Natural England Research Report NERR010

Impact of heathland restoration and re-creation techniques on soil characteristics and the historical environment

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Isabel Alonso (Heathland Ecologist, Natural England), Joy Ede (Historic Environment Advisor, Natural England) and Julie Holloway (Senior Soil Specialist, Natural England) provided contacts, information, references and edited the report.

A summary of the findings covered by this report, as well as Natural England's views on this research, can be found within Natural England Research Information Note RIN010: Impact of heathland restoration and re-creation techniques on soil characteristics and the historical environment.

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Summary

Lowland Heathland is a Priority Habitat for conservation under the UK Biodiversity Action Plan (BAP). This Habitat Action Plan (HAP) aims to arrest loss of lowland heathland habitat, improve the condition of existing heathlands and to create new areas of lowland heathland. Sites to be restored to favourable condition, from dense scrub or bracken cover for example, may require litter removal and/or soil disturbance. Furthermore, a significant percentage of the new HAP target for heathland expansion is likely to come from ex-arable land and conifer plantations, which will require more drastic intervention.

Under the First Soil Action Plan for England, Natural England will have regard to the proper management of soil alongside other requirements. However, the conservation and restoration of habitats such as heathlands, supported and promoted by Natural England, involves widely-used techniques which could potentially pose a risk for the soil and archaeological interest of soils.

A project was set up in 2007 to:

1) define the importance of heathland soil features and their archaeological interest;
2) provide an analysis of the existing scientific literature of the benefits vs. problems of various methods of soil preparation for heathland restoration (improve the condition) and/or re-creation (change the land use from agriculture or forestry) practices on the soil characteristics and archaeology;
3) evaluate, through a questionnaire for site managers and case studies, how often these practices have been carried out during heathland restoration/re-creation activities in the UK in the last 10 years.

A best-practice guidance based on the findings is proposed for future restoration and re-creation projects.

Methodology

A literature review was carried out on the range of methods for heathland restoration and re-creation being applied across Europe, their potential impact and their relative efficacy in different situations. The methods available to contemporary practitioners were categorised based upon the general broad similarity of methodologies.

The extent to which heathland restoration and re-creation have altered soils, or not, was explored through a questionnaire sent to 66 site managers and advisors. A total of 26 questionnaires were completed covering a wide range of restoration and re-creation projects of varying size in a variety of geographical locations across the UK.

Results

Soil preparation techniques were classified into four categories:

1) Surface vegetation (herb layer) management and removal techniques (grazing, cutting, herbicide application and burning).
2) Soil acidity and nutrient status amelioration techniques (cropping and acidification with sulphur, bracken/pine litter or peat).
3) Surface and below-ground vegetation (trees and shrubs) removal techniques.
4) Soil disturbance and soil removal techniques (litter removal, surface disturbance, ploughing, inversion and rotovation). The potential for damaging impacts was in general inversely related to their effectiveness, although most techniques were used in combination.

The impact of these techniques on carbon sequestration was also considered. Restoration from forestry could decrease carbon stocks if performed by rapid clear felling. Restoration without clear felling could maintain stocks. The stocks could increase when restoring heathland from former agriculturally improved heathland soils.

Discussion

The long-term persistence of acidic podzol soils and seedbanks under conifer plantations suggest that this should be the most practical and cost-effective method for restoring lowland *Calluna* heathland. The timber crop can be sold in some cases to offset costs of restoration, and there should be no need to dispose of large volumes of soil. In addition there would be little need to improve the soils. As a precursor to most of the forestry on heathland in some areas, wet heath and mire was drained and most sites ploughed. Heathland restoration involves not just removing trees but restoring the original hydrology along with the capacity to store carbon in peat and undisturbed soils.

The re-creation of heathland on former arable land can prove more problematic and expensive owing to the presence of soils with a high nutrient status and elevated pH. The wholesale removal or deep ploughing that might be necessary could compromise any archaeology that might have survived the previous agricultural processes. In addition, any acidification of the soil using elemental sulphur in particular, could affect soil processes and archaeological preservation.

Heathland is a fantastic land use for preserving archaeology, much much better than woodland or arable. However, in soils confirmed as having scientific and conservation value, or any archaeological interests, non-disturbance methods are the only option to avoid causing irreversible damage to these features. Methods such as cutting, burning, or herbicide application can be successful in restoring (ie from neglect) former heathland, but their effectiveness in successfully re-creating (ie from different land use) heathland can be limited where soil nutrients need to be reduced. It will be then unpractical or undesirable to consider heathland re-creation on arable land, especially if archaeological interest is suspected. When there is archaeological interest in conifer plantations or secondary woodland, then the use of methods that do not cause mayor disturbance, such as shallow rotovation or burning followed by grazing, has been proven to produce good results.

The questionnaire results suggest that nearly two thirds of heathland restoration practitioners that responded were aware of the need to protect any archaeological interest. However, project management practice did not always incorporate an appropriate archaeological assessment, which could inform the restoration approach or give the same regard to the intrinsic scientific and nature conservation value of soils.

Recommendations

Consider the outlined guidance for the protection of soils and archaeological interest when restoring or re-creating heathlands. In particular:

1) investigate the initial condition (land use, soil characteristics and potential archaeology) involving relevant experts;
2) evaluate the potential impact of the intervention versus the value of the soils and the habitat to be restored; and
3) apply the most appropriate techniques to reduce disturbance and increase efficacy.

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1 Introduction

The importance of lowland heathlands

1.1 The Biodiversity Action Plan definition of the priority habitat 'Lowland heathland' (BRIG 2007) is as follows:

"Lowland heathland is a broadly open landscape on impoverished, acidic mineral and shallow peat soil, which is characterised by the presence of plants such as heathers and dwarf gorses. It is generally found below 300 metres in altitude in the UK, but in more northerly latitudes the altitudinal limit is often lower. Areas of heathland in good condition should consist of an ericaceous layer of varying heights and structures, plus some or all of the following additional features, depending on environmental and/or management conditions: scattered and clumped trees and scrub; bracken; areas of bare ground; areas of acid grassland; lichens; gorse; wet heaths, bogs and open water. Lowland heathland can develop on drift soils and weathered flint beds over calcareous soils (limestone or chalk heath). Lowland heathland is a dynamic habitat which undergoes significant changes in different successional stages, from bare ground (eg after burning or tree clearing) and grassy stages, to mature, dense heath. These different stages often co-occur on a site. The presence and numbers of characteristic birds, reptiles, invertebrates, vascular plants, bryophytes and lichens are important indicators of habitat quality".

1.2 The extent of lowland heathland decreased significantly in the UK, especially during the twentieth century, as a result of development, afforestation and lack of management. However, during the last decade, a huge effort has been made to recover the area and the condition of lowland heathlands across the country.

1.3 Heathland has considerable significance for both archaeology and landscape history and archaeological remains are more likely to survive under heathland management than under forestry or arable operations. References to it occur in numerous works on the subject (Fowler 1981; Lewis, Mitchell-Fox & Dyer 1997; Dark & Dark 1997; Thirsk 2000). Research in the post-war era by pioneers like G.W. Dimbleby (1962) and J.G. Evans (1975) demonstrated that heathland was not 'natural' but a consequence of human interference with vegetation and soils. It should not be a surprise, therefore, that heathland and archaeology are closely entwined. Good introductions to the issues can be obtained from Nigel Webb's 1986 study, Heathlands, or Oliver Rackham's The History of the Countryside of the same year, who discussed it primarily in the context of the medieval landscape. Rackham concurred with current definitions by ecological criteria, differentiating heathland from moorland (which was often in the past described by the same term) largely on the issue of the presence or absence of peat.

Heathland restoration and re-creation

1.4 Heathland **management** is defined as operations (such as low-intensity stock grazing, controlled burning, heather cutting, rotovation and the creation of bare ground) which are carried out to maintain the quality of existing lowland heathland vegetation and landscapes.

1.5 Heathland **restoration** is defined as operations (such as scrub removal, bracken and rhododendron control) which are carried out to improve the quality of existing lowland heathland vegetation and landscapes by recovering heathland vegetation in situations where it has been partly, but not totally, lost to the invasion of other vegetation types such as bracken, scrub and rhododendron.

1.6 Heathland **re-creation**, by contrast, refers to situations where the intention is to create new heathland. This implies a change of land use in situations where heathland vegetation is currently absent. Examples include agricultural land, forestry and established deciduous woodland. The classification of forestry plantations is a difficult area because heathland vegetation may be present in rides and other places, but it is suggested here that this should generally be regarded as re-creation because in most situations only a relatively low proportion of heathland vegetation remains in relation to the overall area of the relevant parcel of land.

1.7 The National and Local Biodiversity Action Plans (BAP) have ambitious targets for restoring and re-creating significant areas of heathland. In order to restore heathlands to favourable condition or to reclaim them from recent secondary growth and occlusion, there have been large scale projects, eg Tomorrow’s Heathland Heritage funded through the Heritage Lottery Fund, the LIFE projects (EU funded) and agri-environment schemes. These have supported the removal of extensive tree and scrub cover as well as bracken from heathland over the last 10 years or so. However, when restoring or re-creating lowland heathland there is the potential, depending on which methods are adopted, for deleterious impacts to occur to the soil and the historic environment.

1.8 Much of the re-created heathland is expected to be reclaimed from conifer plantations and farmland where heath has been recorded in the historic past. Since the soils under many plantations and agricultural land have been modified for their new land uses, a number of methods have been developed to assist in restoring the characteristics that support heathland. This may be through chemical means to increase acidity or reduce nutrients, whilst other methods offer the opportunity to mechanically manipulate soil profiles in the search for a more appropriate substrate for heathland. These latter techniques include removing or burying the litter layer, the whole turf layer, the upper soil horizon, or inverting the whole soil profile. These methods have the potential to alter the soil structure and processes, and interfere with any archaeological interest preserved in them. It should be considered, though, that forestry operations and felling in particular will also affect the soil and that heathland restoration sometimes involves not just removing trees but restoring the original hydrology along with the capacity to store carbon in peat and undisturbed soils.

1.9 New heathland might also be created on ex-mineral sites such as gravel workings, sand pits or coal spoil heaps. These and others in the same category are not included in the scope of this project since they are formed on raw or created substrates of little or no archaeological value, and frequently the geodiversity value has been compromised (note: disturbed soils are still able to perform some functions but this may have been reduced by disturbance).

The scope for damage to soils

1.10 There are several aspects to the issues of soils that need to be addressed. First, soils are part of the earth sciences, and therefore are subject to the protocols for nature conservation in the same way as other physical sciences and habitats. However, the nature conservation interest in soils is not fully developed or widely appreciated amongst other nature conservation interests yet (Bruneau 2004, Burek 2005). The British Society for Soil Science is developing some guidance on the nature conservation of soils, but this is not yet mainstream. Soils that have been undisturbed for some time (centuries potentially) and exhibit features responding to natural processes and function are of intrinsic value in the same way as long-established habitats, and indeed form part of their ecosystems. Where soils also vary across natural topography showing the relationship between environmental variables and edaphic features, they are also of high intrinsic and educational value.

1.11 The First Soil Action Plan for England:2004-2006 (Defra, 2004), recognises that soils are one of the essentials of life along with air and water. Its aim is to ensure that England’s soils are protected and managed to optimise the varied functions that soils perform for society (eg supporting agriculture and forestry, protecting cultural heritage and shaping our landscape, as a platform for construction and a source of minerals), and supporting diverse ecological systems and interactions between soil, water and air.

1.12 The majority of current guidance on soil protection such as the First Soil Action Plan for England 2004-2006 (Defra 2004) and the EU Thematic Strategy for Soil Protection (Commission of the

European Communities 2002; European Commission 2006a), recognise that soil is essentially a non renewable resource. They aim to combat soil degradation exacerbated by unsustainable human practices and protect the soil to enable it to fulfil its many functions, including hosting the biodiversity pool and storing the geological and archaeological heritage. Despite the growing number of soil protection policies only nine European Union member states have specific legislation and it is for this reason the Commission has developed a more comprehensive EU strategy specifically dedicated to soil protection.

1.13 The purpose of the Thematic Strategy is to maintain the capacity of the soil to fulfil ecological, economic, social and cultural functions. It identifies the threats: soil loss by water and wind erosion; the decline in organic matter; compaction of the soil by cattle trampling and machinery tracking; salinisation made worse by inappropriate irrigation; landslides; contamination that can pollute groundwater and surface water threatening drinking supplies and aquatic ecosystems and sealing, whereby the soil is lost beneath concrete and tarmac (European Communities 2006b). Member States are obliged to take measures to reduce the effect of these threats. Loss of soil biodiversity loss is acknowledged as a threat but the Commission considers that the current scientific knowledge is insufficient to allow for specific provisions to be identified.

1.14 All of these threats are real and the need for action is imperative. These threats jeopardise the productive capacity of the soil, such as its ability to provide food, materials, and clean water and to play a key part in the process which regulate the global ecosystem. A degraded soil results in a reduction in the ability of the soil to perform these vital functions and in turn a despoiled landscape and loss of aesthetic appeal and cultural heritage. It could be argued that there is an implicit requirement in the Thematic Strategy (and other policies of soil protection and they are mentioned in the introduction) to protect the intrinsic scientific interest and the soil biodiversity value of soils. However, it can also be argued that this message needs to be brought to the fore and stated directly.

