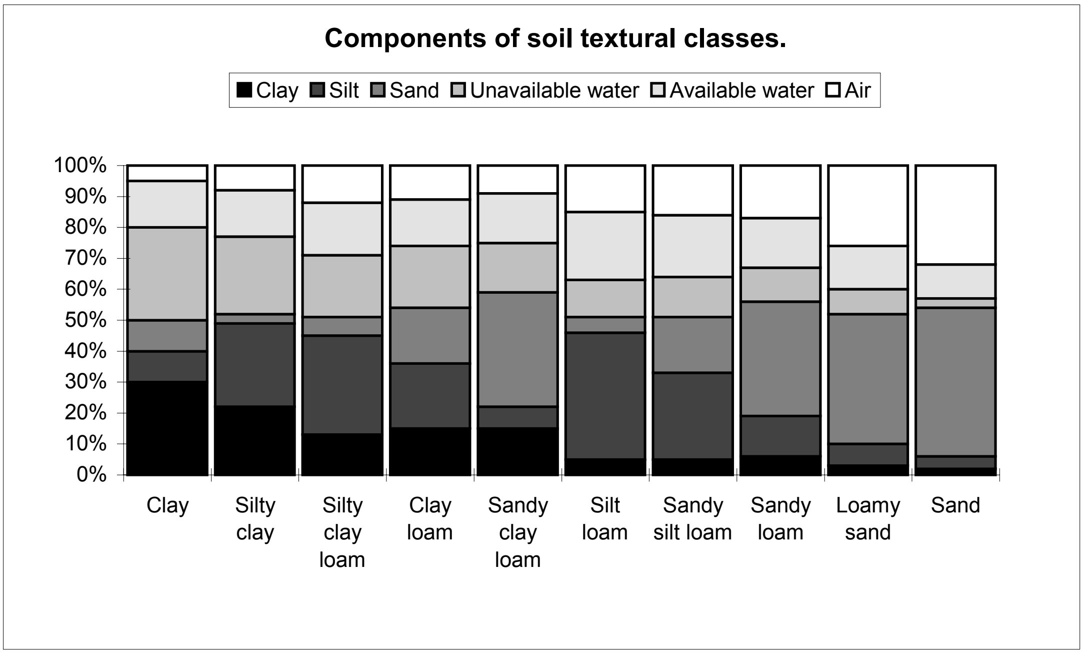


Figure 3.5. Phase diagram showing typical particulate composition, air and water content at field capacity for mineral soil texture classes. Data from Biddle (1998).

A seasonal soil moisture deficit occurs when a soil water content falls in summer and is recharged in the winter. A persistent soil moisture deficit exists where the total amount of water a soil can hold (its field capacity) is not replaced during a single winter and is thus worsened during the following summer. Persistent moisture deficits are currently rare in the UK. The influence of trees on soil moisture is also seasonal and will therefore increase the amplitude of any water table fluctuations. The degree to which this happens will depend upon the tree species, their age and condition, water availability, soil characteristics, local climate and site topography (Biddle, 1998).

Many woodland and agricultural soils have been artificially drained to alleviate waterlogging, improve soil conditions and to aid root penetration. Drainage will have a greater influence on soil water content than any vegetation type.

Archaeological consideration – The anaerobic conditions in permanently waterlogged soils prevent oxidation and chemical degradation of many types of archaeological evidence. The lack of oxygen also reduces faunal populations and inhibits root growth. Any reducing environment formed may also produce compounds such as hydrogen sulphide, which are toxic to most organisms. Waterlogged environments are most commonly found under deep peat soils or alluvial deposits where the water table remains high. For example, in the Severn

Estuary, waterlogged peat deposits contain well preserved timber structures. These include prehistoric boats, trackways and buildings (Bell *et al.*, 2000). Dehydration of these peats accompanied by increased oxygen levels and biological activity would result in the eventual destruction of the timber. Waterlogged soils are not always low lying and perched water tables are likely to be more susceptible to dehydration through drainage and vegetation uptake.

Figure 3.6 shows how the degree of water saturation within a soil and the depth of burial influence archaeological preservation (especially organic based materials such as leather and wood). Any land management that reduces either the soil water content in the proximity of any archaeological evidence or the depth of overburden is likely to increase the risk of damage.

Figure 3.6. The relative effects of burial depth and soil water content on the preservation of archaeological evidence such as wood, leather and pollen.

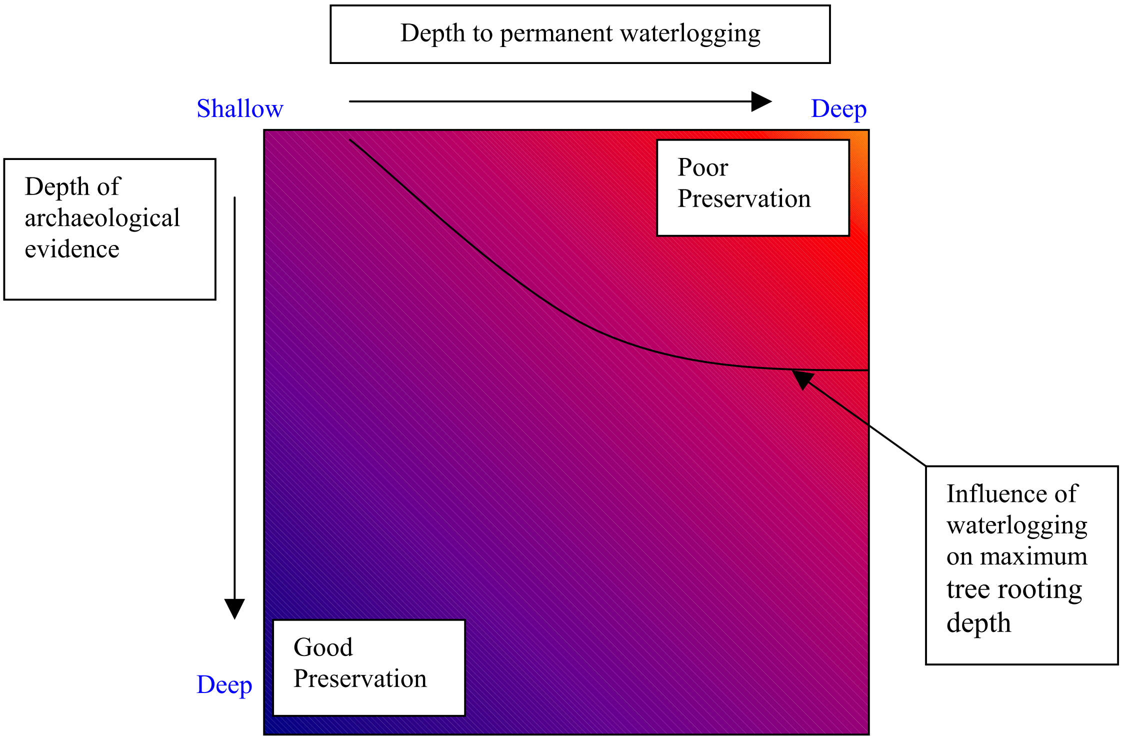


Figure 3.6 also shows how a shallow water table reduces the maximum rooting depth of a tree. However, even on drained soils, tree roots will not descend indefinitely in pursuit of water and a maximum depth will be reached beyond which they can not extend.

Due to the diverse nature of archaeological evidence, its burial depth, the physical and chemical properties of wetland deposits, site hydrology, drainage, previous land use and the current or proposed type of woodland, it is not possible to provide a single recommendation. However, as shown in Figure 3.6, any action which reduces either the water table or burial depth would increase the risks of loss to any archaeological (especially organic based) evidence present.

Trees in wetland areas

In some parts of Britain, there is a renewed interest in the establishment and restoration of wet woodlands for their ecological value and possible potential to act as a form of flood control. One of the problems with many wetland areas is that while they may have a perceived archaeological potential, the exact occurrence or depth of burial is often unknown.

The largest potential impact could arise from new broadleaved woodland or SRC establishment on former floodplains where there is a greater potential for lowering the water table. Under such circumstances, the effects of any existing site drainage must be considered. If a site has been extensively drained and under agriculture for some time, then establishing tree species may have little additional impact as the upper 1 - 2 m of soil may have been an unsuitable environment for good archaeological preservation over a considerable timeframe.

For wet woodland, where water levels are actively maintained and the site remains saturated throughout the year, there is likely to be little hydrological impact on any buried remains that is directly related to tree growth. However, such permanently flooded sites are uncommon. The potential chemical impacts from any woodland growth will be very site specific and dependant upon many factors such as soil type, tree species, local air quality and former land use.

Physical damage to buried archaeological evidence from tree roots could also potentially be an issue but high water tables would produce a very shallow rooting system. The management for small wood products (from coppice, pollards etc) would also reduce the need for large structural supporting roots. Under such management and environmental conditions, unless the archaeological evidence is very close to the soil surface, any rooting impacts are likely to be minimal. Archaeological damage from forest operations would also be unlikely on very wet sites, as vehicular trafficking may be inhibited. One slightly dryer, seasonally waterlogged sites, there is a potential risk of soil damage and rutting. This risk can be minimised if soil conservation guidelines are followed.

3.6. Effect of tree growth on soil biota

Limbrey (1975) split soil fauna into two categories and their implications for archaeological evidence vary significantly:

mesofauna or *meiofauna* - small animals that are able to live between the soil particles without physically altering it, and

macrofauna - larger animals that disturb the soil as they pass through it, enlarging pores, pushing particles aside or eating their way through.

One of the obvious effects of tree cover on any site is the production of leaf litter. Complex but close relationships exist between the type of litter (dependant on tree species), its palatability to soil organisms and the form of humus produced (Malcolm and Moffat, 1996). Humus is formed by the incorporation of organic matter (mull) or its accumulation on the surface (mor) and different groups of soil organisms are associated with each type (see Table 3.1). Mull is the less acidic and supports a larger faunal population, resulting in rapid breakdown and incorporation into the mineral horizons. Mull is usually associated with broadleaf woodlands. Converting other types of land to woodland will usually result in an increased accumulation of litter. The nature of this litter will depend upon the existing soil type, the soil organisms present and the species of tree planted. However, one common feature will be increased moisture in the upper soil horizons due to the high water retaining capacity of organic matter.

Within an area of Epping forest, Harris and Hill (1995) recorded successional changes in the soil fauna under meadow and different woodland cover. They found that the extensive fine root network associated with the grasses exude large amounts of soluble carbon in the form of sugars, organic acids and amino acids. The fine root structures also resulted in the formation of readily decomposable organic matter from the sloughing of the root cap cells. These carbon sources contributed towards a rich microbial and earthworm community with the latter often attracting moles. When grazing or cutting was removed from the meadow, scrub and woodland development began to occur. Harris and Hill found that the carbon input into the soil was increased by leaves and woody material. Both of these components are constructed of more complex carbon structures such as lignin and polyphenols that are less readily broken down by many soil fauna. Most earthworms avoid soils of low pH and litter with high lignin content, and were found to be absent from three out of the four forest sites at Epping. Moles, which feed primarily on earthworms, were not found in any of the mature woodlands.

Table 3.1. Soil biomass estimates from different ecosystems. Values are mg dry wt per m^2. Data from Newman (1988).

Fauna	Grassland	Coniferous forest	Deciduous forest (mor soil)	Deciduous forest (mull soil)
Mesofauna				
Nematodes	440	120	330	330
White worms	330	480	430	430
Springtails	90	80	130	110
Mites	120	500	900	300
Total	**980**	**1180**	**1790**	**1170**
Macrofauna				
Earthworms	3100	450	200	5300
Millipedes	1000	50	420	420
fly larvae	60	260	330	330
Centipedes	140	70	130	130
Beetles	80	120	90	90
Spiders	30	50	40	40
Slugs/snails	100	20	270	270
Ants	100	10	10	10
Total	**4610**	**1030**	**1490**	**6590**
TOTAL	**5590**	**2210**	**3280**	**7760**

Archaeological consideration – earthworms are likely to have the biggest impact of any invertebrate on archaeological remains. While they may not be common in all woodland types, they can be found in dense populations (500 per m^2; Limbrey, 1975) and responsible for the movement large amounts of organic matter. [*Lumbricus terrestris* has been found to move 90% of the autumn leaf fall in an apple orchard during the following winter (Wood, 1995)]. Most of the earthworms recorded from a mull soil are likely to be in the upper organic layers. Limbrey (1975) describes how worms that cast on the surface will move soil from below an artefact and deposit it above thus resulting in the gradual burial through the "worm sorted layer". The activities of worms on archaeological sites have long been recognised as a potential archaeological problem. Atkinson (1957) referred to the ability of worms in casting "2-24 tons per acre" of soil per annum from lower levels to the soil surface. Ants also build heaps of fine soil above ground that may incorporate small objects. Limbrey suggested that ant activity may be responsible for the uniform fill often found in post-holes. Any wooden structure left in the hole is decomposed primarily by fungal action, which in turn is fed upon by the ants. The wood is then replaced by fine soil often associated with ant nests. However, Newman (1988) associated such fungal gardening more with termites that are not found in the UK. Ants generally build their nests in areas that receive good sunlight and thus are more common in open areas of grassland or under broken canopy.

Hopkins (1996) noted that very little had been written on the biology of soils at archaeological sites and yet knowledge of such activity is highly relevant to preservation. From the literature reviewed it is clear that soil biota will vary under different tree species and may be of a either a greater or smaller population than that found under pasture. However, Soil type and properties will be highly influential. Without more specific studies, it is not possible to draw conclusions regarding the impacts of different soil fauna on archaeological evidence.

3.7. Forest operations

Where woodland cover is to be retained on or near an archaeological site, operations such as felling will be inevitable unless there is a deliberate conservation policy that stipulates "no-fell". The *Forests and Water Guidelines* (Forestry Commission, 2000) and the *Forests and Soil Conservation Guidelines* (Forestry Commission, 1998_b) provide examples of how mechanised operations can be conducted with reduced ground disturbance. These publications are part of a series of Guidelines that are intended to encourage environmentally sensitive sustainable forest management. Within the Forestry Commission estate, mapping of archaeological sites and the use of Forest District conservation plans and the forest design planning process have greatly increased the awareness of important features during any operations. Less obvious archaeological sites are marked during operations to further reduce chances of accidental damage. The incorporation of archaeological layers into the Forestry Commission computer based Geographic Information System (GIS) is further facilitating site management. Mechanised operations required through the life of an established woodland are outlined below.

Thinning

This is carried out by foresters to manipulate the development of the stand and achieve the best quantity and quality of final crop. The removal of trees during a crop rotation allows more light into the forest and reduces competition for the remaining individuals, thus enhancing development. There are two main types of thinning:

- Selective thinning, where damaged, suppressed or dead trees are individually removed. This is labour intensive and not the preferred option.
- Systematic thinning, where predetermined areas such as entire rows (racks) are removed, e.g. one row in three is removed. This method is usually fully mechanised and is the more common practise. Mixtures of both methods are occasionally employed (Crowther *et al.*, 1991; Evans, 1991; Hart, 1991).

Equipment used in any mechanised thinning will be partly dependant upon stocking density, age of the crop, access, etc. With any method, the stem is usually cut close to ground level and the remaining stump left in the ground. Removal of trees creates newly exposed areas into which wind can penetrate and may increase the risk of windthrow. Adjacent trees may not have a root system capable of dealing with the increased stress and on some sites root upheaval has been a serious problem.

Felling

When a commercial stand has reached maturity, harvesting usually follow which can be subdivided into three stages.

- Felling - the action by which the tree is removed from its standing position.
- Processing - cutting the tree into desired, manageable sizes and removing unwanted brash.
- Extraction - physically removing the cut material from the point of felling.

The actual method used for any forest operations will depend upon many site specific factors such as the species, age, stand density, site access, gradient, soil type and the roughness of the terrain, but where practical and acceptable, processes are mechanised to increase cost effectiveness. Many types of equipment are available to carry out the three stages of felling and are described by Hughes and Roebuck (1991).

The method of tree removal preferred on many archaeological sites is manual felling by chain saw to reduce the likelihood of vehicular ground disturbance. This is easily achieved on small earthworks such as individual barrows, and justifiable when a real threat of windthrow exists.

On larger sites such as field systems or cairn fields, where tree removal has been decided upon, manual felling is not so practical and forest machinery may have to be considered. A modern mechanised harvester, used by an experienced operator, is a very precise tool and can be effective in careful tree removal on appropriate sensitive sites. Where heavy machinery is used, the soil beneath is at risk from physical damage such as compaction, displacement and erosion unless suitably protected (Forestry Commission, 1998_b). Soil erosion rates may increase in the short term from unprotected sites following harvesting operations (Moffat, 1988 and Soutar, 1989) until a protective vegetation layer has again become established. However, this erosion is preventable with appropriate soil protection. Increased soil bulk density (resulting from compaction on unprotected sites) impedes root penetration, reducing both aeration and drainage. Thus, future plant cover will be inhibited, and combined with reduced drainage and potential rut formation, will increase the susceptibility to erosion, especially on slopes. To minimize such damage, the use of brash mats has become commonplace and is now the standard procedure in most harvested sites. These mats significantly reduce the compaction and rutting by distributing the load over a larger area of soil. Table 3.2 gives soil types showing their susceptibility to ground damage caused by trafficking. During any forest operations, all known sites (not just scheduled monuments) must be located and marked in the field to reduce the risk of accidental damage.

Archaeological consideration - surface scatters without any protection are unlikely to survive mechanised trafficking without any form of disturbance resulting and any near surface artefacts/ecofacts are also at risk from damage through rutting. While brash application can help to reduce soil damage, there have been incidences where the protective cover has hidden small archaeological extants that were subsequently damaged by vehicle passage. Ironically however, it is possible that soil conditions resulting from compaction, with impeded root penetration, reduced aeration and reduced drainage, may actually create conditions that favour the preservation of deeper archaeology. This possibility needs further investigation.

Whether any vehicular movement can be tolerated on a known or potential archaeology site, will inevitably depend upon the type of evidence, the soil type and its condition. However, the correct use of brash material can greatly reduce the risk of damage.

Timber processing

This may be carried out before or after extraction depending upon site access and conditions. However, it should not occur on archaeological sites (in accordance with current FC guidelines), and timber should be processed elsewhere.

Table 3.2. Soil types and their susceptibility to compaction through trafficking damage.

Risk category	Soil types
Low	Brown earths, podzols, rankers, skeletal soils, limestone soils and littoral soils except sand with shallow or very shallow water table.
Medium	Shallow peaty soils (peat <45 cm deep), surface water gleys, ground-water gleys and ironpan soils.
High	Peatland soils (peat>45 cm deep) and littoral soils with shallow or very shallow water-table.

(From *Forests & Soil Conservation Guidelines.* Forestry Commission, 1998_b).

Timber extraction

The traditional method using horses is still used in some areas and has enjoyed a revival over the past few years for the extraction of timber from inaccessible or sensitive sites. Line or grapple skidders can also be used to drag stems off site. Where access and conditions permit, stems can be loaded onto a forwarder that has an integral trailer and the load driven out of the forest. The compaction issues raised above are again relevant. The number of passes a vehicle needs to make over the soil should also be considered. A small skidder will have to make more passes over the soil than a forwarder to extract the same quantity of timber. Which method will cause the least disturbance will depend upon the soil physical properties, the site topography and the crop being removed. Another method that is employed on inaccessible sites or steeper slopes is by cable crane. This system extracts timber wholly or partially clear of the ground. While this method is less damaging to the soil structure, it is more expensive per stem and therefore less attractive to a commercial forest owner. As with felling, the method used will be determined by the nature of the archaeological evidence and site conditions. Whatever extraction method is to be employed, one important consideration will be the route to be used. For example, the entrance of a hillfort will provide an obvious preferred access route for timer extraction. However, entrances are generally considered to be of high archaeological interest with a potential for aiding site interpretation. If the hillfort is surrounded by large ramparts, avoiding any entrance may require traversing these earthworks which could be both dangerous to the machine operators and damaging to the monument.

Under such circumstances, consultation with the local authority archaeologist is essential to discuss the options available and develop an agreed mitigation strategy.

Whole-tree harvesting

Whole-tree harvesting is practised at a few locations in the UK, but it may become more common as the demand for biofuels increases. The practice results in the removal of brash to be sold as wood fuel or chipped and stock piled to form compost. In Thetford Forest, the harvesting of pine has also resulted in the removal of roots due to the additional problem of a root and butt rotting disease commonly known as Fomes (*Heterobasidion annosum*). This Basidiomycete produces spores that infect cut stumps. The fungus travels down the butt into the roots where it can remain viable for up to 20 years (Gibbs *et al.*, 1996). When the next crop is planted, infection of the young trees occurs via root contact. To minimize the incidence of Fomes, the whole root plate is pulled from the ground (destumping) following felling. These are eventually chipped and burnt. Mechanised operations are carried out all year in the Brecklands as the well-drained soil is less prone to compaction. These soil conditions are also ideal for burrowing and make the Brecklands a favoured location for rabbits, and historically many areas were actively managed as rabbit warrens. Recent problems with rabbits have also been intensified by the practice of whole-tree harvesting. Roots following extraction are placed in rows around the outside of the cleared area and left for several months. This serves two purposes, firstly to allow the soil held within the root ball to weather out before the roots are chipped and secondly to provide wind breaks for subsequent replantings. These roots also provide ideal shelter for the rabbit populations that then browse the new plantings.

Earlier uses of the Breckland landscape is indicated by concentrations of worked flint. Randall and Dymond (1996), estimate that the Breckland contains 1 million worked flints per square mile. Any ground disturbance will alter the flint distribution patterns and hinder their interpretation. Before forestry, the Brecklands were extensively farmed during the mid 19th century and rabbit warrens were very common. With a history of ground disturbance, it is difficult to assess the damage of root extraction alone upon scatter distribution without a field walking exercise before and after. However, archaeological walk-over surveys are carried out by local authority archaeologists on behalf of the Forest District to note any important features prior to any destumping.