1.15 At national level, there are a number of other soil policies that have been developed recently, for example, by the National Trust (1999); a guidance document developed for the former English Nature (Bradley and others 2006) and the proposed European Soil Directive. A new Soil Strategy for England (to replace the previous Action Plan) is also under preparation by Defra. These focus on protecting soil as a multifunctional resource, in particular in terms of careful management to avoid erosion on slopes and sedimentation into water courses, in line with the requirements of the EU Water Framework Directive. However, there is wider recognition of the function of soils in terms of its soil biota and ecosystem, and its role in protecting our archaeological heritage (Defra Soil Action Plan 2004 – 2006). More recently the key role of soils in environmental regulation, particularly in carbon storage and the impacts that has on the effects of climate change, has come to the fore. Good soil management is equally applicable to all land management, but it is the alteration of in situ soils and the effect of this on the multi-functionality of soils, especially with respect to biodiversity and archaeological value that is the core consideration in this study.

The scope for damage to the historic environment

1.16 Heathland restoration and re-creation programmes that disturb soils also have the potential to affect the historic environment. Long undisturbed soils could hold important clues for interpreting the past. These could include features of the soils themselves which reveal details about the changes over time of the environment – through soil structure, animal remains (beetle sequences for example), pollen analysis and other sources. There may be charcoal layers, which can be dated and related to human use of the environment, or human artefacts, structures or remains may be preserved in or on the soil. Damage to the soil strata or removal of soil layers have the potential to destroy the context, lose the historical palimpsest[1], or damage the archaeological material itself.

[1] Often used by archaeologists to describe superimposed artefacts of human activity.

The project aims and objectives

1.17 This report illustrates the extent to which alteration to soils has the potential to damage the value of the soils themselves and/or that of the historic environment, when restoring or re-creating lowland heathland.

1.18 The objectives were to:

- Identify all the methods adopted in the restoration/re-creation of lowland heathland in the UK in the last 10 years.
- Evaluate how often topsoil removal practices have been carried out during heathland restoration/re-creation activities in the UK in the last 10 years.
- Evaluate how often soil acidification practices have been carried out during heathland re-creation activities over the last 10 years in the UK.
- Evaluate how often soil inversion practices have been carried out during heathland re-creation activities in the UK over the last 10 years.
- Provide an analysis of the existing scientific literature of the benefits and problems associated with these practices, including work undertaken in other European countries.
- Provide an evidence-based analysis of the impacts of the different options for topsoil removal, inversion, acidification or other methods of soil preparation on the soil characteristics (physical, chemical and structural).
- Provide an evidence-based analysis of the impacts of the different options for topsoil removal, inversion, acidification or other methods of soil preparation on features of the historic environment.

1.19 Chapter 2 sets out the features of value in relation to soils and the historic environment that could be affected by heathland restoration and re-creation activities.

1.20 Chapter 3 presents the results of the literature review, focusing on the last 10 years of investigations or applications of methods for restoring or re-creating lowland heathland in the UK and in other European countries. This includes a consideration of the role that new heathland can make in sequestrating carbon.

1.21 Chapter 4 presents the results of a questionnaire survey into practices on the ground.

1.22 Chapter 5 provides an analysis of the results of chapters 3 and 4 in relation to the potential for damage to the nature conservation value of soils.

1.23 Chapter 6 presents the same analysis for the historic environment.

1.24 The final chapter 7 draws together a summary of the findings and the conclusions of the study in the context of relevant soil protection policies, directives and guidance.

2 The important features of soils and the historic environment

Soils and soil conservation

2.1 Although there is a general understanding of what is meant by 'soil' there are many definitions depending on the perspective of different disciplines and the purpose soils are seen to serve.

2.2 Soil can simply be viewed as the outermost layer of the earth – the *pedosphere* which is subject to soil forming (pedogenic) processes. It occupies an essential position at the interface of the lithosphere, hydrosphere, atmosphere and the biosphere and is one of the earth's most valuable natural resources, fundamental to natural processes and human survival. Britain has a great diversity of soils because of the diversity in the soil forming factors – geology, climate, topography and historical land use. There is general acknowledgment that soils have been adversely affected by a wide range of human activities such as mining, construction, poor farming or forestry practices and pollution. All these, unfortunately, have led to a reduction in the productive capacity, loss of biodiversity and nature conservation value as well as loss of an important historical archive.

2.3 Despite its importance, the soil is, nevertheless, fairly ill-understood. Even though soil biodiversity is greater than the aerial biodiversity it supports, little is known of the soil ecosystem and the many biological components of fungi, invertebrates and bacteria that operate at a microscopic level. Research is active and initiatives such as the 'Soil Biodiversity Programme' (NERC 2006) are leading to a better understanding of soil biodiversity and the roles played by soil organisms in ecological processes. Soil research has also acquired a new impetus driven by the realisation of its fundamental role in, for example, nutrient recycling, carbon recycling, carbon sequestration and climate change.

2.4 Traditionally, the value of a soil has been measured in terms of its economic value, ie for development, as a source of materials and in its ability to grow crops and timber. The protection of the 'best and most versatile agricultural land' defined as Grades 1, 2 and 3a in the *Agricultural Land Classification (ALC)* (MAFF 1988) remained for many years a primary objective in planning guidance. Whilst the productive function of soils is still important, over recent years there has been a subtle change in emphasis and ALC grading plays a less pre-eminent part in guiding development. Today, consideration is given to a broad range of soil qualities in land use planning and soil value is no longer expressed in terms of its agricultural value alone. For example, guidance in agricultural development policy given in *Planning Policy Statement 7* (PPS7) comments that when determining planning applications, the best and most versatile agricultural land should be considered alongside other sustainable considerations such as biodiversity, landscape character, amenity, soil quality and heritage interest. The EU Environmental Impact Assessment and Strategic Environmental Assessment, the Habitats Directive and the Water Framework Directive also indirectly protect soils.

2.5 Statutory and non-statutory agencies have developed soil protection Codes of Practice. The *Soil Code* was published by MAFF (1998), as well as a range of guidance leaflets and manuals on soil erosion control (MAFF 1997, 1999a, 1999b, 1999c) and soil handling (MAFF 2000). Non-government agencies like the Council for the Protection of Rural England (CPRE 2000) and The National Trust (1999) have soil protection strategies. Awareness at the European level has been raised with the launch of the *Thematic Strategy for Soil Protection to '…keep Europe's soils* *robust and healthy'* (European Commission 2006a). *The First Soil Action Plan for England: 2004-2006* (complemented by the publication of *The State of Soils in England and Wales* (Environment Agency 2004)) commits the Government to improve soil management and introduces soil protection measures. It identifies 52 Actions to 'ensure that England's soils are protected and managed to optimise their functions in keeping with the principles of sustainable development'. The First Soil Action Plan adopts a multifunctional outlook, considering a wide range of issues reflecting the many functions of soils (Defra 2004). The Environment Agency recently launched their soil strategy (Environment Agency 2007). Defra's Soil Strategy for England will be out for consultation soon.

2.6 All of the above policies aim to guard the soil resource, although no legal framework exists for its direct protection and conservation. Implicit in all these strategies, and stated directly in some, is that the soil merits protection not only because of the functions it can perform but also because of specific interests the soil contains ie the intrinsic soil conservation value. This might be because of archaeological artefacts and evidence of human activities, or that the soil records former climate and habitat conditions. A soil at a particular site may be an excellent example of a soil type, and just as protection is afforded to valued plant and animal assemblages, the soil could also be conserved for its inherent scientific, aesthetic and diversity interest.

2.7 This view is promoted as part of earth heritage, geological conservation and geodiversity. Earth heritage conservation in the UK involves recognising, protecting and managing sites and landscapes identified as important for their fossils, minerals or other geological interest (Joint Nature Conservation Committee 2007). One definition of geodiversity is: 'the natural range (diversity) of geological rocks, minerals, fossils, geomorphological (landform and processes) and soil features. It includes their assemblages, relationships, properties, interpretations and systems' (Gray 2004). However, geodiversity also encompasses the multi-functionality of soils, including sustainable consumption and production (Stace & Larwood 2006).

2.8 The case for protecting the great geodiversity in the UK so that it remains available for future research, as a teaching aid and for recreational purposes, is made relatively easily and generally well received. However, although soils are part of geodiversity, there is a danger that they are overlooked and they become a poor relative in the earth heritage family (Bruneau 2004; Burek 2005).

2.9 The National Soil Map (NATMAP) URL://www.silsoe.cranfield.ac.uk/nsri/services/natmap.htm (1:250,000 scale) has established exactly where different soil types can be found, and also identifies 296 soil associations. However, it does not evaluate soils that are particularly representative or special soil types. There are, however, standard or 'benchmark' soil descriptions for each included soil series. Work is in progress to develop criteria for evaluating the conservation value of soils, based on rarity, diversity and representativeness (Stace & Larwood 2006). Action 41 of the England Soil Action Plan (Defra 2004) asked English Nature to examine the advantages of establishing a series of benchmark sites for soil biodiversity. This may be achieved by looking at soil types in Sites of Special Scientific Interest (SSSIs) and Regionally Important Geological and Geomorphological Sites (RIGS) where there is a greater likelihood that soils have been relatively undisturbed. These soils, which are several thousand years old, may also contain features of archaeological interest. Action 43 also requires English Nature to provide guidance on the use of soil in the restoration of wildlife and wildlife habitats (Wetherell 2006). This was addressed with the publication of the English Nature Research Report 217 '*Guidance on understanding and managing soils for habitat restoration projects*' (Bradley and others 2006). These and other actions are being developed now by Natural England.

2.10 Soils in Britain are all relatively young and have formed over the last 10,000 years, and under a cool temperate climate soil formation is generally slow. However, estimating the relative age or degree of maturity is difficult. Soils are continually adjusting to environmental conditions such as climate and modifications through human intervention. It has been held that the larger the number of distinct horizons, the more likely the soil is mature and may have developed over many hundreds of years.

2.11 The great variety of British soils represent, not only a productive resource, but also a valuable record of environmental change and human action. There is growing recognition that soils have an intrinsic conservation value and they are worth conserving in their own right. The opening of England's first RIGS 'Soil Trail' in Delamere Forest, Cheshire, dedicated to illustrating the rich diversity of soil types, is one example of this growing recognition (Burek 2005). However, soil remains the 'Cinderella' in geodiversity and is often ignored even in nature conservation efforts. Unless suitable consideration of the soil resource is made, habitat recreation involving disturbance of the soil has the potential to destroy or damage valuable soil features.

Heathland soils

2.12 Lowland heathland is associated with a moist temperate 'oceanic' climate lacking temperature extremes, with relatively high annual rainfall. It can develop on a range of parent materials. In Britain this includes aeolian deposits of sand and loess (ie fine, windblown deposit derived from glacial deposits), glacial till, fluvio-glacial deposits and other fairly well-drained substratum. They tend to be less represented on sedimentary rocks, especially those containing clay and rich in calcium although there are a few unusual exceptions, for example, in the Bovey Basin where heath has developed on ball clay. They are also found widely on acid peat where there has been drying of the surface and bog vegetation has been replaced by 'wet heath'. Further drying of peatlands is favourable for the development of *Calluna*-dominated heaths, which are widespread in lowland and peat-covered areas in northern England and Scotland (Gimingham 1972). As well as regional trends, there can be great small-scale lateral and vertical variability in heathland soils related to local differences in the underlying geology, past and present land use, subtle changes in topography and the effect this has on water movement and storage.

Table 1 Soil types characteristic of lowland heathlands (modified after Mackney and others 1983)

Code	Sub-type	Soil type and parent material	Key Locations
		Brown Rendzina	
343	f	Chalky drift	Brecks
		Brown sands	
521	-	Chalky drift	Brecks
551	a	Carboniferous sandstone	Wirrel
551	b	Permo-triassic sandstone	Sherwood
551	g	Glaciofluvial drift	Sandlings
554	b	Glaciofluvial drift	Brecks
		Humic brown podsol	
611	d	Paleozoic sandstone	Forest of Dean
612	b	Acid igneous	Coastal west
		humo-ferric podsol	
631	a	Palaeo-mesozoic	
631	b	Permo-triassic sands	
631	c	Creto-tertiary sands	
631	d	Creto-tertiary sands	

Table continued…

Code	Sub-type	Soil type and parent material	Key Locations
631	e	Devonian conglomerate	E Devon
631	f	Glaciofluvial drift	Cheshire, Lincs,
633	-	Devonian red sandstone	Exmoor
634	-	Plateau gravel	
		Gley podsols	
641	b	Tertiary sands	Dorset
643	a	Tertiary sands	New Forest
643	b	Drift over sandstone	Ashdown
643	c	Plateau gravel	New Forest

2.13 Anthropogenic expansion of heathlands, around 3,000 BC, probably occurred on brown woodland soils (Dimbleby 1962). A mature heathland podzol with clearly defined horizons may have developed over thousands of years. The soil forming process often associated with well-developed heath vegetation is podzolisation. Podzol soils form under acid weathering conditions and under natural or semi-natural vegetation. There are a number of podzolic subgroups but characteristically they have an unincorporated acid organic surface layer or 'mor' humus layer (see Figure 1 below and Plates 1 and 2). They also have very clearly defined horizons in the profile. This occurs because rainfall percolating through the organic surface layer picks up organic acids that remove soluble metal-humus complexes in the upper mineral horizon. This silica-rich eluvial horizon (E) is usually ash-grey in colour owing to the loss of soluble materials. Below is a dark brown horizon (Bh) of translocated organic material and an iron and aluminium (Bs) enriched illuvial horizon. In some instances an 'ironpan' layer forms where iron oxides accumulate (Avery 1980, 1990; Clayden & Hollis 1984).