Most forest operations carry a risk of damage to archaeological sites. Nevertheless, with increased awareness of the archaeological resource and further guidance on practice to reduce impacts on sites as a whole, the continued management of both the evidence and forest should be possible.

3.8. Minimizing windthrow

Although windthrow is undesirable to both foresters and archaeologists, silvicultural measures can be taken to minimise the risks (Quine et al., 1995). Some of the key points for consideration are outlined briefly below.

- Soils should be prepared to encourage tree rooting. However, this can require cultivation methods that may conflict with archaeological conservation.
- In areas of high risk, thinning that results in the creation of large gaps should be avoided. The smaller the gaps created in the canopy the better. Self thinning mixtures such as Scots pine and Sitka spruce should be planted as an intimate mixture. A no-thin policy may be necessary in wind-prone regions.
- Wider spaced planting at stand edges increases wind permeability. Planting slower growing trees at the edges help smooth the stand profile. The length of the newly exposed edge should be minimised.
- Felling coupes should be designed to utilise natural or established edges. Where this is not possible, newly exposed edges can be smoothed by topping edge trees. Felling should take place at the down-wind edge of a coupe.
- When retaining a stand, south-west slopes, exposed hilltops, soils hostile to rooting, furrow ploughing or parts of valleys where wind is restricted or accelerated should be avoided.

Modern computing technology has allowed the evolution of Windthrow prediction. Early methods for scoring windthrow susceptibility considered the geographical location (wind zone), the site elevation, exposure, soil type and aspect. These were then related to the tree height and stocking density, factors that are especially important for upland forests at higher risk from windthrow. A more recent computer based model (ForestGALES) uses additional information on the crop and silvicultural regime (Quine and Gardiner, 1998). More detailed information can be obtained from Forestry Commission Bulletin 114 or the ForestGALES web site (www.forestry.gov.uk/forestgales).

Such issues are relevant to any archaeological remains located within a forest or woodland. In a survey of 316 scheduled ancient monuments in Scotland, 6% had cases of wind blown trees (see Appendix 4). If a few trees exist on a burial mound and at risk of windthrow, then pruning the tree and removing some of the above ground biomass may be a better alternative to felling. This will reduce the risk of windthrow whilst maintaining the structural integrity of the soil.

3.9. Coppice silviculture

Coppice management may provide a long-term option for tree cover on some archaeological sites. Well maintained coppice stools can, in principle, be worked indefinitely, although this is usually limited by nutrient availability and stool mortality. Oak coppice can be economically maintained for up to 130 years (Crowther and Evans, 1984)[v] cut on a typical rotation of 6-30 years. An alternative method of management is coppice with standards. Here a single shoot from each stool is not coppiced on the normal rotation but left to develop into a timber quality stem. This method has historically been the standard practice and ancient coppice stools are common. Coppice systems (without standards) have the benefit of minimal soil damage during harvest, a reduced need for weed management, physical protection of the site, negligible risk of windthrow and where markets for the product exist, a cash return for the landowner. Nevertheless, concerns may still exist over potential damage to archaeological remains due to root penetration. Where standards are left to develop, the risk of windthrow increases and the rooting structure is likely to be more substantial.

The primary functions of roots is to provide nutrients, water and support for the above ground component of the plant. As a direct result of this function, the above-ground tree biomass is directly related to the root biomass and *vice versa*. The “root:shoot ratio” is a relatively constant value but will vary slightly with species, site conditions and silviculture. Using this relationship trees have often been pruned above-ground as a controversial method of reducing both root growth and water uptake on sites where trees in close proximity to buildings have caused damage (Biddle, 1998). It is believed that the process of pruning reduces the surface area of the tree available for photosynthesis that in turn lowers the total amount of carbohydrates available to feed the root system. Once the root reserves are used, the excess root will die until the ratio is re-established. However, if a mature tree is only lightly pruned, photosynthate levels may not significantly drop to require utilisation of root reserves.

Various root responses have been observed following coppicing. Dieback has produced soil channels left by decayed roots that were subsequently reoccupied by new ones when growth was re-established (Bédéneau and Auclair, 1989$_a$). This could mean minimal disturbance for

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[v] Oak coppice is less common today with most interest in hazel and chestnut, or in fast growing crops such as poplar or willow to be sold as pulpwood or a renewable energy source.

any subsoil archaeology. Bédéneau and Auclair (1989_b) found that root activity was reduce for several years following birch coppicing, whereas chestnut produced new fine roots with variable effects on older ones and oak developed new roots. Shepperd and Smith (1993) found no initial change in aspen root volume following coppicing, but a change in the ratio between large and fine roots was seen to favour the latter.

Figure 3.7. A section of hillfort defences with lime tree cover.

At one Forestry Commission managed hillfort ancient lime coppice covers much of the site, which has reverted to high forest which is likely to increase the risk of windthrow (Figure 3.7). The monument form is well preserved and the woodland cover itself is considered of high historical value. There is therefore no desire to remove the woodland, but to reduce the risk of windthrow and subsequent monument damage, the lime is to be gradually put back to coppice management. However, felling the trees and opening the canopy, provides a better habitat for invasive weed species. This, combined with the dense young coppice regrowth may restrict public access to the site in the short term, creating a new set of challenges. Clearly, the management of such a site is complex and more information on any subsurface archaeology, the impacts of leaving trees standing, reverting to coppice and general root interactions with any remains would be beneficial in making long term decisions.

Short Rotation Coppice (SRC) is harvested on a cycle of only 2-4 years. Fast growing poplars and willows are the usual crop with stems being sold as pulpwood or for fuel as a source of renewable energy (Figure 3.8). With the UK government committed to renewable energy providing 10% of electricity supplies by the year 2010 (DTI, 1999), the interest in SRC crops is increasing. Wood burning power stations are already in place and grants available to encourage farmers to convert some arable land to SRC production. Concerns have been raised regarding the different rooting habits to arable crops and their impacts on any subsurface archaeology. In direct response to this, Forest Research conducted a survey of SRC rooting habits on four major soil types (Crow and Houston, in press). All of the stools assessed showed preferential rooting in the plough soil and a relationship was found between the maximum root diameters and the frequency with which the stem is cut. While root diameters ranged from 45 mm to 0.1 mm, the vast majority were less than 2 mm. In a recent study of short rotation willow, Rytter (1999) found that there was a regular turnover of fine feeder roots with some dying back whilst others were being produced. This was a continuous process throughout the growing season (*ibid.*). Such fast vigorous growth is believed to have a higher water consumption than that of standard plantations (Dobson and Moffat, 1993; Hall, 1996) which has implications for planting where waterlogged archaeological deposits may exist (see section 3.5 on site hydrology).

Figure 3.5 Poplar SRC showing 3 years above ground growth

Further research is required in the UK into the dynamics of coppice roots for various species and under different conditions such as soil type, rotation length, fertilizer application, weeding and the time of harvest. However, coppice root systems seem to consist of finer less extensive roots than standard trees (Figure 3.6) that are subjected to some degree of checking following coppicing. With their long life potential, coppice stools should be considered as an alternative to grass where grazing or intensive management is not an option, or to standard tree cover where associated operations and larger, deeper rooting are less desirable. Species for coppicing are listed in Appendix 2. No observations of SRC root systems on archaeological features are currently available.

Figure 3.6 Profile of SRC roots that are predominantly found in the plough soil.

CHAPTER 4.

The management of archaeological sites in woodland clearings

On some sites there will undoubtedly be a need for tree removal and on those such as Bury Ditches (Shropshire), this can be a very successful operation (Darvil, 1987). The most frequently quoted example of removal is where mature trees are at risk from windthrow. The upheaval of a windthrown root plate may physically damage or displace any immediately adjacent archaeological evidence (Barclay, 1992$_a$; Cleal and Allen, 1994). Such damage to important archaeological sites is clearly undesirable and steps should be taken to minimise the risks. However, the effects of tree removal must also be considered, as it will cause change in the surrounding environment and may impact upon the remaining archaeology. For example, within one woodland in southern England, trees have been removed from a small barrow. It was not long before this newly cleared earthwork and surrounding opened space was being exploited by mountain bikers and suffering rapid erosion (Shanks, pers. comm. (Forest Enterprise)). Such problems elsewhere have led to trials of barrow repairs that are being carried out in collaboration with local authority archaeologists.

4.1. Residual stumps and roots.

Where the decision has been made to remove trees from sensitive sites, they are usually felled and the stumps left in the ground to rot, thus minimising below ground disturbance. The remaining stump and root system can still produce growth long after the stem has been removed. Many tree species (especially hardwoods) are renowned for their ability to produce new vegetative growth (coppice shoots), but this differs with tree age and species (see Appendix 2). As any regrowth will ensure the continued growth of the root system, fresh stumps are typically given an application of herbicide. The practicality of this process may be limited as herbicide is often only translocated a short distance (<0.5 m) into the stump (Biddle, 1998) and its application may be considered environmentally undesirable.

The effectiveness of these chemicals can be improved by making diagonal cuts through the remaining exposed bark, a process known as "frill-girdling" (Biddle, 1998). This may be more effective on the butress roots, but there may still be a chance that suckers from further down the root system and away from the stump will be produced (see Appendix 2). Treatment of suckers is possible with a systemic contact herbicide such as Roundup™, the use of which may be ecologically undesirable.

Where plenty of notice is possible prior to felling, a process known as "ring barking" may be employed to minimize the chance of regrowth. By removing a strip of bark from around the trunk of a tree, no newly synthesised sugars can be passed to the root system. Eventually, the root itself will exhaust any food reserves. After a period of 6-12 months (during which a root may still be viable), the tree can be felled with little chance of either coppice or sucker growth. More work is needed to determine the effectiveness of herbicide and other methods of root control on cleared archaeological sites.

Once severed from the stem, roots will use stored starch reserves for their own survival. As starch is a high-energy source, the vulnerable root system will be subject to attack from soil micro-organisms. Once these reserves are depleted, the more complex molecules such as lignin and cellulose will be broken down by fungal and bacterial action resulting in the eventual loss of root integrity (Richardson, 1995; Biddle, 1998). Once a root has decayed, voids may be left within the soil. Water can drain through these channels and the surrounding soil will creep in from the sides. Any remaining organic material from the root itself may be mixed with the soil by the faunal population (Limbrey, 1975). Such voids may cause problems where movement of soil and artefacts occur, thus confusing the stratigraphic interpretation and archaeological context (Darvill, 1987).

4.2. Changes in the soil.

The removal of trees from raised earthworks such as banks or burial mounds can have an adverse effect on the stability of the remaining soil. Soil consists of particles capable of moving past each other and allowing larger scale migration, especially on slopes. The shear strength is a function of the friction created between adjacent particles that results in a resistance to such gravitational movements. A wet soil will have an increased volume that expands the spaces between particles thus reducing their friction and the soil shear strength (Biddle, 1998). The presence of roots within soil significantly increases its resistance to shearing (Waldron and Dakessian, 1981) by providing a lattice to support it. Tree removal and subsequent root death on a sloping soil with little other vegetation cover, may lead to a higher risk of soil erosion.