2.14 Dry heathlands have freely drained soils developed on sand and gravel substrates, especially in the Midlands, south and east of England. Soil nutrients are removed by leaching so that the soil is hostile to many plant species. Heather *Calluna vulgaris* and bell heather *Erica cinerea* tend to be dominant on these well-drained acid podzolised soils.

2.15 Wet heathland soils are periodically waterlogged. Anaerobic soil conditions inhibit decomposition of vegetation and peat accumulates. Nutrients are leached and highly soluble nitrogen compounds are lost in solution. These conditions can result in the development of stagnopodzols, which have peaty topsoil. The cross-leaved heath *Erica tetralix* along with a variety of bog mosses *Sphagnum* spp. favour these damp, acid conditions found on the boggy margins on heaths.

2.16 There are also soil and vegetation transitions between dry and wet heathlands, as well as humid heathland which are only seasonally waterlogged.

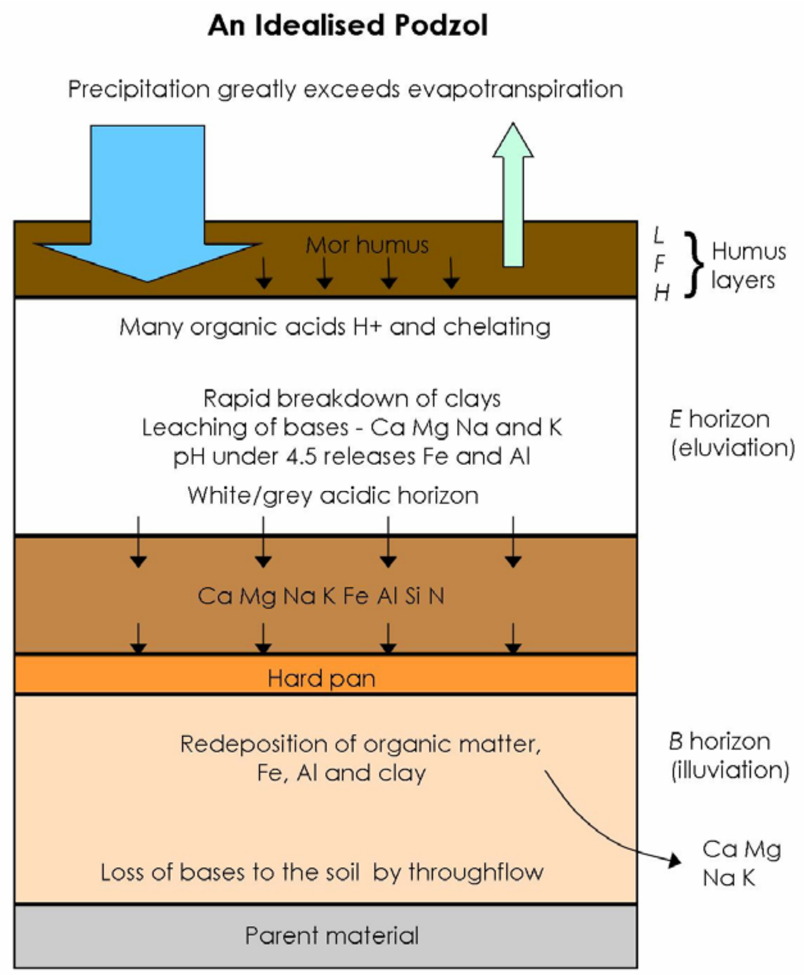

Figure 1 Soil forming processes of a typical podzol soil

Threats to valuable heathland soil features

2.17 Heathland soils, like many other soil types, are susceptible to surface damage and loss of vegetation through trampling and recreational pressures (Gallet & Roze 2002). Soils can become vulnerable to water erosion especially on steeper slopes and where the vegetation has been lost through over grazing and burning. Acid heathland soils are particularly sensitive to atmospheric pollution, notably nitrogen washed from the air by rain. This is thought to be an insidious but important cause of habitat degradation (Power and others 1998; Roem and others 2002; UK National Focal Centre 2007). High nitrogen levels can encourage ruderal and grass species that can out-compete heathland species and invade dwarf-shrub stands. An increase in the cover of grasses such as purple moor-grass or wavy hair-grass is thought to be evidence of this disturbing process (eg Alonso and others 2001, Britton and others 2003, Thompson & Truckell 2005). Different management measures such as mowing, prescribed burning and sod-cutting, are being evaluated for their effectiveness in reducing the impact of atmospheric nutrient loads in heathlands (Härdtle and others 2006).

2.18 Heathland podzol soils are generally inappropriate for productive use because of high acidity, lack of plant nutrients (especially phosphorus) and high carbon/nitrogen ratios. These characteristics are sometimes the result of the historic use such as grazing, gathering of firewood, heather, furze and of turf cutting. Selecting many heathlands as common land in the past was also a reflection of their low productivity and the need to use better soils for crop land. The agricultural improvement of heathland soils has usually involved liming to increase soil pH and long-term fertilisation but the inherent conditions do not favour cropping agriculture. However, light sandy soils which were formerly heathland are often suitable arable and horticultural soils especially in drier locations not well suited to grass production – eg Breckland areas – especially if irrigation is available. Consequently, where not converted to arable use, heathlands have often been used for rough grazing, forestry and leisure. Restoration of heathlands which have been converted to more productive agriculture must reduce artificially high nutrient levels and lower the pH so that it is once more capable of supporting heathland plant communities and associated animal species.

2.19 It has been shown that the characteristic profile of a podzol can persist even when factors that normally affect the soil forming process have changed (Rackham 1986). This means that although past heathland may have undergone quite radical land use changes, eg agricultural improvement, afforestation, scrub and woodland encroachment, the distinctive horizonation may endure. It is therefore possible that soil disturbance such as tree extraction, soil inversion and deep ploughing completed as part of heathland habitat re-creation could destroy excellent examples of this soil type, as well as harming wider soil functionality.

2.20 The persistent nature of the podzol profile, and because the process of soil podzolisation may have been initiated many thousands of years ago, means it can represent a valuable record of the past. Organic accumulations within the soil may even hold a pollen and/or diatom[2] assemblage that enables past habitat reconstruction, as might the discovery of preserved bone and snail shells. Carbon dating of organic material (eg macro-botanical remains or snails if the soil is not too acidic) can provide a stratigraphy important in both charting environmental change and the impact of human occupation. Recent developments in C^{14} dating of organic matter that has been locked in mineral soils by clay minerals and in ironpans mean that the date of formation of these soil features can be more accurately determined (Lascelles and others 2000).

2.21 Another valuable soil feature in danger of being lost because of ground disturbance is a palaeosol. This is a former soil, preserved by burial beneath younger sediments eg sand, peat, alluvium and loess. These ‘fossil’ soils may have formed under very different environmental conditions so that their chemical and physical characteristics bear little relationship to the present day climate and vegetation (Retallack 2001). They can indicate changes in climate, help in the reconstruction of past environments and help to establish a chronology for landscape evolution (see Plates 3 and 4).

2.22 At different times, Britain experienced a periglacial climate when extremely cold and dry conditions prevailed and the ground was affected by intense freezing and permafrost. The effect of frost action and repeated cycles of thawing and freezing can produce a range of soil and surface features. Many lowland and upland areas that are presently heathland experienced these conditions immediately before, during and after glacial periods over the past 2 million years. Soils can be affected by cryoturbation (frost churning), where horizons become disturbed and mixed or even ordered by repeated freezing, when soil materials are organised according to their size. Evidence of this effect may be visible in present day soils in the form of sand wedges where frozen ground has contracted and later filled with sand or other stony material. Further evidence of cryoturbation may be involutions (wave-like features in the soil) and at the surface, ice frost action can organise stones to form patterned ground of stripes, circles and polygons (French 2007). These soil and surface formations and other ‘cryogenic’ landforms are rarely readily apparent and may go undetected and be lost in the process of habitat re-creation.

The historic environment

2.23 The origins of heathland can be traced back to early prehistory, where hunter-gatherers in the later Mesolithic (the seventh to fourth millennia BC) made clearings in the wild-wood by burning , at least in part (Webb 1986), although these communities also had flint axes. The purpose was probably to encourage animals (such as deer) to congregate where trees and bushes were putting out new, fresh growth for them to browse, which made hunting much easier.

[2] Diatoms are a widespread group of phytoplankton with cells encased within a cell wall made of silica. They are found in the oceans, freshwater and soils.

2.24 Following the intensification of land-use associated with the introduction of agriculture and domestication of livestock, heathland spread across the Neolithic, Bronze Age and Iron Age periods, in part at least as a result of human activity. Many, if not all, such areas seem previously to have been wooded, with a similar mix of tree cover (predominantly lime, hazel and oak). The principal mechanism by which heathland was created was arguably grazing of livestock. The introduction of a wood-pasture regime saw woodland gradually give way to more open country as grazing pressure limited the growth of young trees from seedlings. Woodland was also cleared for agriculture, then abandoned once the initial fertility had declined, reverting to heathland where conditions favoured this outcome. Some heathland areas were of considerable importance to prehistoric man. For example, the Grimes Graves (Norfolk) flint mines were located in heathland and were used intensively in the Neolithic Age. Numerous flint scatters, albeit generally peripheral to heathland, have been identified around them.

2.25 Occasionally, prehistoric communities took advantage of the comparatively open aspects that heathland offered to construct a variety of monuments, such as burial mounds, some at least of which were arguably intended to be seen from a distance. At the same time, in comparison with farmland for example, heathland was probably comparatively expendable, and therefore considered as suitable for a variety of structures which were not dependant on the fertility of the soil. That said, some later heathlands carry archaeological structures which were built prior to the development of heath. For example, Neolithic Long Barrows were often built over agricultural soils but in an environment which might eventually become heathland (Moor Green Barrow, Hampshire). The remains of prehistoric burial chambers are frequent on heathland in western Britain, from Stronsay in the north (for example, the Neolithic chambered tomb near Hillock of Baywest) to Cornwall (for example, Lanyon Quoit).

2.26 By the Roman period (AD43-410), there were already numerous heaths and woodland had been reduced nationally to about 10% of the total ground surface (Dark & Dark 1997). As wood-pasture was grazed by domesticated livestock, regeneration was affected and either heathland or grassland tended to spread at the expense of woodland. The Roman period witnessed a peak of population in Britain at perhaps three to five million, leading to pressure on erstwhile unsettled areas. In some old heathlands, field-systems were laid out and agriculture took place, with fertility maintained by extensive manuring which leaves its trace as a thin scatter of pottery shards and other manufactured items. Indeed, such scatters are often the only trace of Roman period farming, which gave way to heath once more when impoverishment of the soil or declining population pressure led to abandonment. In most instances, however, the actual settlements tended to be peripheral to the heathland.

2.27 A survey of place-name evidence reveals the omnipresence of heaths in the lowlands of Anglo-Saxon and Medieval England. Even in such areas as Cheshire, where there is very little heathland today, the place-name evidence is considerable (Dodgson 1981), with a minority now surviving as public open spaces although without the vegetation characteristic to heathlands such as Knutsford Heath. Some played a significant role in the management of the earldom in the twelfth and thirteenth centuries as sites where men could be marshalled (as Rudheath near Norwich), but were assarted (cleared for agricultural or pastoral use) and laid out as fields within the Middle Ages.

2.28 Nationally, many heaths which survived the Middle Ages were subjected to enclosure either by private agreement or by Act of Parliament in the seventeenth, eighteenth or nineteenth centuries. Place-name evidence implies that heaths in the Middle Ages concentrated in those areas of the North-west and South-east which have been known since at least the sixteenth century as ‘woodland’ or ‘ancient’ landscapes (Rackham 1986), as opposed to the ‘champion’ areas characterised by open field in Central England (in a belt running from Hampshire to Northumberland). This is certainly the case today, with major concentrations in Cornwall, Dorset and East Anglia. That said, this may simply be due to the tendency of open fields to stretch across the entirety of townships in this region, so overlaying and rendering obsolete earlier place-naming strategies. The comparative absence of heaths in the Middle Ages from the Central Province where open field predominated need not, therefore, imply their absence in these areas at an earlier date. IIt should be noted that this absence was, even in the Middle Ages, relative rather than absolute. In the early post-medieval period, there were significant areas in the East Midlands, as well as Dorset, where a sheep/corn agrarian regime consistently made use of heathland as a reservoir of fertility which was transferred to arable fields via grazing livestock feeding on the heaths then folded on the fields at night (Thirsk 1987).