Upstanding earthworks are usually constructed from the contents of an adjacent ditch. As deeper material is removed from the ditch and placed on to the top of the raised feature, a reversed soil stratigraphy is produced. A simplified diagram of an earthwork in cross-section is shown in Figure 4.2.

Figure 4.1 shows the remains of a pine root and the "shadow" formed as it decays. This root still remains from a tree that was removed 23 years ago. (Coloured segments of scale are 10 cm)

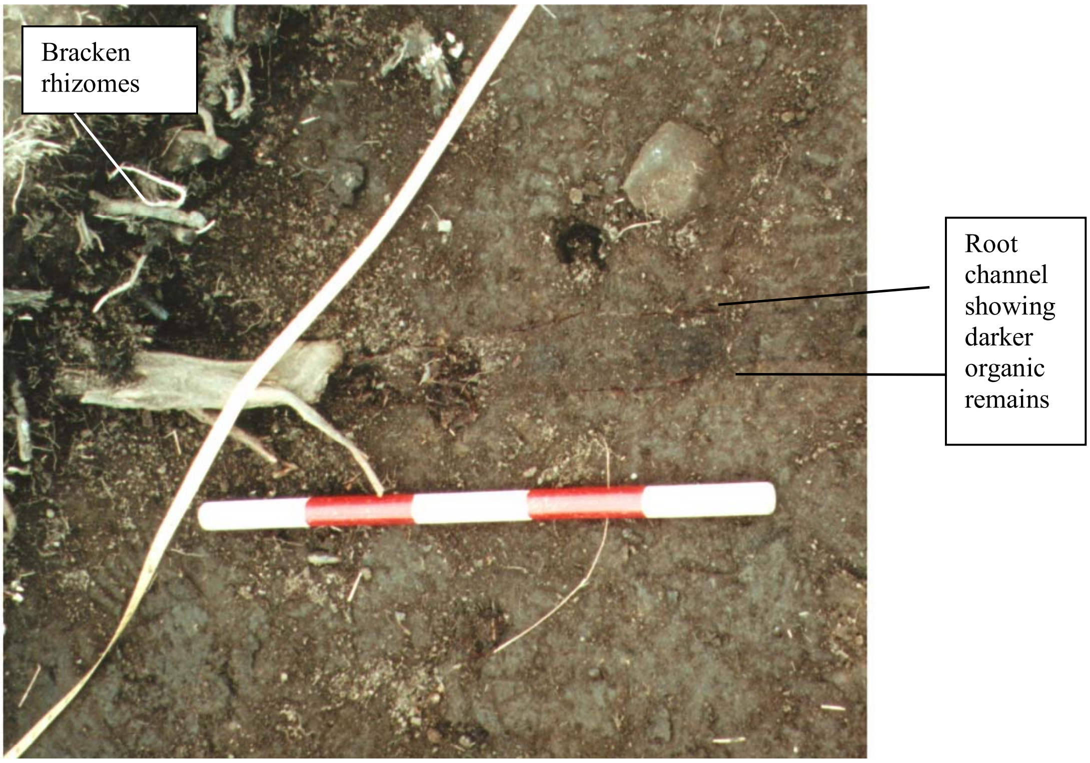
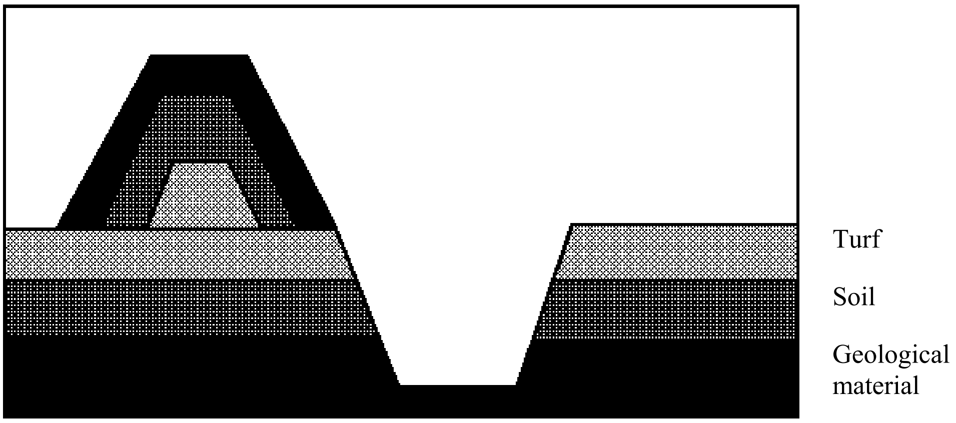


Figure 4.2. A simplified cross section showing earth bank and adjacent ditch.



Due to the reversed stratigraphy, the surface layers of the bank are formed from the less fertile horizons from the bottom of the ditch. This, combined with the increased susceptibility of banks to desiccation, can cause considerable problems in establishing a conserving vegetation cover (Jones, 1998). A typical example is from Berkshire, where an Iron Age hillfort at Caesar's Camp, Bracknell, had conifers removed from some areas prior to an application of grass seed. This was subsequently washed downslope by heavy rain (Frodsham, 1994)[vi] resulting in poor vegetation establishment and leaving exposed soil at risk of weathering. Surface scatters occurring on a slope where the protective tree cover has been removed are at risk from displacement via movements of the soil surface, or the actions of water (Allen, 1991).

4.3. Increased site exposure.

The removal of tree cover from an archaeological feature will alter the microclimate of the site and may subsequently enhance the natural processes of monument erosion through increased exposure. Generally, woodlands have a higher degree of shade, reduced wind speed, increased humidity and reduced temperature fluctuation (Stoutjesdijk and Barkman, 1992) when compared to open grassland (Table 4.2).

[vi] At this site tree removal has also caused some public relations difficulties.

Rain is one of the most efficient causal forces of erosion. Several studies have looked at the kinetic forces of rain drops and how they can physically dislodge soil particles (Evans, 1980; Imeson, 1984; Allen, 1991; Tamm, 1991). When rainfall occurs on a slope, a downward movement of any exposed soil particles will result, producing a slow but steady form of erosion. This process is more effective on soils devoid of a protective layer of plant cover (Evans, 1980). Surface runoff begins when rainfall exceeds plant uptake and soil infiltration. Under certain conditions this can lead to sheetwash, rilling or gullying that will inevitably result in soil displacement of a more vigorous nature (Allen, 1991). There are reports of channel formation under closed canopy following the shading out and subsequent death of grass and herb cover with their more abundant root systems (Moffat, 1988; Soutar, 1989). However, a woodland canopy with its increased evapotranspiration and interception, generally reduces the quantity of rainfall that reaches the soil compared with open ground or grassland. Rain droplets passing through the canopy may increase in size following accumulation on the leaf surfaces. Where rain does reach the forest soil it has a reduced kinetic energy resulting from impacts with vegetation on its way through the canopy, understory and finally a protective cover of leaf litter, thus minimizing any soil movements from rain splash.

Air temperature. ^{0}C	Ground surface temperature ^{0}C.		
	Woodland	Open shade	Grassland (full sun)
5.50	0.00	-3.50	0.50
2.00	-2.00	-3.00	2.00
3.70	-1.50	-3.50	-1.00
-6.00	-9.00	-12.00	-9.50
2.00	-1.00	-2.00	3.00
-1.60	-5.70	-11.50	-5.50
14.10	6.50	4.00	13.00
6.90	1.50	-1.00	9.30
3.20	2.00	0.50	13.00
15.00	8.00	8.30	34.00
Mean 4.48	-0.12	-2.37	5.88
Stdev. 6.42	5.09	6.18	12.34

Table 4.2. Temperature variation under different types of vegetation. The standard deviations (Stdev) are less for woodland. Data from Stoutjesdijk and Barkman (1992).

Wind can directly cause the translocation of soil particles but is more of a local phenomenon. Areas most at risk in Britain are the Brecklands, the vales of York and Pickering, the "Black Fens" and parts of the West Midlands, Lincolnshire, east Nottinghamshire and south Lancashire (Wilson and Cooke, 1980). Tree cover decreases the efficiency of wind erosion by reducing wind speed and filtering out any wind borne soil particles. Such protection has been used in agriculture, in the form of shelterbelts.

The susceptibility of a site to either rain or wind-induced erosion is dependant upon many factors such as soil type, slope angle and length, vegetation cover and geography. Tree removal will result in some short-term bare soil exposure. When combined with any other site conditions which are hostile to plant colonization, the exposed soil may take longer to stabilize.

Freeze-thaw is a process generally associated with the disintegration of rock. Water percolates into small fissures on the surface. When it freezes, the ice expands and the fissures widen further. Examples of this weathering can be seen on Dartmoor, where resilient medieval granite crosses show degradation. Carved relief is at most risk from such processes. As temperature fluctuations are less within woodland, any freeze-thaw should be less likely to occur. The wet deposition in a woodland environment (throughfall) has a higher ion content than rain water, and this further decreases its freezing point. Benedict (1993) found that varying quantities of snow and lichen cover on rock surfaces also influenced rates of freeze-thaw action. The highest weathering was found in areas of shallow to moderate winter snow accumulation, with lichen cover from 25 to 60%. Here wetting-drying cycles were found to be more numerous than in areas of late-lying or permanent snow. Under such conditions, postglacial weathering was found to remove, on average, 10 - 11mm of granite rock face and much more locally. Benedict also suggested that maritime environments (such as the UK) might further encourage chemical dissolution of minerals. Woodland may increase physical protection from processes of freeze-thaw, and may support a different lichen community to that outside. However, the chemical influence of atmospheric input from an adjacent canopy should also be considered. These issues are relevant when considering long term conservation of carved stones e.g. cup and ring marked rocks or memorial slabs.

4.4. Risk of further tree loss

The reason for including the topic in this section is that the removal of trees from within an area of woodland can put adjacent trees at risk from windthrow. At particular risk are dense upland conifer plantations, often grown on poor or thin soils producing trees with potentially shallow root systems. If areas within such forests are opened up to expose archaeological sites, the trees on the newly created edges are at risk of windthrow due an insufficiently developed root system and a sudden increase in exposure. Such implications must be considered prior to opening a site within any woodland.

4.5. Impacts of subsequent colonising flora.

Archaeological sites within open areas of land still require some form of management to prevent invasion of unwanted weed species. In archaeological literature and Forestry Commission guidelines, the recommended approach has been the use of grazing if practical and appropriate. However, this form of land-use is not without risk as overstocking can lead to surface soil erosion and it should only be used on suitable sites with careful management. On many sites, grazing is not a practical option and if the trends in farming continue, others that are currently grazed may need scrub control. Thus, the demand for manual cutting of invasive weeds and scrub is likely to increase. In a survey of 316 scheduled archaeological sites in Scotland, 48% were recorded as having some degree of harmful weed cover (see Appendix 4). There are also many published examples where natural colonisation and regeneration of weed species have become a management problem (Barclay, 1992_a, 1992_b; Lee, 1995; Thackray, 1995; Macinnes, 1997).

For most of the British Isles the natural vegetation cover is woodland, and without continuous management in non-wooded habitats, most would slowly revert. Vigorous weed growth may impact below ground through root activity, or by visibly masking the site and putting it at risk from accidental vehicular damage. Colonizing species vary from site to site depending upon soil type, altitude, exposure and neighbouring flora (Harmer, 1999). It is therefore difficult to generally predict what plants will colonize. The reversed stratigraphy associated with most banks may result in a different flora to the surrounding soil.

Some trees are renowned for their colonising ability. For example, silver birch (*Betula pendula*) produces 43,000 wind-borne seeds per square metre of ground (Hearn, 1995) thus enabling rapid dispersal and comprehensive woodland expansion. Smaller woody shrubs also take advantage of open land. Species such as gorse (*Ulex europaeus*), broom (*Sarothamnus* *scoparius*) and rhododendron (*Rhododendron ponticum*) may be a problem locally (Lee, 1995).

Non-woody species can also be very invasive. The common bracken (*Pteridium aquilinum*) is found throughout the UK, in habitats from sea level to an elevation of 600 m (Page, 1997). In 1986 the estimated area of the UK under bracken cover was 6720 km^2 (an area equal to Devon) and the rate of expansion was predicted as 1-3 % a year (Taylor, 1986). Page attributed much of this area to past forest and woodland clearance. Indeed, on Forestry Commission land in Thetford where pines have been removed from archaeological sites, bracken is invading rapidly. With its main rhizome penetrating at least 0.4 m into the soil (fine roots deeper) and with a lateral growth rate of 1 to 2 m a year, the potential impact of bracken on subsoil archaeology should not be underestimated.

In recent excavations of a roundhouse on Dartmoor, the onslaught of bracken following tree removal 23 years beforehand had led to a density of 275 m of rhizome per square metre (Gerrard, 1999). Where it has become established, current control methods require extensive use of herbicide, a process that many landowners prefer to avoid. Examples include earthworks within Sites of Special Scientific Interest (SSSIs) or ancient woodlands where desired flora such as bluebell (*Hyacinthoides non-scripta*) would be eradicated by herbicide application (Forestry Commission, 1998c). Mechanised weed removal, such as mowing, may be hampered by the presence of the tree stumps left after site clearance (Lee, 1994). Bracken is less palatable to sheep than many other vegetation types and so grazing may not be a successful means of control.

Several research projects are now investigating the impacts of bracken and some arable crops on archaeological evidence, but further research is still needed to cover the major types of both archaeological evidence and soils.

4.6. Potential damage from animal activity

Archaeological literature contains many references to site damage caused by the overgrazing of sheep (Barclay, 1994; Berry, 1994$_b$; Frodsham, 1994; Lee, 1994; Streeten, 1994), cattle (Griffiths, 1994) and burrowing by rabbits (Barclay, 1994) and badgers (Taylor, 1994; Thackray, 1994). In parts of Wales, hillforts and cairns have been damaged by overgrazing, visitor pressure, burrowing animals, mountain bikes and motorcycles (Rees, 1994). The potential for damage from burrowing animals has also prompted Historic Scotland to produce a

Technical Advice Note (TAN) on their control and management (Dunwell and Trout, 1999). Livestock may use trees for shade, shelter or scratching posts (Webster, 1997), and where barrows exist as tree-covered knolls, the summits may act as a focal point for any grazing animals that have access to them. Overgrazing can lead to increased soil erosion caused by treading or by actively digging to produce shelter pockets or dust baths (Berry, 1994_b). This erosion is heightened in wet weather when the soil integrity may be compromised by reduced soil shear strength. On any ground with bare soil exposed, the continual passage of stock will inhibit the establishment of any stabilizing ground cover. In addition to sheep and cattle, in areas such as the New Forest, pigs also roam freely during the autumn pannage. They feed primarily on acorns and do not significantly dig into the soil. Ponies may be a local problem and, like cattle, possess a substantial live weight that increases a soil's susceptibility to erosion. In parts of the Scottish highlands and islands, goats may have similar impacts to sheep (Hester *et al.*, 1998) and even otters have been noted as a cause of site damage. While mammals are the most obvious potential problem, the Historic Scotland TAN also give advice on ground nesting birds such as Puffin and Shearwater. Some species are discussed below. (Animal references taken from Corbet and Southern, 1977; Harris and Harris, 1997).

Rabbits - are able to live in all types of woodland, but prefer grassland, heath and fields with adjacent cover such as hedge or woodland edge. They prefer soft well-drained soils for their burrows such as sand or soils over chalk, but will use most types except the very wettest. They are recorded as causing extensive archaeological damage (Barclay, 1994; Berry, 1994_b; Frodsham, 1994; Taylor, 1994; Thackray, 1994). They are likely to continue to be a problem, as their UK populations are on the increase.

Hares - are usually found on agricultural land or moorland. They may use woodland in winter for shelter. Their population densities are much less than rabbits and they do not burrow.

Moles - prefer pasture and open deciduous woodland where earthworms are plentiful. They avoid conifers and dense tree cover of any kind, and dislike shallow, stony, very acidic or waterlogged soils. A tunnel system may extend for 400-2000 m^2 and consist of tunnels 5-20 cm below the surface.

Field voles - Their optimum habitats are those of rough grass with plenty of cover. Numbers have increased in some areas following clearing of scrub and woodland. They will inhabit young forest plantations and open mature woodland where sufficient ground cover exists. Nests are built at the base of grass tussocks or in burrows.

Bank voles - They are found in coniferous, deciduous woodland, scrub and hedgerows and seldom venture from such protection. An important habitat is ground cover such as bracken and nettle but it is rare within closed canopy forests. Runs and nests are made above and below ground.

Wood mice - have similar habitat requirements to voles. They prefer woodland edges with a good cover of bramble or bracken and avoid dense plantations. Runs are made within the soil litter layer but also in the soil mineral layers.

Foxes - are adaptable to a wide variety of habitats. They can be found in any deciduous or conifer woodland with ground cover, but are most abundant where the habitat is varied. Freely draining and easily excavated soils are preferred for dens.

Badgers - prefer deciduous or mixed woodland, but will inhabit conifer stands. Other habitats have been quoted as "hedgerow and scrub, open fields, embankments, moorland, rubbish dumps, caves, coal tips, other mine waste and iron-age hill forts (Corbet and Southern, 1977)". Few setts are found in the centre of extensive areas of woodland, as easy access to various habitats is desired. As badgers and their setts are legally protected, a licence is required from MAFF before a sett can be disturbed. Where badger populations are stable, new sets are rarely dug and they may be tolerated on some larger archaeological monuments. However, where they become established on smaller sites, some control measures may be required. There have also been reports of many artefacts associated with entrances to badger setts, which are exposed on the surface as subsurface soil has been excavated. Freely draining soils are required that are easy to excavate and firm enough not to collapse. Such conditions are typical of earthworks on chalkland.

Deer - although preferences will differ, all species of deer found in British woodlands will feed upon some flora associated with clearings. Erosion damage will relate to population densities and whether the site contains any point at which they may congregate, e.g. for shelter. Features such as standing stones may be subjected to abrasion by deer "scratching" their antlers.

Many woodlands now contain open areas designed to increase their biodiversity and ecological value. Where a woodland is to have a glade created, and archaeological evidence exists, there may be a desire to combine the two by creating the glade around the feature. Where both do occur, fences may need erecting to exclude larger animals from the feature. Glade creation will often attract an increased number of deer and many burrowing mammals prefer open ground with adjacent shelter rather than dense woodland. Other site factors such as soil type, drainage and location will also have an influence on the mammal species that will utilise the site. Depending on the type of archaeological feature, the active encouragement of mammal species may not be preferable for its conservation.

4.7. Root control

In some areas of the construction industry, physical barriers are placed underground to impede root growth and to reduce soil shrinkage caused by dehydration. Such protection has been considered for archaeological sites but the use of root barriers has met with mixed success. Concrete is the cheapest option but may not be able to withstand sub-soil movements. Steel reinforced concrete will endure greater forces, but like normal concrete, will involve considerable ground disturbance during installation and thus be unusable. Sheet steel can be driven into the soil but care must be taken over the construction of the any joints as these can be areas of weakness (Marshall *et al*., 1997). Geotextiles, geomembranes and Biobarriers™ are various terms that are used for the separation of underground objects, the latter containing a slow-release root growth inhibitor (Moffat *et al*., 1998). Edwards *et al*. (1999), studied the roots of trees grown in Geotextile fabric bags. They concluded that whilst some roots penetrated through the membrane, thicker fabrics had more resistance and trees grown in these bags had their growth checked. Edwards *et al*. recommended that any root barrier should be as far from the tree as possible to reduce the size of the root encountered.

Installation of any membrane would require significant ground disturbance, a process that would be undesirable on or close most archaeological sites. However, such membranes may be of use to protect evidence that has been excavated, recorded and re-buried *in situ*. If such a site is to be re-vegetated with ground cover, sufficient topsoil must be placed above any membrane to provide sufficient rooting space and reduce the likelihood of root impacts. Figure 3.3 shows an example of a hawthorn root that had penetrated an inadequate polyethene sheet placed over a previously excavated mosaic floor. Only 10 cm of soil had been placed back on top of the polyethene. The durability of many barriers below ground is also uncertain and those that do carry guarantees against degradation are for 20-30 years, considerably less that the lifespan of trees or archaeological remains. Marshall *et al*. also gave examples where roots had circumnavigated barriers and, in the case of a poplar, had grown above ground.

Many textiles, membranes and soil stabilising sheets are available and have been used for archaeological conservation. Berry (1994$_a$) gave examples of their misuse where geotextiles (designed to separate sub-soil features) have been used as stabilising ground cover. Subsequent trampling and exposure to ultra-violet light resulted in rapid degradation of the material. Berry also raised the issue of chemical composition and asked whether items made from non-renewable sources should be used and what impacts impregnated biological growth inhibitors would have on archaeological evidence. Temporary soil stabilisation to enable plant recolonisation may be obtained by the use of biodegradable products. An extensive list of textiles, membranes, their suppliers and recommended function is given by Haygarth (1994).

Whilst it is clear that such materials, when correctly selected, can aid soil surface stabilisation and reduce erosion from grazing or visitor pressure, the use of barriers to inhibit roots is less guaranteed. Considering the soil disturbance in their installation, their replacement every 30 years and the costs involved, their use is unlikely to be proposed for the majority of sites occurring in woodland

4.8. Management options

When a site of archaeological interest exists within a forest or woodland, the landowner must know whether or not it is scheduled as this will have a bearing on what work, if any can be carried out (Her Majesty's Government, 1979). The majority of archaeological sites are not scheduled and here the long-term fate of any archaeological evidence is largely dependent on the landowner and 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. Lee (1995) commented that many monuments suffer damage from a wide range of minor forest operations due to a lack of awareness or information available to contractors. Within the Forestry Commission, all scheduled monuments are recorded on a GIS and each has its own management plan. Additionally, many unscheduled sites are also mapped and some forest districts have commissioned their own archaeological surveys. The use of markers to indicate a site, is a point of debate, and many types have been tried. These vary from wooden stakes of a particular colour (which may be masked by vegetation or attract unwanted human interest) to individual trees of a different species to those in the immediate vicinity. As yet no standard convention exists and while features may appear on a map, identification and location on site may be problematic.