2.29 Heaths and other areas of common grazing could and did attract settlement in the Anglo-Saxon period and Middle Ages, sometimes giving rise to place-names which reflected this particular environment (as Haddon, Hadley, Hatton, from the Old English hæð (heath)), or Brampton, Bromley, from the heathland plant broom). In Norfolk, nucleated settlement around parish churches tended to dissipate in the eleventh century and settlement drifted to the edges of commons. This included heathland overlaying exposed sand and pebble substrates. The majority of medieval farms in Norfolk are thought to have overlooked common land (Williamson 1993). Numerous parish churches are isolated as a result. This pattern was only eventually obscured by the enclosure of most of these open spaces in the late eighteenth and nineteenth centuries, leading to a regular fieldscape, although much of that was swept away via hedge removal during the twentieth century. In these landscapes there is little or no remaining heathland.

2.30 This pattern does not recur in the champion landscape of Central England, where medieval settlement tended to be nucleated in comparatively tightly defined villages around the village church and at the core of extensive open field systems, but numerous hamlets are to be found in a heathland environment in the West of England, the Marches and the North-west. In some parts of England, therefore, there can be a comparatively close connection between historic heathland and dispersed rural settlement - a category of which has attracted much new interest in recent years (Jones & Page 2006).

2.31 This brief overview demonstrates the potential for heathlands to hold historical and archaeological value. Therefore, (if the soils are not already damaged through other activities, and in occasion even then), the restoration of heathland in most parts of England could have serious archaeological implications which need to be considered firstly in the planning stage and then throughout the process. The following sections are an attempt to set out the major types of evidence and the particular issues involved.

Threats to valuable archaeological features

The artefact scatter

2.32 A major type of archaeological evidence is the artefact scatter, comprising any objects which are man-made (such as pottery, glass, metalwork, clay pipes, roofing slate) or man-affected (as struck flints of so-called 'knapping floors'). These certainly occur on heathland, either on the surface or deeper as a consequence of the deposition of later wind-blown sand or similar. They can be the first hint of the presence of more complex archaeology. The visibility of artefact scatters is highly variable, depending very largely on vegetation coverage and the nature of land-use. Existing heathland, particularly where there is little erosion, rarely reveals artefact scatters very easily, due to vegetation, litter and organic matter on the surface. At Piping Common, Sussex, for example, Mesolithic flints were concentrated thirty centimetres below the present surface. Only where erosion has occurred are these likely to be obvious.

2.33 Coniferous woodland on old heathland provides a comparatively open soil and field working produces results as, for example, in Paul Brooker's current work in Thetford Forest (Suffolk/Norfolk borders). Artefacts are most visible on cultivated land, particularly where ploughing has only recently occurred, preferably following rain.

2.34 In drainage hollows or at the edge of a valley, several metres of deposition may occur, burying a range of archaeological material in a chronologically differentiated matrix. In coastal heaths, sand dunes may be present, which similarly will have buried archaeologically important soils, with or without artefact scatters.

2.35 In later periods, hoards of metalwork such as coins or jewellery are an important source of archaeological information and these can be identified both by archaeological observation through field-walking and by the controlled use of a metal-detector. The location of artefact scatters is also an important means of locating later prehistoric, Romano-British, Anglo-Saxon and medieval settlements which tend not to leave major earthworks. Shards of pottery have, for example, alerted archaeologists to the existence of a twelfth-century site on the Brandon/Wangford border (Suffolk). Bovey Heathfield (Devon) was the site of a Civil War battle in 1646, leaving considerable evidence in terms of personal effects and spent shot.

2.36 Artefact scatters were deposited on the surface at the time (for example as flint scatters or pottery from manuring) or just below. Some may have since been brought to the surface, in part at least, by cultivation. Anglo-Saxon cemeteries, in particular, are very vulnerable to even shallow surface disturbance. Many graves tend to be so close to the surface that ordinary modern ploughing hits and eventually destroys the remains. These can occur on old heathland, as at West Stow Heath, Suffolk, where a linked early Anglo-Saxon settlement and cemetery were discovered. The only extensive Viking cemetery so far identified in England is that at Heath Wood, Ingleby (Richards 2004).

2.37 There is also an archaeological issue relating to the top-soil which might be removed or brought in as part of a heathland restoration project. Where this contains archaeological material such as pottery, flints or metalwork, it could in the future lead to the belief that a new site had been identified rather than coming from the original location from which the material had been transferred, where buried archaeological features (such as filled-in ditches or post-holes, for example) might well still survive. Such relocation of material and the potential separation of archaeological features from associated small finds have potential to cause considerable difficulties for the understanding of our archaeological heritage.

Upstanding structures

2.38 Upstanding structures occur on many heathlands. These may include Neolithic, Bronze Age, Iron Age and/or Anglo-Saxon burial mounds, which are generally low symmetrical mounds covering human remains and accompanying artefacts. Many are well-known and are likely to be listed in the Sites and Monuments Record but new ones are occasionally identified and it is very important to remember that the archaeological record is far from complete, particularly on heathlands. For example, during recent soil removal at Stackpole NNR (Stackpole Head) in Pembrokeshire, previously unknown archaeology was uncovered, even though previous assessments had not discovered any significant finds (Haycock & Tuddenham 2004). White Hill Bell Barrow (Suffolk) was only identified after the recent felling of coniferous woodland which had been planted across it. Bronze Age barrows have been excavated at Knighton Moor, Dorset, and in the New Forest, and found to be particularly common monuments in the case study of Hartland Moor near Wareham, Dorset (Darvill & Fulton 1998). Barrows on Dartford Heath (Kent) produced spectacular hoards of gold brooches and bronze axes from the second millennium BC. These are particularly important monuments, containing evidence of human burial practices often from several periods. They also cover and protect pre-existing soils which can reveal the nature of the environment and human action thereon at a specific period in the past, using pollen analysis, C^{14} dating and the investigation of the soils themselves and of objects within. For example, snail shells can preserve well in soil and provide a useful source of information, particularly in chalk heathland where acidity levels are relatively low.

2.39 The world-famous Anglo-Saxon barrow cemetery of Sutton Hoo lies today on grassy heathland in the custody of the National Trust. Human and animal remains in such environments are not well preserved, because the acidity of heathland soils removes the skeletal framework, but mound 1 (excavated in 1939), covered a ship burial containing the most spectacular grave goods from the Early Middle Ages ever found in Britain. Such evidence has allowed archaeologists to understand much about life and death in this period.

2.40 Individual barrows often served as the foci of extended flat (ie not visible today) Anglo-Saxon cemeteries in the early Middle Ages, so it is not just the specific barrow itself which needs to be respected today but the immediate area around it for perhaps 100 m in all directions, until that possibility has been tested effectively.

2.41 Settlements are somewhat rarer on heathland, at least from the Roman period onwards; poor access to water and fertile soil seem to have proved a disincentive. Many heathlands are, however, crossed by old tracks or roads, sometimes with substantial banks to the side which may tie into extensive landscapes of old field boundaries (Plate E). Numerous other categories of monument, in addition to those mentioned above, were recorded at Hartland Moor, Dorset, including Iron Age, Romano-British and Medieval features. There are a variety of other monuments located on heathland, including Iron Age hillforts (as at Tadmarton Heath Camp Hillfort, Oxfordshire) and major dykes (such as Black Ditches on Cavenham Heath, Suffolk).

Land use signs

2.42 It is worth looking out for ridge and furrow, the remains of early ploughing. This phenomenon occurs in many parts of Britain, particularly where early fields have been abandoned at some stage, and can signal the presence of complex archaeological landscapes. Ridge and furrow is to an extent dateable. For example, cord rig has been identified as prehistoric across parts of the North and Scotland and occurs beneath several forts on Hadrian's Wall. On the other hand, long, slightly curving broad (>8 m) ridge and furrow is generally medieval. Post-1600 ploughing tends to be in shorter, straighter runs and narrower (3-5 m), formed by horse-ploughing and, latterly, traction engines.

2.43 Elsewhere, heathlands cultivated since enclosure and reverted back may contain plough-damaged sites of many kinds, including burials. Because the margins of heathland have been highly fluid over thousands of years, archaeological sites have the potential to reveal a variety of episodic periods of land-use across a period stretching from the Neolithic to the Medieval and beyond. At Bovey Heathfield, Devon, which covered over 400 ha in the seventeenth century, archaeological finds included a Bronze Age barrow and the remains of leats used in the Middle Ages to collect tin within the tin extraction industry, as well as a unique earthwork built in association with the Civil War battle which occurred there.

2.44 A variety of other types of monuments may also be associated with heathland, due to specialised uses of this particular landscape as a resource. Bracken was cut as animal bedding across a wide timescale, and hunting and hawking occurred widely. Although these activities will not leave a mark on the landscape, they may have contributed to the maintenance and distribution of heathlands in the country. In the Middle Ages, warrens were frequently constructed to manage rabbits, then a highly-prized, imported species, leaving tell-tale pillow mounds sometimes surviving to the present, or the bank and ditch which often protected the warrens. In some instances, the medieval homes of the warreners survive, such as Mildenhall Warren Lodge in Thetford Forest, which is a substantial stone structure. Sand pits are common, having been used to a limited extent in the Middle Ages to extract sand to improve wetland soils, but more commonly at a later date for building material. Similarly, pebbles were extracted for road-metalling. Many heaths are, therefore, deeply pitted with excavations associated with extractive industries (as Dartford Heath, Kent, or Cannock Chase, Staffordshire).

2.45 It is also worth keeping a variety of other activities in mind, such as mining (for example, for iron in the Kentish and Sussex Weald) and quarrying, where stone outcrops occur. Excessive concentrations of charcoal on the soil surface may reveal the presence of charcoal burning to produce the fuel for metal-working, where woodland was present in the past. Turf and peat digging also leave characteristic remains such as a landscape of uneven surface topography, turf stacking platforms and drying shelters.

2.46 Many heathlands were used in the early to mid twentieth century to site wartime emplacements such as anti-aircraft batteries, leaving behind reinforced concrete platforms and similar, much of which still remains. Some are still used as military ranges and training grounds for example in Surrey and Dorset. Such features merely continue a long-established practice of using open heathland for a wide variety of activities involving numerous people such as annual camps for militias and regiments, fairs, ecclesiastical synods (in the Anglo-Saxon period) and recreational activities of all sorts. Many such activities leave comparatively little structural evidence, but they tend to leave a scatter of artefacts which can provide a clue on the type of usage that occurred and when it happened. The presence of tents in the past may in some instances be detectable archaeologically.

2.47 Numerous heathlands were planted with conifers over the last 150 years or so, often employing a forestry deep plough for the purpose. Where this has occurred, archaeological features may have been damaged to a very great extent, but archaeology was on occasion identified and saved during planting (round barrows often occur in East Anglia on the very edge of forestry, as at Dunwich Forest). In the absence of deep ploughing, the shallow-rooting conifers generally do comparatively little damage to archaeological deposits.

2.48 In summary, there are three groups of artefacts or/and features associated with heathlands:

1) those from land uses before the development of heathland (ie before approx. 3,000 BC);
2) those directly associated to the use of heathlands anytime during the last 5,000 years; and
3) those associated to land use changes, eg enclosures, settlements, woodland development, military activities.

3 Heathland restoration and re-creation techniques – a literature review

Background

3.1 The very existence of heathlands, and their persistence today, is the result of anthropogenic influence. Heathlands only came into existence following initial forest clearance by Neolithic man, and where they have persisted, they do so only owing to the intensive management that prevents their reversion to scrub and woodland (Webb 2001). Plant materials like heather, bracken, gorse and turf were used for burning, thatching, animal bedding or fodder (Webb 1986). At the same time, many heathlands provided sources of sand, and later may have been military training grounds, all of which would have damaged any pristine soils.

3.2 Heaths were also managed in order to sustain them for livestock and for growing crops in adjacent areas. In general, livestock (either sheep or cattle) would have been grazed upon the heath for around six hours daily (Webb 2001), after which they were removed to a barn/byre overnight. The barn/byre floor would be lined with turves cut from the heath, which would contain newly emergent heathland vegetation. Fodder would also be cut and placed in the barn/byre on which the animals could browse. The turves would absorb the excrement from the animals over a period of time before being removed and added to arable soils, thus raising the soil levels over time by up to 80 cm and providing a fertile tilth on which crops could be sown. This method is known to have been used until very recently in the Lüneburger Heide (Germany) and is still used for educational purposes (Keienburg & Prüter 2004). These are known as plaggen soils but there is no clear evidence of this practice from Britain (Webb 2001).

3.3 This system (with its geographic variations) provided more fertile arable soils for crop production, prevented scrub invasion on the heath, and impoverished the heathland soils. The system abated in the eighteenth century when Britain and Europe started to import large amounts of fertilizer products from around the globe. This eventually led to the wholesale conversion of large tracts of heathlands and grasslands to arable land (Webb 2001) or to widespread abandonment. As a result, in the absence of management, many remaining heaths succeeded to scrub, were converted to forestry or were lost to development.