Many important sites within woodlands are devoid of tree cover and adjacent felling can often provide an opportunity to further enhance the setting of the archaeological remains. Here management issues include some of the following:

- Public access - where visitor numbers are likely to be high, erosion control may be required. For example, Griffiths (1994) refers to an apparently irresistible human urge to move smaller stones from monuments around on Dartmoor. The lighting of fires is also very common inside burial mounds and henge monuments. Careful consideration is required to determine the likely visitor impacts. If the site is not to be opened to the public then access for management purposes should still be maintained. This is of particular relevance to the Forestry Commission as it is policy to increase public access to the estate.

- Weed control - if areas of young plantation exist nearby, grazing will not be desirable without the extensive use of fencing. Occasional weed/grass cutting is likely to be required.

- Ground cover - some lowland site managers prefer to allow grass cover to revert to native meadow species whereas others at sites with high visitor numbers use amenity grasses. Table 4.2 shows some of the advantages and disadvantages for three grassland types.

Table 4.2. Selection of grass cover.

Grass type	Benefits	Risks
Pasture	Under strict stock control can cause minimal damage	Grazers can erode the soil (see 2.1.6.) Needs occasional fertilizer application
Native species	Beneficial to native fauna. Needs no fertilizers	Not resistant to treading. Increased fire risk. May be regarded as “unsightly”
Amenity	Resistant to treading Slow growing	Needs labour intensive maintenance such as mowing. Difficult on earthworks

Data from Jones (1998).

For other sites, such levels of grass maintenance and weed control may not be practical and some degree of tree cover may be desired or required as a form of site stabilisation or long term protection. Improved understanding of tree/archaeology interactions will allow better informed decisions to be made on the management of archaeological sites.

Conclusions

Current Government policy is to expand the total area of woodland in the UK. In addition, it has committed itself to reducing the use of non-renewable energy sources and is promoting the establishment of biofuels such as Short Rotation Coppice (SRC). Combined with the recent farming problems in Britain, there is an increasing interest in converting areas of farmland to non-agricultural uses. It is inevitable that proposals for new tree cover will involve land with archaeological potential. Many of the issues raised in this paper are not only limited to Britain. For instance, a recent publication on forestry and archaeology that reviews the policy of the forest industry in Ireland also expresses the need for improved communication and further research (Johnson, 1998).

This document shows that there are many ways in which tree growth can have an impact on, or be benign to archaeological evidence, but the literature reviewed indicates that little detail has been published on tree/archaeological interactions. During archaeological excavations, tree roots are seldom recorded and subsequently often omitted from published reports. Whether or not tree cover would be beneficial or detrimental to archaeological evidence will depend upon both the nature of the archaeology, and its surrounding environment. Windthrow and past forest operations have been the frequently quoted cause of damage to some archaeological features. However, modern woodland management, in conjunction with increased awareness, has reduced these threats.

Tree removal has occurred on many archaeological sites and subsequent weed establishment has been a major management problem. On some sites, the possibility of tree cover as an alternative means of archaeological site preservation may be tolerated and practices such as coppicing may help to further lessen the risks of any detrimental impacts. Appendix 5 shows that sites under tree cover were generally found to be in better condition than those under cultivation or in areas of development. Nevertheless, it is clear that more research is needed in many of the areas addressed by this document.

The types of archaeology found within forests or woodlands are very diverse and of varying degrees of importance. Similarly, the site conditions in which they are found and the local flora and fauna also differ greatly. With such variations general recommendations on site management are difficult. For a site-specific, optimum management strategy to be determined, more information would ideally be available on the type of archaeological feature, its importance, its depth if buried, its composition and also on site details such as soil type, altitude, exposure, slope etc. and proposed crop details. Professional judgement on a site-by-site basis is always needed. Nevertheless, it is hoped that a proper discussion of both the advantages and disadvantages of a woodland cover will promote a better, more informed, dialogue between interested parties.

While much of this document refers to Forestry Commission owned land, many of the issues raised are relevant to all land management. The Forestry Commission, in collaboration with archaeology and heritage bodies, is, and should continue to lead by example on the management of important archaeology sites under woodland management.

It is not the intention of this document to suggest tree retention or planting at the expense of the archaeological resource, but to promote further detailed scientific discussion on the issues covered. This, with appropriate research, will lead to a more informed management decision where each site is evaluated on its own environmental and archaeological merits.

References.

Aldhous, J.R. and Mason, W.L. (1994). (eds.) *Forest nursery practic*e. Forestry Commission Bulletin 111. HMSO, London.

Allen, M.J. (1991). Analysing the landscape: a geographical approach to archaeological problems. *In*: A.J. Schofield, ed. *Interpreting artefact scatters; Contributions to the ploughzone.* Oxbow Monograph **4**. 39-57. Oxbow Books, Oxford.

Atkinson, R.J.C. (1957). Worms and weathering. *Antiquity* **31**, 219-233.

Augusto, L., Ranger, J. Turpault, M.-P. and Bonnaud, P. (2001). Experimental *in situ* transformation of vermiculites to study the weathering impact of tree species on the soil. *European Journal of Soil Science,* **52,** 81-92.

Bannister, N.R. (1998). *Woodland Archaeology in Surrey: its recognition and management*. Surrey County Council, Kingston upon Thames.

Barclay, G.J. (1992$_a$). Forestry and Archaeology in Scotland. *Scottish Forestry* **46**, 27-47.

Barclay, G.J. (1992$_b$). Vegetation management on ancient monuments in forestry and other areas. *Aspects of Applied Biology* **29**, 105-111.

Barclay, G.J. (1994). Earthwork erosion in eastern Scotland. *In*: A.Q. Berry and I.W. Brown, eds. *Erosion on Archaeological Earthworks: its Prevention, Control and Repair.* 25-30. Clwyd County Council.

Bauhus, J. and Messier, C. (1999). Soil exploitation strategies of fine roots in different tree species of the southern boreal forest of eastern Canada. *Canadian Journal of Forest Research* **29,** 260-273.

Bédéneau, M. and Auclair, D. (1989$_a$). The study of tree fine root distribution and dynamics using a combined trench and observation window method. *Ann. Sci. For.,* **46,** 283-290.

Bédéneau, M. and Auclair, D. (1989$_b$). A comparison of coppice and single-stem root distribution using spiral trenches. *Acta. Oecologica, Oecologica Apllicata,* **10,** 213-220.

Bédéneau, M. and Auclair, D. (1989$_c$). Effect of coppicing on hybrid poplar fine root dynamics. *Ann. Sci. For.,* **46 suppl,** 294s-296s.

Bell, M., Fowler, P.J. and Hillson, S.W. (1996). (Eds.) *The experimental earthwork project, 1960-1990.* CBA Research Report 100, Council for British Archaeology, York.

Bell, M., Caseldine, A. and Neumann, H. (2000). *Prehistoric intertidal archaeology in the Welsh Severn Esturuary.* CBA Research Report 120, Council for British Archaeology, York.

Benedict, J.B. (1993). The influence of snow upon rates of Granodiorite weathering, Colorado, Front Range, U.S.A. *Boreas*, **22,** 87-92.

Berry, A.Q. (1994$_a$). Counting the cost of erosion on archaeological earthworks. *In*: A.Q. Berry and I.W. Brown, eds. *Erosion on Archaeological Earthworks: its Prevention, Control and Repair.* 1-4. Clwyd County Council.

Berry, A.Q. (1994$_b$). Counting the cost…the sequel. *In*: A.Q. Berry and I.W. Brown, eds. *Erosion on Archaeological Earthworks: its Prevention, Control and Repair.* 45-54. Clwyd County Council.

Biddle, P.G. (1998). *Tree root damage to buildings: causes, diagnosis and remedy*. Willowmead Publishing, Wantage.

Bloemker, J.D. and Oakley, C.B. (1999). The Firebreak Plough and subsurface site discovery. *Journal of Field Archaeology*, **26,** 75-82.

Broad, K. (1989). *Lichens in southern woodlands.* Forestry Commission Handbook 4. HMSO, London.

Broadmeadow, M.S.J. and Freer-Smith, P.H. (1996). *Urban woodland and the benefits for local air quality.* DoE Research for Amenity Trees 5. The Stationery Office, London.

Brodo, I.M. (1973). Substrate Ecology. *In:* V. Ahmadjian and M.E. Hale, eds. *The Lichens.* 401-442. Academic Press, London.

Cleal, R.M.J. and Allen, M.J. (1994). Investigation of tree-damaged barrows on King Barrow Ridge and Luxenborough Plantation, Amesbury. *The Wiltshire Archaeological and Natural History Magazine,* **87,** 54-84.

Corbet, G.B. and Southern, H.N. (1977). *The Handbook of British Mammals, 2nd ed.* Blackwell Scientific Publications, Oxford.

Courchesne, F. and Gobran, G.R. (1997). Mineralogical variations of bulk and rhizosphere soils from a Norway spruce stand. *Soil Sci. Am. J.* **61,** 1245-1249.

Cressey, M. (1996). *Forestry and Archaeology at Tamshiel Rig, Scottish Borders*. Report 308. Centre for Field Archaeology, University of Edinburgh.

Crow, P. (1998). *Mineral bag method: progress report.* Internal Forest Research report, Unpublished.

Crow, P. (2002). *A soil guide to longevity: Woodland soil chemistry and implications for the archaeological resource*. MSc Dissertation. University of Reading, 85 pp.

Crow, P. (2003). Community woodland establishment on the Avon Levels and archaeological site assessment: a case study. *Archaeology in the Severn Estuary 13.*

Crow, P. and Houston, T.J. (in press). The rooting habit of Short Rotation Coppice (SRC) on Pelosol, Brown earth, Surface and Ground Water Gley soils.. *Biomass & Bioenergy.*

Crow, P. and Yarnell, T. (2002). Preservation or destruction? Archaeological site management in woodland environments. *Forestry and British Timber,* January, 14 - 16.

Crowther, R.E. and Evans, J. (1984). *Coppice.* Forestry Commission Leaflet 83. HMSO, London.

Crowther, R.E., Low, A.J. and Tabbush, P.M. (1991). Establishment and tending. *In:* B.G. Hibberd, Ed. *Forestry Practice.* Forestry Commission Handbook 6. HMSO, London. 41-80.

Cunliffe, B. (1984). Danebury - an Iron Age hillfort in Hampshire. Vol. 1**.** –The excavations, 1969-1978. C.B.A. Research Report 52. Council for British Archaeology, York.