3.4 In 1992, heathlands were identified in the European Habitats Directive as a habitat to be targeted for protection. The UK Biodiversity Action Plan in the mid 1990s also targeted lowland heathlands due to their high nature conservation value even before the need to extend their coverage had been identified (Gilbert & Anderson 1998). As a result, in the 1980s and 1990s, the momentum to re-create heathland gathered pace (Webb 1994), especially on arable farmland and in forestry plantations. This was largely in response to incentives offered through agri-environment schemes or grants from the Heritage Lottery Fund (HLF), Aggregates Funds and others. Most of this re-creation focused on the re-establishment of ericaceous heathland, although some emphasis, particularly in the UK Brecklands, was targeted towards grass heath mosaics. However, much of the approach to restoration occurred on an *ad hoc* basis (Dolman & Land 1995).

3.5 There are many commonly-used techniques for heathland re-creation and restoration in operation today. In some cases they may be replicating past practices dating from before the agricultural revolution in Britain and elsewhere in Europe, which may have little additional effect on soils or archaeology. In other cases, new (potentially) damaging practices are being applied where little disturbance occurred in the past. The literature findings in this chapter set out the range of methods being applied, their potential impact and their relative efficacy in different situations.

3.6 Understanding traditional methods of heathland management is important for contemporary heathland conservation and management. The main problem in restoring and re-creating heathland on sites where the heathland has been lost is that of high residual soil fertility, which must be tackled if the restoration is to be successful. One particular problem, especially on former arable soils, is that of high levels of extractable phosphorus and high pH resulting in the proliferation of undesirable species at the expense of natural heathland vegetation (Dolman & Land 1995) which then fails to establish. Most current methods of heathland management tend to alter the structure or composition of heathland vegetation, but fail to reduce soil nutrients or control invasive species such as scrub or purple moor-grass *Molinia caerulea*. Scrub invasion cannot always be effectively controlled by grazing alone (Webb 2001). These are prime considerations when attempting to restore or re-create heathland ecosystems, in particular, in the ground preparation stages.

3.7 The literature review has focused on the methods developed or trialled for restoring or re-creating lowland heathland in the UK and other European countries, particularly in the last 10 years. Additional previous information has been used when particularly relevant research was available. What was clear from the literature is that many of the methods highlighted in the following sections have been used in an experimental capacity to assess their success. Many of the techniques were used in combination, often in an experimental design field setting, although some were investigated as single methods against a control. Although largely of an experimental nature, the techniques trialled were primarily undertaken in conjunction with large-scale restoration projects, for example, as part of the HLF funded Tomorrow's Heathland Heritage 'Sandlings Project' at Minsmere, and on Breckland heaths.

3.8 Information for the review was collated from a number of resources. Access to academic and grey literature has been sought, for example, from heathland conferences, specialists and practitioners, and through Liverpool University library and the internet. The extensive library held by the authors, which includes most of the lowland heathland conference reports as well as various project reports over the last 30 years, was also used.

3.9 The methods available to contemporary practitioners in heathland restoration and re-creation were categorised based upon the general broad similarity of methodologies. Categories of heathland restoration and re-creation techniques are as follows:

1) Surface vegetation (herb layer) management and removal techniques.
2) Soil acidity and nutrient status amelioration techniques.
3) Surface and below-ground vegetation (trees and shrubs) removal techniques.
4) Soil disturbance and soil removal techniques.

A list of the commonly used re-creation and restoration techniques highlighted during the literature trawl can be found in Table 2.

3.10 The four categories are described later in this chapter looking at the methods used (Table 2) and discussing each one's efficacy. The potential effect that each of the broad category techniques may have on the carbon balance is also discussed when information is available.

3.11 The potential for damaging valuable soil functions, especially in terms of their conservation interest and archaeology are discussed below with the generally less damaging techniques presented first. As a broad principle, those methods that disturb/remove soil horizons have the highest potential to compromise the integrity of any soils and archaeology and can also liberate large quantities of carbon from the biotope. However, such methods are thought to produce better re-creation and restoration outcomes.

Table 2 List of common methods used in the re-creation and restoration of heathland

Treatment	Treatment category			
	Category 1 (Herb layer management/ removal)	**Category 2 (pH and nutrient reduction)**	**Category 3 (tree/shrub removal)**	**Category 4 (soil disturbance & removal)**
Grazing	X			
Cutting	X			
Herbicide application	X			
Burning	X			
Cropping (if it implies ploughing)		X		
Acidification		X		
Tree/scrub (incl roots) removal			X	
Litter disturbance/removal			X	
Disturbance of soil layers				X
Removal of soil layers				X

3.12 This chapter focuses primarily on lowland dry heaths, although some references are also made to wet heaths. Most of the heathland discussed is situated in the southern half of the country, which contains most of Britain's heathland. Reference is also made to some European heaths.

3.13 In the following section, restoration and re-creation will be referred to under the single umbrella term of restoration for the purposes of brevity.

Surface vegetation (herb layer) management and removal techniques

Grazing

3.14 Although grazing was one of the most important and commonly used techniques in heathland management, its use in restoration depends on the state of the heathland to be restored. If colonisation by scrub, trees and bracken is extensive, then these would need to be controlled first and grazing used to manage the regenerating heathland, such as in the Suffolk Sandlings Project (Dolman & Land 1995); the Surrey Heathlands project with goats (Surrey Heathland Countryside Management Project 1994); or Ashdown Forest (Marrable 2004). Aftercare grazing has been, and is still being used, in many heathland restoration projects in the UK (Bullock & Pakeman 1996; Pakeman & Marshall 1997; Hulme and others 2002; Pakeman and others 2003; Britton and others 2005), and Europe (Bokdam & Gleichman 2000; Gallet & Roze 2001; Keienburg & Prüter 2004). Grazing intensity tends to be higher for restoration compared with maintenance grazing levels.

3.15 The details of the efficacy of stock type, number, grazing season and other factors are beyond the scope of this account, but see Lake and others (2001) in particular for further information in relation to grazing on lowland heathland.

3.16 Grazing tends to repress (but not eliminate) scrub and open up the vegetation, encouraging low-growing plants and promoting growth in dwarf shrubs (Bullock & Pakeman 1996). Although it reduces surface biomass, it does not reduce the nutrient loading of the soils significantly compared to nutrient stripping techniques, as most nutrients are redistributed within the biotope through dunging (Webb 2001). A net reduction on nutrients can only be observed if animals are housed or moved elsewhere for the night or by a high grazing pressure (not recommended) (Keienburg & Prüter 2004). Appropriate stocking densities, however, can produce a mosaic of vegetation structure on a much smaller scale than is achievable by other methods, such as cutting or mowing (Woodrow and others 1996a, Lake and others 2001).

3.17 Grazing can impact negatively on soils and archaeology: trampling (which will affect the litter depth, soil organic matter, nutrient status and nutrient cycling); poaching (resulting in soil disturbance, changes in soil structure and nutrient cycling and compression); erosion (in case of overgrazing and by removing the vegetation cover) (Lake and others 2001). On the other hand, reducing the size of tree seedlings and the rate of scrub invasion could maintain the existing soil characteristics and potentially the archaeology which would otherwise be destroyed by the root growth.

Cutting

3.18 Cutting removes part of the above-ground biomass, thus at least temporarily releasing any semi-natural ericaceous vegetation from competition with purple moor grass, bracken, or other shrubs and trees for example. It is also often used as an alternative to burning heather (to encourage all stages of the heather cycle), which can be impractical on small sites and where the public's perception of a burn could be negative. Cutting heather in spring allows for the more rapid regeneration of ericaceous vegetation, and accordingly reduces the potential for surface erosion (Dolman & Land 1995).

3.19 When cutting, it is important to remove all cut material to achieve a net removal of nutrients from the site (Britton and others 2000) and to avoid covering the seed bed. Leaving the cut material *in situ* could lead to nutrient accumulation and the retention of soluble phosphorus in the soils. This can lead to the development of rank grassland and scrub (Chapman and others 1989; Gimingham 1992), or smother smaller growing heathland plants. Increased soil moisture could arise from the retention of cuttings and lead to the proliferation of more competitive species such as *Molinia* and *Deschampsia* on drier soils. Such a scenario has been blamed for the accelerated loss of heather and subsequent development of rank grassland in the Weald (UK). A forage-chop harvester used with a trailer can remove cut material if it is cut on level terrain; however, on uneven ground alternative methods would need to be employed (Dolman & Land 1995).

3.20 Used alone, cutting aerial biomass tends to be of limited use in heathland restoration: if an undesirable species is dense and blanketing out the dwarf shrub heath, then cutting will not usually kill, remove or control it adequately. The use of cutting has therefore focused on bracken control primarily or to rejuvenate heather stands. In the first case, cutting would have to be practiced annually; possibly up to two or three times each year, and would therefore also affect any heathland vegetation underneath it.

3.21 From the reviewed literature it is clear that cutting is one of the most frequently used experimental techniques in the management and restoration of heathland in Britain and Europe today, whether used in isolation, or in combination with other methods. Cutting has been employed on numerous UK heathland restoration projects over the past few decades, for example, in the UK Brecklands (Lowday & Marrs 1992; Marrs & Lowday 1992; Marrs and others 1992; Wright 1993; Marrs and others 1998a; Britton and others 2000) and Dorset (Pickess and others 1989; Woodrow and others 1996b; Mitchell and others 1999). In many cases, it has been carried out to remove invasive bracken on many British heathlands (Snow & Marrs 1997).

3.22 Cutting can be used in the ground preparation for the restoration of heathlands provided the undesirable species have been controlled and their litter or arisings removed first. This provides a bed onto which ericaceous seeds can be introduced via strewing for example. Compared to turf stripping and rotovating, cutting in isolation generally does not produce the desired effects in restoration as it fails to control the offending species, so is more suited to a combination with other techniques (Britton and others 2000). Cutting the vegetation does not provide the bare ground required to produce a good seed bed so Britton and others recommend that this technique is probably best employed where *Calluna* is already established and needs maintenance management.

3.23 Cutting should not lead to the wholesale destabilisation and erosion of heathland soils. It will not damage archaeology unless there were upstanding remains that could be damaged by mechanical operations.

Herbicide application

3.24 The use of herbicides in ground preparation for heathland restoration is a common pre-establishment practice. Herbicides, primarily those that are selective such as Asulox (Asulam), and less often the non-selective roundup Glyphosate are most commonly applied on heathland as a method of bracken control. They can also be used to reduce grass cover or for scrub control. Cut stumps, or previously cut re-growing shrubs may also be treated with herbicides. Herbicide application has been widely used over the past few decades in some areas such as Suffolk (Fitzgerald and others 1987), the Brecklands (Lowday & Marrs 1992; Marrs & Lowday 1992; Marrs and others 1992; Marrs and others 1998a), Dorset (Pywell and others 1995; Woodrow and others 1996a; Mitchell and others 1999), the Midlands heaths (Symes & Day 2003), and further north (Snow and others 1995).

3.25 The use of herbicide to control bracken is arguably be the most cost effective way to contain this fern, and can be 85-100% effective given the right spraying conditions (Woodrow and others 1996a). 100% success is rarely achieved without follow up treatment, as Lowday and Marrs (1992) demonstrated at Cavenham Heath (*Calluna*) and at Weeting Heath (grass) in the Breckland (UK). Asulox is considered a most effective method of bracken control following a burn to remove the accumulated litter (McCracken and others 2005).

3.26 Pywell and others (1995), in comparing methods for restoring heathland on abandoned farmland, demonstrated that herbicide application was not an effective treatment in isolation as the dead vegetation inhibited the regeneration of heathland plants. However, when used in combination with cultivation and the addition of harvested shoots (heather and other characteristic species), results improved. The best results were achieved when topsoil or turves had been added as a source of seed.

3.27 The killing of surface vegetation using herbicides, although preserving the integrity of soils and any archaeology, will not give favourable results in heathland restoration unless used in combination with other techniques that disturb the litter/soil layers (Dolman & Land 1995).

Burning

3.28 The main use of burning tends to be for maintenance purposes, for instance, in the form of controlled winter burns, rather than in pre-restoration ground preparation, such as that used at Stiperstones in the Shropshire Hills (Wall 1993). As a maintenance technique, burning is invariably used in combination with other techniques, most often grazing. Burning results in an even age stand of heather (Dolman & Land 1995), and a relatively short, open vegetation structure (Bullock & Pakeman 1996). It has been an important technique in the management of heathland in Europe (Bullock & Webb 1994; Keienburg & Prüter 2004; Mohamed and others 2006). However, although it can kill trees and shrubs on heathland, burning then provides an ideal seed bed for the colonisation of more trees and shrubs. It also prevents the full development of the heather cycle by rejuvenating the plants.

3.29 Depending on the heat of the fire, burning can consume much of the accumulated litter layer thereby affecting the long-term nutrient status of a site. A proportion of the nutrients from the standing vegetation and litter are lost in the smoke during the burn (Dolman & Land 1995), although this is mostly the nitrogen (and sulphur) rather than the phosphorus which is released to the soil (Allen 1964; Evans & Allen 1971). Burning increases the concentration of NH^{4+} in the organic layer but does not significantly affect the A-horizon (Keienburg & Prüter 2004, Härdtle and others 2006). However, burning can result in a large input of potash to the soil which can support vigorous bracken growth (McCracken and others 2005). Burning therefore is a cheap, useful technique to help keep some soil nutrient concentrations low (Webb & Haskins 1980). Such conditions are essential for the restoration of heathland communities, although severe burns (normally wildfires in summer which are not part of the suite of restoration techniques) can significantly inhibit recolonisation by *Calluna* (Bullock & Webb 1995) by destroying the seed bank.

3.30 In the Dorset heaths in the mid-1970s, burnt heaths (mostly from wildfires in the 1976 drought) returned to their pre-burning states within ten years, a rate of recovery that corresponds closely with the building phase of *Calluna* of 10 to 11 years. During this regeneration phase, *Calluna* became established in 13.5% of areas formerly dominated by grasses such as *Agrostis curtisii* in dry heathland, and became established in 23% of the area formerly dominated by *Molinia caerulea* in wet/humid heathland (Bullock & Webb 1995). However, such burning can sometimes result in patches of bare ground remaining from many months to some years afterwards, and when recolonisation occurs, this can be colonized by undesirable species of tree and shrub (Bullock & Webb 1996). The severity of summer wildfires in terms of the removal of the vegetation and the litter layer shows the level of disturbance that can benefit heathland restoration in the long term in respect of nutrient removal (although it is obviously not recommended as a technique due to the potential damage to the seed bank).

3.31 Through experimental burning of bracken litter in Breckland (UK), Lowday & Marrs (1992) concluded that seedling establishment of *Calluna* can be speeded up, finding it comparable to litter incorporation by rotavation, raking and litter removal.

3.32 In the Cantabrian Mountains in León (NW Spain) Calvo and others (2002) showed that, in combination with grazing, controlled burning on a humid heath, which tends to be a shallow burn owing to the moist ground conditions, resulted in better regeneration of *Calluna* compared to cutting. In the same experiment they showed that cutting led to replacement by other ericaceous species and ploughing produced results similar to those achieved by burning.

3.33 Burning should always be carried out in accordance with the Heather and Grass Burning Code and Regulations (Defra 2007a&b):

3.34 The removal of heathland/scrub vegetation by managed burning is unlikely to lead to the wholesale erosion of the soil as it leaves the root/soil interface largely unaffected. However, it will depend on the depth of the burn and the resulting rate of heather regeneration. Practices such as burning bracken litter are unlikely to cause any significant soil erosion, unless the site is steep and recolonisation of the ground is slow, or prevented, for example, by rabbit grazing. Deeper burns, on the other hand, could result in greater incidences of soil erosion owing to the destabilization of soil surface horizons. Burns carried out on slopes could result in increased soil erosion (and could thus potentially affect archaeology) during heavy rains as a result of the washing of exposed soil downslope.

Surface vegetation management and removal: Summary

3.35 Most of the above methods involving the reduction or removal of surface vegetation are less effective when carried out in isolation when restoring heathland. Each performs better when used in combination with other methods, in particular those that disturb/remove the topsoil. However, where the integrity of soils and archaeology are a consideration, these non-disturbance methods may be the only available techniques for re-establishing traditional heathland vegetation. None of the above methods are effective in significantly removing soil nutrients or reducing soil pH in isolation, although burning, and cutting and removal, serve to reduce soil nutrient loadings to some degree.

Soil acidity and nutrient status amelioration techniques

Cropping

3.36 Residual fertility is perhaps the biggest problem associated with ex-arable land as it impedes successful re-establishment of a heathland flora (Marrs & Owen 2002). The need to effect a reduction in soil pH and nutrient levels when reverting ex-arable soils for heathland restoration has been highlighted by a number of workers (Marrs 1985; Pywell and others 1994). Consequently, cropping linseed, spring and winter barley, or cereal rye for example, is sometimes used for a few years to reduce or remove the nutrient loading prior to attempting restoration back to heath. Cropping has been undertaken with some success at Minsmere (Marrs & Owen 2002; Marrs and others 1998b) and in the Brecklands (Pakeman & Marshall 1997). Ground preparation for sowing such nutrient stripping crops however, will involve ploughing the soils prior to sowing, and adding some elemental nutrients (inorganic nitrogen and potassium - Marrs & Owen 2002) in order to maximise the removal of phosphorus by the crop.

3.37 Historical heathland soils are characteristically free-draining and sandy (Chambers and others 1996), from which the leaching of nutrients, such as phosphorus, should be relatively rapid compared with other soil types having higher mineral/organic contents (Marrs and others 1998b; Marrs 2002). Walker and others (2004) suggest that cropping could be of limited value on sandy heathland substrates where considerable reductions in phosphate may be required.

3.38 Most arable soils will have been managed by inversion ploughing. Although archaeological remains could be still found within the profile they may have been damaged. However, ploughing is usually confined to the topsoil so archaeological remains should be present intact below this in the subsoil unless disturbed by deeper cultivations (eg subsoiling or deep ploughing) or drainage operations. No new damage should be experienced with an appropriate assessment. Direct drilling at reduced depth could be more appropriate before cropping to reduce nutrients (see section on soil disturbance later in this section).

Acidification

3.39 Owing to higher soil pH levels as a result of elemental nutrient additions to arable land, soil pH amelioration often needs to occur before restoration is attempted. The commonly used method for lowering nutrient status and pH is to acidify the soil following the removal of vegetation. This has been tried by adding bracken litter (and occasionally pine litter), elemental sulphur or acid peat, usually to a pre-prepared surface. Such methods have been employed with some success in the Suffolk Sandlings, Minsmere (see paragraphs 3.44 - 3.49), the Brecklands and Pembrokeshire in recent years (see below).

Elemental sulphur

3.40 Research undertaken by Liverpool University in the 1990s demonstrated that the acidifying nature of sulphur could potentially be used as a chemical ameliorant to lower soil pH levels prior to the restoration of heathland (Day 2005). When added to agricultural soils, elemental sulphur can reduce pH to within normal heathland pH tolerances (Owen and others 1996). Soil acidification is today seen as the most efficient way of quickly re-establishing low soil pH to former arable soils (Owen and others 1996; 1999; Owen & Marrs 2000; Lawson and others 2004; Tibbett & Diaz 2005), and can even assist in limiting the availability of nutrients in the soil including extractable phosphorous and exchangeable calcium (Owen and others 1999; Lawson and others 2004; Ausden & Kemp 2005).

3.41 Sulphur is normally applied following initial vegetation clearance (cutting, felling or burning), sometimes following cropping and some kind of soil disturbance (rotovating, ploughing or topsoil removal) (Ausden & Kemp 2005). The addition of sulphur has the added advantage of reducing extractable phosphate, potassium and magnesium levels in the soil (Chambers and others 1996). Sulphur is incorporated into the soils via rotovating before a propagule source (seeds, cuttings or brash) is added (Owen and others 1996; Owen & Marrs 2000).

3.42 The addition of sulphur has been shown to achieve successful re-establishment of *Calluna* on arable soils (Owen and others 1999), although ruderal incursion can sometimes be a problem that needs addressing with herbicide before the acidification process (Owen and others 1996; Owen & Marrs 2000). However, the addition of elemental sulphur whilst lowering soil pH, also releases cadmium, the potentially toxic cation which can inhibit the root colonization by ectomycorrhizal fungi so important in the successful establishment of *Calluna* (Diaz and others 2006, 2007). The adsorption properties of cadmium are greatly reduced with increasing acidity making it more readily available for uptake by plants (Green and others 2006).

3.43 Adding sulphur to the soil surface should not result in any significant damage to historical soils. However, when rotovated into the soil (as is the common practice) it has the potential to affect soil-forming processes, although this could just be converting them to a former pattern. Obviously, rotovation has the potential to destroy archaeological artefacts in the upper soil layers, as can ploughing. Mixing-in large quantities of sulphur could also affect the archaeological preservation of artefacts by acidification of the soil and increase the corrosion rate of metal, glass and bone (Willem and others 1997). Diaz and others (2006, 2007) also reported negative impacts of sulphur on mycorrhizae development, resulting in *Calluna* absorbing toxic elements. Invertebrates appeared to be negatively affected too (Diaz and others 2007).

Bracken and pine chippings

3.44 Similarly to the addition of elemental sulphur, acidic residues are commonly added to the soil in the form of bracken cuttings or fresh pine litter. Bracken has been shown to effect a reduction in soil pH, whereas pine litter produces only limited reductions (Welch & Wright 1996), as found in the case study described below.

Case study: Soil acidification following cropping at Minsmere, Suffolk

3.45 Soil surveys established that ex-arable soils earmarked for heathland re-creation at Minsmere had high residual fertility and pH levels. These levels were too high to enable successful heathland establishment without amelioration. They would also favour the establishment of undesirable species and rapid succession to scrub and bracken. Soil acidification methods were trialled following an initial period of cropping such as had been used at Roper's Heath (Dorset) and in the Breckland ESA. The rationale was to remove more of the soil nutrients via the crop to impoverish the soils than had been added during agricultural improvement, and then to acidify the soil artificially.

3.46 Nitrogen was initially added (supplemented by potassium in certain fields) to some of the plots to fertilize the crop, with ammonium sulphate (nitrogen) added from 1993 onwards to reduce soil pH levels. Above-ground biomass was removed annually. During the first year soil pH, Ca and P levels fell, whilst Mg and K remained around their baseline levels. Assuming that rates of decrease remained constant, it was predicted that pH (which fell at between 0.5 and 1.7 pH units in the first year) would take between three and eight years to reach target levels of pH 3.5, whilst Ca would take between four and six years to reach acceptable levels. In year two, Ca levels rose but started to decline again by 1994 – 1996; but pH levels failed to decline further over this period. Over an initial seven year period, there were no significant alteration to soil properties overall. Therefore, it was concluded that cropping only slowly (if at all) impoverishes the soil and should be viewed purely as a medium to long-term option. It was considered that the nutrients removed in the crop had been replaced naturally via weathering and mineralisation processes.

3.47 Following a period of two years cropping, some areas were taken out of the cropping experiment and were entered into acidification trials. Topsoil stripping and deep ploughing were not feasible options owing to there being no changes in soil nutrients or pH with depth. Three methods were trialled to reduce pH and the availability of nutrients in the soils: addition of elemental sulphur and the addition of pine (pH 5.8) and bracken (pH 4.2) litter. Sulphur was added at between 1 and 12 t S ha^{-1} to pre-rotovated soils, whilst the litter was added to a depth of between 2 cm and 10 cm.

3.48 The application of sulphur significantly reduced soil pH directionally proportional to the volume added. An application of 1-2 t S ha^{-1} saw levels fall to pH 4 after just nine months, whereas application rates of 4 t S ha^{-1} resulted in a drop to pH 3 after twelve months. Application rates above this did not result in further significant reductions. After this first year, however, soil pH raised a little, but the rate slowed by years two and three. As such, acidification using elemental sulphur was considered the most appropriate method for quickly reducing soil pH to suitable heathland levels, and did not result in a significant increase in Ca and P. This was considered suitable for the establishment of *Calluna*.

3.49 Bracken litter applied at 2 – 4 cm reduced pH by 1 – 1.5 pH units in the first year, but this was not considered sufficient to suppress arable weeds. Pine litter applied at 4 cm depth resulted in only a slight decrease in soil pH.

3.50 In summary, at this site sulphur and bracken litter reduced soil pH and the amount of exchangeable Ca. Bracken litter application does not sufficiently impoverish the soils to levels suitable for the establishment of *Calluna*, but if applied with sulphur, the volume of sulphur required could be reduced. For a full summary of these trials and their outcomes, see Mitchell & Hare (1999).

Peat

3.51 In experiments undertaken in Suffolk, peat incorporated into surface soils has also been shown to reduce soil pH rapidly down to as low as pH 2.5 in ex-arable soils, as pyrite becomes oxidized to produce sulphuric acid (Davy and others 1996; Dunsford and others 1996). The peat had been extracted from deep foundations for Sizewell B, and not removed from any existing habitat.

3.52 The potential for affecting soils and archaeology by the application of naturally acidifying soil ameliorants (bracken, pine and peat) directly onto a soil surface at a receptor site should be low. However, some form of soil disturbance usually accompanies the addition of acidifying material. For example, rotovating the material into the soil horizons could have the potential for more significant effects if the receptor site were not already disturbed from such activities. The addition of elemental sulphur, however, could have damaging effects on soils and archaeology.

Soil and litter addition

3.53 Heathland soils (with or without various other vegetative matter such as bracken, pine, heather and peat) can sometimes be incorporated from other sites into the soil at restoration projects to speed up the heathland vegetation re-establishment process. This could disturb any soils of conservation value at the donor site and also compromise the integrity of archaeological artefacts. The donor soil/peat may also be incorporated with the soil at the receptor site (see Dunsford and others 1996), which would be detrimental for soils and archaeology. However, this would not be the case if the material were to be translocated using turfing or scraping up techniques (Anderson 2003), where they would be laid carefully on top. This would be after the removal of the topsoil which the translocated material replaces.