Cunliffe, B. (1995). Danebury - an Iron Age hillfort in Hampshire. Vol. **6.** -*A hillfort community in perspective.* C.B.A. Research Report 102. Council for British Archaeology, York.

Cunliffe, B. and Poole, C. (1991). Danebury - an Iron Age hillfort in Hampshire. Vol. **4.** -*The excavations, 1979-1988: the site.* C.B.A. Research Report 73. Council for British Archaeology, York.

Cutler, D.F., Gasson, P.E and Farmer, M.C. (1990). The wind blown tree survey: Analysis of results. *Arboricultural Journal,* **14**, 265-286.

Darvill, T. (1986). *The Archaeology of the Uplands: A rapid assessment of archaeological knowledge and practice*. Royal Commission on the Historical Monuments (England) & The Council for British Archaeology.

Darvill, T. (1987) *Ancient Monuments in the Countryside: an archaeological management review.* English Heritage Archaeological Report 5, English Heritage, London

Darvill,T. and Fulton, A.K. (1998). *The Monuments at Risk Survey 1995: Summary report.* English Heritage, London.

Dobson, M.C. (1995). Tree root systems. *Arboriculture Research and Information Note 130/95/ARB.* Arboricultural Advisory and Information Service, Farnham.

Dobson, M.C. and Moffat, A.J. (1993). *The potential for woodland establishment on landfill sites.* Department of the Environment. HMSO, London.

DTI. (1999). *New and Renewable Energy: prospects for the 21st Century.* Department of Trade and Industry. Stationery Office, London.

Dunwell, A.J. and Trout, R.C. (1999). *Burrowing animals and archaeology.* Technical Advice Note 16. Historic Scotland, Edinburgh.

Edwards, R.A., Rowe, R.N. and Trought, M.C.T. (1999). Control of tree growth in the urban environment using Geotextile fabric bags. *Arboricultural Practice Note* **4**. Arboricultural Advisory and Information Service, Farnham.

Evans, J. (1991). Forestry in Britain. *In:* B.G. Hibberd, (ed.) *Forestry Practice.* Forestry Commission Handbook 6. HMSO, London, 1-10.

Evans, J. and O'Connor, T. (1999). *Environmental Archaeology: principles and methods*. Sutton Publishing, Stroud.

Evans, R. (1980). Mechanics of water erosion. *In:* M.J. Kirkby and R.P.C. Morgan, (eds.) *Soil erosion,* 109-128. John Wiley and Sons, Chichester.

Forestry Commission (1995). *Forests and Archaeology Guidelines*. HMSO, London.

Forestry Commission (1997). *Annual Report and Accounts 1996-97*. The Stationery Office, Edinburgh.

Forestry Commission (1998_a). *The UK Forestry Standard.* Forestry Commission, Edinburgh.

Forestry Commission (1998_b). *Forests and Soil Conservation Guidelines.* Forestry Commission, Edinburgh.

Forestry Commission (1998_c). *Forest of Dean Forest District Ancient Monument Management Plan.* Unpublished.

Forestry Commission (2000). *Forests and Water Guidelines 3rd ed.* The Stationery Office, London.

Forestry Commission (2001). *Facts and Figures 1999-2000*. Economics and Statistics Unit, Forestry Commission, Edinburgh.

Foster, S.M. and Hingley, R. (1994). The potential and significance of field system remains. *In*: S. Foster and T.C. Smout, eds. *The History of Soils and Field Systems.* 135-144. Scottish Cultural Press, Aberdeen.

Freestone, I.C. (2001). Post- depositional changes in archaeological ceramics and glasses. *In*: D.R. Brothwell and A.M.Pollard, eds. *Handbook of archaeological science*. 615-625. John Wiley and Sons, Ltd. Chichester.

Frodsham, P. (1994). Monument management in Berkshire. *In*: A.Q. Berry and I.W. Brown, (eds.) *Erosion on Archaeological Earthworks: its Prevention, Control and Repair.* 55-70. Clwyd County Council.

Gerrard, S. (1999). *The Dartmoor archaeology and Bracken project: interim report for 1999 season*. S. Gerrard, Hillview, Wembworthy, Devon.

Gibbs, J., Greig, B. and Rishbeth, J. (1996). Tree diseases of Thetford Forest and their influence on its ecology and management. *In:* P.Ratcliffe and J. Claridge, (eds.) *Thetford Forest Park: the Ecology of a Pine Forest.* Forestry Commission Technical Paper 13. Edinburgh. 26-32.

Goldberg, P. and Macphail, R.I. (1989). *Soils and micromorphology in archaeology*. Cambridge University Press, Cambridge.

Griffiths, D. (1994). Dartmoor: erosion on open moorland. *In*: A.Q. Berry and I.W. Brown, (eds.) *Erosion on Archaeological Earthworks: its Prevention, Control and Repair.* 81-86. Clwyd County Council.

Hall, R. (1996). *Hydrological effects of short rotation coppice*. ETSU Report B/W5/00275/REP. ETSU, Harwell.

Hanley, R. and Wordsworth, J. (1997). *Preserved in the forest? Excavations at Glen Brein, Stratherrick, Inverness-shire 1997*. 2nd interim report. Highland Council, Inverness.

Harmer, R. (1999). *Using natural colonisation to create or expand new woodlands.* Forestry Commission Information note 23. Forestry Commission, Edinburgh.

Harris, E.H.M. and Harris, J.A. (1997). *Wildlife conservation in managed woodlands and forests. 2nd ed.* Research Studies Press, Taunton.

Harris, J.A. and Hill, T.C.J. (1995). Soil biotic communities and new woodland. *In:* R. Ferris-Kaan, (ed.) *The ecology of woodland creation.* John Wiley and Sons, Chichester, 91-112.

Hart, C.E. (1991). *Practical forestry for the agent and surveyor. 3rd ed.* Alan Sutton Publishing, Stroud.

Hawksworth, D.L. and Rose, F. (1976). *The lichens as pollution monitors.* Studies in Biology 66. Camelot Press, Southampton.

Haygarth, S. (1994). Product listing. *In*: A.Q. Berry and I.W. Brown, eds. *Erosion on Archaeological Earthworks: its Prevention, Control and Repair.* 117-157. Clwyd County Council.

Hearn, K. (1994). Habitat Re-creation: Possible or Impossible? *In*: A.Q. Berry and I.W. Brown, eds. *Erosion on Archaeological Earthworks: its Prevention, Control and Repair.* 111-113. Clwyd County Council.

Her Majesty's Government (1979). Ancient monuments and archaeological areas Act 1979. HMSO, London.

Herz, N. and Garrison, E.G. (1998). *Geological methods for archaeology.* Oxford University Press. Oxford.

Hester, A.J., Kirby, K.J., Mitchell, F.J.G., Gill, R.M.A., Latham, J. and Armstrong, H. (1998). Ungulates and Forest Management in Great Britain and Ireland. *In:* J. Humphrey, R.Gill and J. Claridge. (eds.) *Grazing as a management tool in European forest ecosystems.* Forestry Commission Technical Paper 25. Forestry Commission, Edinburgh. 24-35.

Hopkins, D.W. (1996). The biology of the burial environment. *In:* M. Corfield, P. Hinton, T. Nixon and M. Pollard. (eds.) *Preserving archaeological remains in situ: (conference proceedings).* Museum of London Archaeological Service.

Hughes, A.J.G. and Roebuck, B.A. (1991). Harvesting. *In:* B.G. Hibberd, Ed. *Forestry Practice.* Forestry Commission Handbook 6. HMSO, London.

Imeson, A.C. and Vis, M. (1984). Seasonal variations in soil erodibility under different land-use types in Luxembourg. *Journal of Soil Science,* **35**, 323-331.

Jackson, A.M. (1978). *Forestry and archaeology: A study of field monuments in south west Scotland.* The British Archaeological Trust, Hertford.

Johnson, G. (1998). *Archaeology and forestry in Ireland*. The Heritage Council, Kilkenny, Ireland.

Jones, K.L. (1998). The state of large earthworks in the UK. *Antiquity*, **72**, 293-307.

Lee, G. (1994). Erosion control on Cawthorn Roman Camps. *In*: A.Q. Berry and I.W. Brown, (eds.) *Erosion on Archaeological Earthworks: its Prevention, Control and Repair,* 87-92. Clwyd County Council.

Lee, G. (1995). Forestry management and archaeology. *In*: A.Q. Berry and I.W. Brown (eds.) *Managing ancient monuments: An integrated approach.* 97-104. Clwyd County Council.

Leyval, C. and Berthelin, J. (1991). Weathering of mica by roots and rhizospheric microorganisms of pine. *Soil Soc. Am. J.* **55**, 1009-1016.

Limbrey, S. (1975). *Soil science and archaeology*. Academic Press. London.

McCombie, P.F. (1993). The relative water demand of broad-leaved trees:- a new analysis of the Kew tree root survey. *Arboricultural Journal,* **17**, 359-374.

McNeil, M. and Selwyn, L.S. (2001). Electrochemical processes in metallic corrosion. *In*: D.R. Brothwell and A.M.Pollard, eds. *Handbook of archaeological science*. 605-614. John Wiley and Sons, Ltd. Chichester.

Macinnes, L. (1997). Archaeology as land use. *In* : J. Hunter and I. Ralston, (eds.) *Archaeological resource management in the UK: An introduction,* 243-255. Sutton publishing & Institute of Field Archaeology.

Malcolm, D.C. and Moffat, A.J. (1996). Forestry, Soils and Sustainability. *In* A.G. Taylor, J.E. Gordon and M.B. Usher, (eds.) *Soils, Sustainability and the Natural Heritage.* HMSO, Edinburgh, 194-209.

Marshall, D., Patch, D. and Dobson, M. (1997). Root barriers and building subsidence. *Arboricultural Practice Note* **4**. Arboricultural Advisory and Information Service, Farnham.

Moffat, A.J. (1988). Forestry and soil erosion in Britain - a review. *Soil Use and Management.* **4**, 41-44.

Moffat, A.J., Bending, N.A.D. and Dobson, M.C. (1998). Barriers against tree roots - an experimental investigation. *Arboriculture Research and Information Note 141/98/ERB.* Arboricultural Advisory and Information Service, Farnham.

Moffat, A.J. and McNeill, J.D. (1994). *Reclaiming disturbed land for forestry.* Forestry Commission Bulletin 110. HMSO, London.

Newman, J. (1988). The soil fauna other than protozoa. *In:* A.Wild, (ed.) *Soil conditions and plant growth, 11th ed.*, 500-525. Longman Scientific and Technical, Harlow.

Ochs, M., Brunner, I., Stumm, W. and Ćosović, B. (1993). Effects of root exudates and humic substances on weathering kinetics. *Water, Air and Soil Pollution* **68**, 213-229.

Ordnance Survey (1973). *Field Archaeology in Great Britain. 5th ed.,* Ordnance Survey, Southampton.

Page, C.N. (1997). *The Ferns of Britain and Ireland, 2nd ed.,* Cambridge University Press. Cambridge.