3.54 The transfer of heathland soils, peat or vegetation has the potential to damage soil functions, including of scientific or archaeological interest at the donor or receptor sites. Care is needed to ensure that soil types are sufficiently compatible, in terms of physical characteristics and required pH and nutrient status and are handled under suitable conditions to minimise soil damage.

Tree and shrub layer removal techniques

3.55 Many heathland restoration projects have taken place on heathland sites where secondary succession over a period of years has resulted in dense tree and scrub cover. Historically, much of Britain's natural lowland heathland vegetation had become out-competed and replaced by species such as birch *Betula* spp. through successional processes, or Scot's pine *Pinus sylvestris*, and other trees through commercial conifer afforestation (Mitchell and others 1997; Pywell and others 2002; Walker and others 2004). To date, the primary focus for restoration in lowland areas has been on afforested areas at former heathland sites (Gilbert & Anderson 1998). Symes & Day (2003) described a number of restoration projects undertaken in afforested areas in England since the 1990s.

3.56 The potential to restore afforested heathland sites has recently been recognised by conservation organisations in the UK. However, efforts still need to be focussed on the best form of ground preparation in order to optimise the re-establishment of typical heathland vegetation following felling (Allison & Ausden 2006).

3.57 The re-establishment of heathland vegetation on former afforested heathland is more successful than on former arable soils as the soils are less nutrient enriched and more akin to those of heathland, and they retain a more comparable seedbank (Walker and others 2004). In addition, heathland seeds can persist for up to 40 – 70 years under plantations (Pywell and others 2002; Walker and others 2004), so it is possible that more plantation deforestation for heathland restoration could take place over the coming years.

3.58 Provided that some heathland propagules persist under recently felled plantation and depending on the depth of the pine litter left, there could be little benefit in removing the humic layers, or adding heathland propagules obtained from other sources. Nevertheless, removing some of these layers, if deep, could prove beneficial in bringing buried *Calluna* seeds to the surface, thus exposing them to the light needed for successful germination (Allison & Ausden 2006).

3.59 Rhododendron (Holmes 1993), gorse, birch (Box and others 1999), pine and bracken (Mitchell and others 1997) invasion are common occurrences on former heaths. Generally woody vegetation is cut using chainsaws and the stumps spot-treated with herbicide. Alternatively, stumps are ground down to the surface level using a stump grinder, or re-growth is treated with a suitable herbicide. These techniques should not affect the soil structure or archaeological remains.

3.60 Podzolic soils that form on heathland tend to be very resilient and can persist unchanged for millennia, even when the vegetation and climate ceases to favour their formation. Conifers also present suitable conditions for their formation (Rackham 1986). Therefore the persistence of these soils under commercial conifer forestry on former heathland sites is possible, although they and any remaining archaeology may have been damaged by ploughing for tree planting. Cutting the trees low and treating stumps would result in less damage compared with hauling the stumps out with machinery and chains (see paragraphs 3.60 - 3.61). However, it is possible that root penetration has disturbed soil horizonation, though this may be reversed in the longer term.

Case study: Caesar's Camp, Berkshire

3.61 The notable archaeology at Caesar's Camp Iron Age Fort in Berkshire needed to be considered in the restoration of heathland. The ramparts and interior of an Iron-age fort had been planted with trees, the root plates of which were damaging the archaeology, particularly when they were uprooted in gales. Following the decision to replace the trees with shallow rooting heathers and grasses to prevent further damage, trials were undertaken to establish best practice for removing the trees. The trials examined the need for litter removal and a grass nurse and tested different sources of heather seed (Gilbert & Anderson 1998).

3.62 It was established that trees needed to be removed and stumps reduced to as close to the ground as possible to permit mowing in the future. The considerable accumulation of brash also needed to be removed. Litter was raked off on the allotted plots with care, using a small excavator bucket to a specified level instructed by the archaeologist (a tractor mounted brush that loosens the litter and vacuums it could also be used effectively without causing damage to archaeology) before a heather inoculum with or without a grass nurse crop was added to their respective plots. Rapid vegetation establishment was then required to prevent soil erosion and subsequent degrading of the archaeology. The plots with tree litter removed but no additional nurse showed the best and most rapid establishment of heather (PAA 1994).

3.63 Soils should only be handled when conditions are suitable (see Defra's Good Practice Guide to Handling Soils URL://www.defra.gov.uk/farm/environment/land-use/soilguid/).

Soil disturbance and soil removal techniques

3.64 As already established above, most heathland re-creation takes place on former agricultural land or on former forestry plantation where some of the archaeological and soil interest may have been compromised due to past management practices. The key constraints to restoration on ex-arable soils are high pH, high residual soil fertility and the impoverished nature of the heathland seed bank. However, in plantation forestry soils, residual heathland seed banks may still persist and nutrient and pH levels can reflect that of more typical heathland soils (Walker and others 2004). The general consensus in the literature appears to be that many of the methods described earlier produce better results when combined with some form of soil disturbance or removal, as this redresses some of the principle constraints to successful heathland restoration. Soil removal can further reduce the amount of available nutrients, including nitrogen, phosphate, as well as total soil carbon (Aerts and others 1995). The potential natural reduction in nutrients with time should be always considered. The process is slower than the following methods, but where archaeology is important delaying the work could be more successful and cost effective than trying to remove nutrients quickly.

Litter removal and/or surface disturbance

3.65 At sites where sufficient seedbank of desirable heathland species remain, removing or disturbing the litter following or during felling is likely to be the most effective method of re-establishing heathland vegetation (Marrs 1987; Lowday & Marrs 1992). In practice, it is impossible to prevent some soil disturbance during felling operations. It could be sufficient (although not always) to scrape away the conifer litter and expose heathland propagules buried in the seedbank. Lowday & Marrs (1992) showed that *Calluna* established from seed considerably faster following the complete litter removal. At sites retaining a good heathland seedbank the removal of the humic layers could potentially reduce the rate of *Calluna* and other heathland species establishment as large numbers of buried propagules could be removed too (Allison & Ausden 2006) unless only the very top layer of tree litter is removed. It is important to understand where the desired seed bank lies in the profile. At sites with large residual seed banks of undesirable species such as birch, pine or bracken, which might have also altered the heathland soils, soil disturbance can increase competition from undesirable species and hinder *Calluna* re-establishment (Mitchell and others 1997; Allison & Ausden 2006).

3.66 Litter removal is a common practice in the restoration of heathland sites following vegetation removal (see Emery 1992; Lowday and Marrs 1992; Pywell and others 1994; Snow and Marrs 1997; Symes and Day 2003). Deep bracken litter in particular inhibits the establishment of heather (Lowday & Marrs 1982).

3.67 It first needs to be established at the outset whether the seedbank contains sufficient propagules of the desired species. If it does, then disturbing or removing the litter is likely to be very cost-effective for re-establishing heathland. In an experiment in Tudeley Woods RSPB Reserve (Kent), where there was good seed availability, there was little measurable difference 10 years post-restoration between treatments that removed the litter and humic layers, and those where just the litter layer had been removed. Both regenerated significantly better than the control plots (Allison & Ausden 2006).

3.68 Litter removal also abstracts large quantities of mineral nutrients (N, P, K, Mg, Ca) that would take (depending on the individual nutrient in question) between 19 and 98 years to replenish naturally from the atmosphere via rainfall (Snow & Marrs 1997, Keienburg & Prüter 2004; Niemeyer and others 2007).

3.69 Soil removal methods can mimic historical ‘plaggen’ systems and have been used as a restoration technique for many years. Whether ex-arable or former forestry, this has a number of advantages. It can help to reduce soil nutrients, reduce the prevalence of unwanted propagules (in particular those of annual plants) and, in the case of former forestry sites, can expose buried heathland propagules that may have lain dormant for over 40 years. Although there appears to be no consistent approach to the depth of soil removal, most practitioners in Britain and Europe strip to an arbitrary depth of between 5 and 40 cm, as shown in the UK by Britton and others (2000) and Allison & Ausden (2006), and by Aerts and others (1995) in The Netherlands. Many machines are now available to undertake this work, which produce an even cut and operate rapidly over larger areas (Overbury 1995).

3.70 However, if turves/sods are removed from biotopes where some heathland vegetation still persists (see paragraphs 3.77 - 3.80), this can also remove arbuscular mycorrhizal fungi (AMF) spores from soils. AMFs are primarily contained in the upper soil horizons, in particular the organic layer, and are now known to play an important role in the re-establishment of ericaceous species (Vergeer and others 2006). As a result of experiments undertaken in The Netherlands, these authors therefore caution that where such methods are applied, they should use care and be on a small scale to conserve non-stripped patches from which AMFs can quickly recolonise.

3.71 When deciding whether to remove soils and considering the conservation value of the soils and archaeology, thought should also be given to protected species. The natterjack toad *Bufo* *calamita* burrows into heathland soils to a depth of 20 cm to hibernate. Accordingly, Wilton-Jones & Ausden (2005) when undertaking site preparation in late autumn, removed just 10 cm of *Deschampsia flexuosa* dominated heathland turf to avoid impacting natterjack hibernation burrows. Natterjack toads still persist at the site in good numbers.

3.72 Removal of soils also results in adverse impacts to the wider environment. Loss of organic matter and exposure of unstable subsoils is likely to damage soil structure and can result in accelerated run-off and further soil loss through erosion and sedimentation. The infiltration capacity of the soil can be reduced with less rainfall available for aquifer recharge. Loss and probable accelerated oxidation of organic material will have an impact on carbon stores. There is also the question of whether the removed material can be beneficially used as it is not very sustainable if the removed material ends up in landfill, or is transported by lorries. For soil/turf removal there are also waste disposal and planning regulations that may need to be adhered to.

3.73 The removal of litter should not cause any significant direct damage to soils or archaeology. Secondary damage (erosion) may occur, however, if the litter removal takes place on steep slopes or if revegetation establishment is protracted (PAA 1994) and unstable subsoils are exposed to accelerated run-off. Previous treatments, such as clearfelling could also render the ground surface more susceptible to secondary damage when the litter layer is removed. The wider impacts on soils and the environment also need to be considered.

3.74 Soil removal may affect not only the soil conservation value and archaeology, but also the capacity of soil to fullfill all its functions, including its the wider environmental regulation role, in addition to the wildlife and the microorganisms that could be removed or destroyed with it. Planning permission and waste regulations need to be considered.

Soil disturbance (shallow and deep ploughing, inversion and rotovation)

3.75 The basic idea behind soil disturbance methods such as rotovation and ploughing is to destroy existing undesirable vegetation or bury an unwanted seed bank. It will not remove nutrients from the surface unless the ploughing is deep enough to bring the subsoil to the surface. It does not result in soil disposal issues, and is very cheap per unit effort (Overbury 1995). The mixing in of soil horizons is a fairly common practice in many experimental, pre-restoration ground preparation in the UK (see Smith and others 1991; Pywell and others 1995; Snow & Marrs 1997; Pakeman & Marshall 1997; Britton and others 2000; Owen & Marrs 2000; Allison & Ausden 2004; Walker and others 2004).

3.76 Rotovating and ploughing generally work at different levels within the soil profile. Rotovating mixes the uppermost soil horizon. Normal ploughing tills a furrow by cutting the topsoil layer and then turns it over into an adjacent excavated furrow, thus inverting the soil to around 20-30 cm. Deep ploughing methods can be used to depths of up to a metre, depending on soil type (Landlife 2006) and have been used for heathland restoration where the subsoils are suited to heathland but the topsoil is not due to past agricultural practices. It would also have the advantage of burying any undesirable seed bank. However, buried organic matter from deep inversion of topsoils and litter layers can give rise to anaerobic layers, which are not conducive to root development and vegetative growth. These are also likely to have significant impacts on soil biology and other soil processes (Bradley and others 2006).

3.77 In Germany, an intermediate method called choppering (or schoppern) has been used. This process involves the near-complete removal of the organic layer (O horizon) leaving just a few centimetres *in-situ*. This creates bare soil, but leaves the A-horizon intact covered by a thin layer of organic material (Keienburg & Prüter 2004; Niemeyer and others 2007). However, choppering is not suitable in areas dominated by *Molinia* as it leaves part of the tussock-stool intact from which it can regenerate (Niemeyer and others 2007).

Case study: Restoring heathland using turf-stripping at Albury Heath, Surrey

3.78 This project aimed to restore a 23 ha heath dominated by wavy hair-grass *Deschampsia flexuosa* as a result of anthropogenically elevated atmospheric nitrogen deposition. Wavy hair-grass is able to colonise and become dominant amid stands of degenerate heather. However, heathland seedbanks can be preserved under wavy-hair grass for many years (Symes & Day 2003). To regenerate heathland in such areas, methods needed to be employed that either brought the extant seedbank back to the surface by rotovating or ploughing, or exposed it by turf-stripping. Removal of large mounds of turf and/or soil can be expensive, and to reduce some of these predicted costs at Albury, the turf was moved to the side of the plots where it was mounded.