Paris, F., Bonnaud, P., Ranger, J. and Lapeyrie, F. (1995). In vitro weathering of phlogopite by ectomycorrhizal fungi. *Plant and Soil* **177**, 191-201.

Patterson, G. and Anderson, R. (2000). *Forests and Peatland habitats.* Forestry Commission guideline note. Forestry Commission, Edinburgh.

Pollard, M.A. and Heron, C. (1996). *Archaeological chemistry.* RSC Paperbacks. The Royal Society of Chemistry, Cambridge.

Proudfoot, E.V.W. (ed.) (1989). *Our vanishing heritage: Forestry and archaeology*. Council for Scottish Archaeology, Edinburgh. Occasional Paper No. 2.

Quine, C.P., Coutts, M.P., Gardiner, B.A. and Pyatt, D.G. (1995). *Forests and Wind: Management to minimise damage.* Forestry Commission Bulletin 114. HMSO, London.

Quine, C.P. and Gardiner, B.A. (1998). ForestGALES - replacing the Windthrow Hazard Classification. *In: Forest Research Annual Report and Accounts 1997-98.* 26-31. The Stationery Office, Edinburgh.

Randall, R. and Dymond, D. (1996). Why Thetford Forest? The human and natural history of Breckland before the early 20th century. *In:* P.Ratcliffe and J. Claridge, (eds.) *Thetford Forest Park: the Ecology of a Pine Forest.* Forestry Commission Technical Paper 13. Forestry Commission, Edinburgh, 1-15.

Ranger, J., Robert, M., Bonnaud, P. and Nys, C. (1990). Les minéraux-test, une approche expérimentale in situ de l'altération biologique et du fonctionnement des écosystèmes forestiers. Effets des types de sols et des essences feuillues et résineuses. *Ann. Sc.i For.* **21**, 529-550.

Rees, S.E. (1994). Erosion in Wales: The extent of the problem. *In*: A.Q. Berry and I.W. Brown, (eds.) *Erosion on Archaeological Earthworks: its Prevention, Control and Repair,* 29-35. Clwyd County Council.

RGAR, (1997). *Acid deposition in the United Kingdom 1992-1994: Forth report of the Review Group on Acid Rain.* Prepared at the request of the Department of the Environment, Transport and the Regions, June 1997. AEA Technology, Abingdon.

Richardson, I.B.K. (1995). Dead or alive? Is it really that simple? *Arboricultural Journal*, **19**, 395-400.

Ryter, R.M. (1997). Fine root production and carbon and nitrogen allocation in basket willows. Doctoral thesis, *Silvestria* **39.** Swedish University of Agricultural Science, Uppsala, Sweden.

Shepperd, W.D. and Smith, F.W (1993). The role of near-surface lateral roots in the life cycle of aspen in the central Rocky Mountains. *Forest Ecology and Management,* **61**, 157-170.

Smout, T.C. (1989). Panel Discussion. *In*: E.V.W. Proudfoot, (ed.) *Our vanishing heritage: Forestry and archaeology*. Occasional papers No. 2, 34-36. Council for Scottish Archaeology, Edinburgh.

Soutar, R.G. (1989). Afforestation and sediment yields in British fresh waters. *Soil Use and Management.* **5**, 82-86.

Stoutjesdijk, Ph. and Barkman, J.J. (1992). *Microclimate, Vegetation and Fauna*. Opulus Press AB, Knivsta, Sweden.

Streeten, A.D.F. (1994). Managing ancient earthworks - diagnosis, cure and prevention of erosion. *In*: A.Q. Berry and I.W. Brown, (eds.) *Erosion on Archaeological Earthworks: its Prevention, Control and Repair,* 5-15. Clwyd County Council.

Sullivan, M. and Malville, J.M. (1993). Clay sourcing at Chimney rock: The chemistry and mineralogy of feather holders and other ceramics. *In:* J.M. Malville and G. Matlock, (eds.) *The Chimney rock archaeological symposium.* USDA Forest Service General Technical Report RM-227, Colorado, USA.

Tamm, C.O. (1991). What ecological lessons can we learn from deforestation processes in the past? *In:* H.A. Mooney et al. (eds.) *Ecosystem Experiments* Scope 45, 45-58. John Wiley, Chichester.

Taylor, A. (1994). Flat earth erosion control: Caring for archaeological monuments in Cambridgeshire. *In*: A.Q. Berry and I.W. Brown, (eds.) *Erosion on Archaeological Earthworks: its Prevention, Control and Repair,* 71-80. Clwyd County Council.

Taylor, C.M.A. (1991). *Forest fertilisation in Britain.* Forestry Commission Bulletin 95. HMSO, London.

Taylor, J.A. (1986). The bracken problem: a local hazard and global issue. *In:* R.T. Smith and J.A. Taylor, (eds.) *Bracken: Ecology, Land use and Control Technology.* Parthenon Publishing. Carnforth.

Thackray, D. (1994). The management of monuments and erosion control on National Trust properties. *In*: A.Q. Berry and I.W. Brown, (eds.) *Erosion on Archaeological Earthworks: its Prevention, Control and Repair,* 103-110. Clwyd County Council.

Walderhaug, O. (1998). Chemical weathering at Rock Art sites in Western Norway: which mechanisms are active and how can they be retarded? *Journal of Archaeological Science* **25**, 789-800.

Waldron, L.J. and Dakessian, S. (1981). Soil reinforcement by roots: calculation of increased soil shear resistance from root properties. *Soil Science*, **132,** 427-435.

Webster, J. (1997). Shelter trees in animal protection. *In:* H. Palmer, B. Gardiner, M. Hislop, A. Sibbald and A. Duncan, (eds.) *Trees for Shelter*. Forestry Commission Technical Paper 21, 24-30. Edinburgh.

Wilson, S.J. and Cooke, R.U. (1980). Wind erosion. *In:* M.J. Kirkby and R.P.C. Morgan, (eds.) *Soil erosion,* 217-251. John Wiley and Sons, Chichester.

Wood, M. (1995). *Environmental soil biology, 2nd ed.* Blackie Academic and Professional, Glasgow.

Yarnell, T. (1999). Woods and forests in the rural landscape: cultural heritage, conservation and management. *In*: J. Grenville, (ed.) *Managing the historic rural landscape,* 101-110. Routledge, London.

APPENDIX 2.

Vegetative nature of some common tree species.

Species	Vigorous coppice	Possible coppice	Unlikely to coppice	Likely to sucker	Occasional suckers
Broadleaves					
Acer		√			√
Aesculus		√			√
Alnus	√			√	
Betula		√			
Carpinus		√			
Castanea	√				
Corylus	√				
Crataegus	√				
Eucalyptus	√				
Fagus			√		
Fraxinus	√				
Ilex	√				
Juglans		√			
Malus			√		
Nothofagus		√			
Plantanus	√				
Populus	√			√	√
Prunus		√		√	
Pterocarya	√			√	
Pyrus			√		
Quercus		√			
Quercus ilex	√				
Salix	√				
Sorbus		√			
Tilia		√			
Ulmus		√		√	
Conifers					
Juniperus		√			
Sequoia	√				
Taxus		√			
All others			√		

Data from Biddle (1998).

Appendix 3.

The table below is a summary of results from the 1987 storm damage survey.
It shows the different rooting characteristics and the soil types on which windthrow occurred.
It should be noted that these results are primarily only from southern England.

Data adapted from Cutler, Gasson and Farmer, (1990)

	Soil type on which windthrow occurred.								Maximum root plate depth (m).					Root plate diameter (m).							
Genus	sand	clay	chalk	silt	loam	gravel	peat	sand&silt	<.5	.5-1	1-1.5	1.5-2	>2	.5-1	1-1.5	1.5-2	2-3	3-4	4-5	>5	Total number of trees
Oak	70	43	14	1	6	25	0	2	4	39	62	31	9	9	24	33	61	17	9	8	161
Beech	35	34	21	1	9	6	0	0	5	28	52	14	4	4	12	10	45	11	10	13	105
Pine	18	6	5	0	0	3	2	1	2	8	16	5	1	0	10	7	13	3	2	0	35
Lime	16	9	5	0	0	7	1	0	1	6	12	4	3	0	3	8	22	5	1	0	39
Spruce	22	16	0	0	0	0	0	1	3	21	10	1	1	0	1	6	20	8	2	2	39
Birch	20	5	1	0	3	3	0	4	4	13	13	1	1	6	7	12	6	2	1	1	35
Ash	10	4	14	0	0	4	0	0	0	10	14	4	3	2	6	8	8	4	2	2	32
Chestnut	13	7	0	0	0	7	0	2	1	6	14	1	2	1	8	9	7	2	1	1	29
Poplar	3	6	0	0	1	4	0	0	0	2	3	6	2	0	2	2	5	2	2	1	14
Fir	11	2	0	0	0	0	0	0	1	4	4	3	2	0	3	3	4	2	0	1	13
Willow	3	3	0	0	0	1	0	0	2	1	4	0	0	1	3	2	1	0	0	0	7
H.Chestnut	4	0	0	0	0	2	1	1	0	4	2	0	0	0	3	3	1	0	0	0	7

Appendix 4.

Summary of survey data
(Data from 316 scheduldded sites in Scotland under FE management).

Site Observation (by type)	**Number of sites**	**%[*]**	**Site Observation (by number)**	**Number of sites**	**%[*]**
Animal-feeding	1	0.3	Forestry- under plantation	168	53.2
Rabbits	6	1.9	Total harmful veg. (non-tree)	151	47.8
Erosion- animal	2	0.6	Shrubs and scrub	75	23.7
Erosion-recreational	2	0.6	Bracken	53	16.8
Erosion-visitor	10	3.2	Trees	51	16.1
Vandalism	1	0.3	Forestry-ploughing	45	14.2
Forestry- under plantation	168	53.2	Other harmful vegetation	23	7.3
Forestry-ploughing	45	14.2	Wind blown trees	19	6.0
Trees	51	16.1	Fencing/walls	17	5.4
Wind blown trees	19	6.0	Drains	13	4.1
Shrubs and scrub	75	23.7	Erosion-visitor	10	3.2
Bracken	53	16.8	Linear/services	9	2.8
Other harmful vegetation	23	7.3	Building decay	8	2.5
Total harmful veg. (non-tree)	151	47.8	Rabbits	6	1.9
Drains	13	4.1	Traffic	6	1.9
Linear/services	9	2.8	Dumping	4	1.3
Stone weathering	3	0.9	Excavation/development	3	0.9
Building decay	8	2.5	Stone weathering	3	0.9
Traffic	6	1.9	Erosion- animal	2	0.6
Dumping	4	1.3	Erosion-recreational	2	0.6
Excavation/development	3	0.9	Animal-feeding	1	0.3
Fencing/walls	17	5.4	Vandalism	1	0.3

N.B. Few problems are seen from grazing as little occurs in Scottish forestry.

[*] Total sum of percentage is greater than 100, as some sites recorded more that one obsevation

Seriousness and causes of damage on Offa's and Wat's Dykes in Wales

Appendix 5.