3.79 In 1990, turf-stripping trials began at Albury Heath in which areas of turf were removed (scraped back) to a depth of 5 and 10 cm using a 360° long-arm excavator. As part of the restoration, some areas were left to regenerate naturally (shallow and deep scrapes) whilst others were inoculated with heather seed (discrete areas within deep scrapes). This was done as insurance against loss of seedbank in the deeper scrapes, although this proved unnecessary as it transpired that there was an abundance of heathland seeds at the deeper levels at Albury.

3.80 Some scraped areas became invaded by birch *Betula* spp. and had to be treated with the herbicide Roundup, taking care to weed wipe above the growing point of the heather only in order to preclude affecting non-target species. Goats were also introduced to graze regenerating birch, but this proved unsuccessful as they also grazed the heather. Rabbit grazing also occurred on site and, although it had some effects on establishing heather, their browsing encouraged branching leading to a more lateral, healthy growth in the plants affected. When ungrazed plants become taller and woodier and thus increasingly unpalatable to grazing animals. This can result in a diverse age and plant architecture.

3.81 Before the trials around 90% of the land at Albury Heath was dominated by wavy hair-grass. Following the trials, this area was reduced to around 50%. The establishment of heather was rapid and most pronounced in the shallow stripped areas, although these areas were also dominated by grass regeneration. The resulting heathland-grassland mosaic added to the general biodiversity of the area. For a summary of the above restoration and its outcomes, refer to Symes & Day (2003).

Soil disturbance and soil removal: Summary

3.82 The heathland restoration and re-creation techniques that depend on soil disturbance and removal of material have the greatest potential to adversely affect soil quality and functionality, including the integrity of any soil conservation interest or the archaeology. However, this will depend on the extent of previous activities such as ploughing which may have already damaged any interests. Wider adverse impacts on the soils and the environment and compliance with planning and waste disposal legislation must also be considered. Topsoil inversion in particular is not suitable for archaeologically sensitive areas.

3.83 Soil removal, rather than soil disturbance, is considered the best method for increasing the dominance of *Calluna* on former grass dominated swards, and out performs rotovation (Britton and others 2000). Michael (1998) demonstrated that soil removal generally leads to larger overall reductions in elemental nutrients (total nitrogen, ammonium-nitrogen, nitrate, and extractable potassium), particularly at the soil surface, when compared to soil disturbance methods. There is little measurable difference in the depletion of exchangeable calcium and magnesium between either treatment. The removal of soil may not reduce pH therefore to any significant degree (Allison & Ausden 2004), depending on its nature.

3.84 Despite considering that soil removal produced the best results in experiments at Knettishall Heath (Breckland, UK), Britton and others (2000) judged that soil disturbance was more cost-effective. For example, there is no need for the use of expensive machinery or the disposal of large volumes of soil. In addition it can help to reduce both available and total nitrogen and possibly extractable phosphate from the system. However, soil removal of the A-horizon generally removes a greater volume of nitrogen (Bacon 1996; Niemeyer and others 2007).

Carbon sequestration in relation to heathland re-creation and restoration

3.85 All green plants assimilate CO_2 from the atmosphere via photosynthetic processes, and some is then released again as CO_2 through respiration. The remaining carbon gets allocated to leaves, roots, stems, woody matter and seeds (Broadmeadow & Matthews 2003). Globally, soils are estimated to contain 1500 gigatonnes of carbon which equates to approximately three-times that contained in the atmosphere and vegetation. The response of soil carbon to changes in land use remains one of the most pressing contemporary issues (Tate and others 1997).

3.86 The environmental regulation role of soils is one of its key functions. Soil is the largest carbon reservoir in the UK, storing in the region of 6 billion tonnes. Carbon concentrations in heathland soils are considered to be greater than in forest soils (Barton and others 1999). Soil carbon density is generally higher under forest and semi-natural vegetation than in soils undergoing more intensive land-uses, for example, arable agriculture, where carbon is regularly liberated into the atmosphere through tillage and the oxidation of organic material (Lal 2005; Sleutel and others 2006). Woodlands and forests remove approximately 4 million tonnes of carbon from the atmosphere annually but store around 150 million tonnes (Forestry Commission 2007).

3.87 Carbon sequestration in trees, woody vegetation and soils is a slow process taking from decades to centuries. However losses as a result of clearfelling, for example, tend to be rapid. When forests are clearfelled and not replanted the carbon reservoir that had been created is removed from site as timber for use in either pulping or furniture (the latter of which would retain a proportion of sequestered carbon). The dry weight of wood comprises approximately 50% carbon and global estimates of carbon lost through deforestation in the 1990s ranged from 0.3 million tonnes to 2.6 million tonnes per year (Tate and others 1997). Soil disturbance associated with forest management also has the potential to release large quantities of carbon into the atmosphere (Broadmeadow & Matthews 2003).

3.88 Milne & Brown (1997) suggested that podzols (upland and lowland) contain about 10% of England and Wales soil carbon, equating to approximately 175-211 tonnes of carbon per hectare, which is relatively high for non-peat soils. On the other hand, brown sands, the most likely result of agricultural improvement of sandy heathland soils, contain approximately 93 tonnes of carbon per hectare.

3.89 Heathland restoration or re-creation has a number of potential implications for the carbon budget. The restoration of scrub-invaded heathland and afforested lowland heathland has been shown to decrease carbon stocks (Colls 2006). However, the UK BAP targets seek the restoration of 10,500 ha lowland heath by 2020 (UK BAP 2006) much of which will be on agricultural and forested land. Forest abandonment can maximise on-site carbon stocks, whereas gradual continuous cover restoration without clearfelling can sustain stocks. However, rapid clearfelling can substantially deplete carbon stocks.

3.90 Lowland heathland restoration from conifer plantation has the potential, therefore, to deplete the pool of carbon in aboveground biomass including trees, dead wood, and litter; the largest change occurring with the removal of trees (Colls 2006). However, as the plantations are not left on site permanently, this probably also occurs when the forest crop is felled. When restoring heathland from former agriculturally improved heathland soils, the suggestion of Milne & Brown (1997) that podzols can contain significantly more carbon would go some way to redress the potential loss from forestry.

3.91 Using data derived from the Tomorrow's Heathland Heritage restoration programme (UK), Colls (2006) showed that as a consequence of the restoration of 879 ha forested heathland and 4937 ha of scrub-invaded heathland, a total of 0.09 MtC (0.6 MtC through scrub clearance, and 0.03 MtC through forest removal) had been released. However, these figures can be affected by such disposal methods as removing trees/scrub or, for example, whether residues are burned or left to decay. Burning can release further stores of carbon in the form of CH_4 and N_2O (Colls 2006). This author, however, did not look at the potential sink of C from arable land converted back to heathland.

3.92 When peat-based soils, which have a high organic matter content dry out, usually as a result of draining or afforestation, the peat oxidizes, resulting in large amounts of carbon being lost to the atmosphere as CO_2. More carbon may be lost by peat drainage than is actually sequestrated by a stand of spruce over an 8–12 year period. However, it is considered that the carbon assimilated by grasses and other vegetation colonizing a newly afforested area can help to offset this loss to some degree as net carbon uptake in the new plantation can begin earlier (Broadmeadow & Matthews 2003).

3.93 Burning also impacts upon soil carbon balances (Forgeard & Frenot 1996). It leads to pH rises in the soil, possibly due to ash production. Where temperatures achieved in heathland burning reach approximately 300 °C, large proportions of soil organic matter and therefore carbon can be removed from the system. The behaviour of the soil differs greatly between 300 °C burns and cooler burns of 150 °C, the former of which will also reduce the carbon assimilation capacity of heathland soils.

3.94 For semi-natural ecosystems, particularly wet nutrient-poor sites with low decomposition rates under conditions of elevated atmospheric nitrogen deposition, it is considered that the soil storage (sink) capacity could potentially increase significantly (Evans and others 2006). Based on a single lowland heath site in northwest England, Evans and others (2006) estimate that this could equate to as much as 262 kg C ha^{-1} $year^{-1}$. Increased nitrogen deposition can cause increased carbon accumulation as it stimulates vegetation growth and results in increased litter production as a result of its fertilising properties (Vitousek and Howarth, 1991; Townsend and others, 1996) and could also potentially reduce decomposition rates (Berg and others, 1998; Hagedorn and others, 2003; Franklin and others, 2003). Fertilisation by atmospheric nitrogen deposition is already considered to have increased carbon storage in forest biomass and soils to varying levels (Peterson and Melillo, 1985; Schindler and Bayley, 1993; Townsend and others, 1996; Holland and others,1997), although a relationship between these two parameters does not always exist, suggesting effects could be highly site specific (Dise and others, 1998). Other authors have also suggested that nitrogen deposition makes a relatively minor contribution to overall carbon sequestration (Nadelhoffer and others, 1999; Currie and others, 2004). Where atmospheric nitrogen deposition leads to carbon accumulation, nitrogen enrichment of the soil (expressed in terms of C/N ratio) will be slowed, or potentially halted (Evans and others, 2006).

Conclusions

3.95 Throughout Britain and Europe during the last decade or so, heathland restoration has expanded in scope. Many authors across Europe have investigated the most cost-effective methods of achieving the best results. However, although science has had a large input into modern restorative techniques, many of these techniques have been based on practitioner experience and historical methods. Heathland practitioners have been able to utilise a number of different methods of ground preparation and amelioration of soil conditions for restoration or re-creation, the most widespread of which are, alone or in combination: soil, turf or litter stripping; ploughing, soil inversion or rotovating; and the application of acidifying material. Many are variations on a theme that can be traced back over centuries and which attempt to create results akin to those produced as a result of past management practices, such as plaggen.

3.96 The main conclusions that can be drawn from the literature review is that level of nutrients and pH are key to the relative suitability of sites. The removal of scrub or coniferous species from former heathland appears to offer the most practical and cost-effective method for restoring lowland *Calluna* heathland. The timber crop can be sold in some cases to offset costs of restoration, and there should be no need to dispose of large volumes of soil as disturbance of the O horizon should be sufficient to regenerate heathland vegetation from the seedbank and is less damaging to the soil resource and wider environment overall. In addition, the less modified soils means that with lower nutrient and pH levels, there would be little need to ameliorate the soils using acidic materials such as elemental sulphur. The long-term persistence of acidic podzol soils and seedbanks under conifer plantations suggest that this should be a relatively straightforward process compared to attempting restoration on ex-arable soils (Walker and others 2004).

3.97 The re-creation of heathland on former arable land can prove more problematic owing to the presence of soils with a high nutrient status and elevated pH. The difficulties and costs involved in removing large volumes of soil for disposal, or adding elemental sulphur, means that plant hire and transport can be high. On ex-arable land, the wholesale removal or deep ploughing that might be necessary for heathland restoration, could compromise any archaeology that might have survived the previous agricultural processes. Deep ploughing is considered a potential cause of damage to structural remains and artefacts that might persist below normal ploughing depths. This was demonstrated nationally in the 1998 English Heritage Monuments at Risk Survey (Darvill & Fulton 1998). In addition, any acidification of the soil using elemental sulphur in particular, could affect soil processes and archaeological preservation. However, it is very important to point out that some archaeological and conservation soil interest is likely to have been already lost as a result of ploughing practices, depending on the agricultural history.

3.98 In soils confirmed as having scientific and conservation value, or any archaeological interests, non-disturbance methods are the only option to avoid causing irreversible damage to these features. Methods such as cutting, burning, or herbicide application can be successful in restoring former heathland, but their efficacy in successfully re-creating heathland can be limited where soil nutrients need to be reduced. It will be then unpractical or undesirable to consider heathland re-creation on arable land, especially if archaeological interest is suspected. Where there is archaeological interest in conifer plantations or secondary woodland, the use of methods causing minor disturbance, such as shallow rotovation or burning followed by gazing, has been proven to produce good results.

3.99 Trees and soils have been shown to be carbon sinks. The removal of trees (Tate and others 1997) and soils (Broadmeadow & Matthews 2003) and the disturbance of soils will, therefore, affect the release of carbon from these sinks, largely into the atmosphere. Carbon concentration is generally higher under semi-natural vegetation than under more intensive land-uses such as arable agriculture, in which carbon is regularly liberated into the atmosphere through ploughing (Lal 2005; Sleutel and others 2006). Thus, it can be reasonably expected that the conversion of ex-arable land into semi-natural vegetation, such as heathland, means that such projects, over time, have the potential to be carbon neutral, or increase soil carbon storage, given the carbon storage capacity of the semi-natural vegetation, and of podzolic soils (Milne & Brown 1997), whereas restoration from former forestry could result in a carbon deficit.

3.100 However, UK-wide, carbon balance specifics will depend on the relative proportion of restoration taking place on forestry to those on ex-arable habitats. In addition, heathland restoration projects should not be viewed in isolation when considering carbon balances. The Woodland Trust's indicative target (if achieved) of creating a further 400,000 ha of new native woodland for biodiversity over the next 50 years (Smithers 2006) could, over time, more than offset any carbon deficit caused as the result of restoring former forestry back to heathland. The potential loss of at least 0.09 MtC due to lowland heathland restoration in the Tomorrow's Heathland Heritage programme represents a very small carbon source and must be seen in the context of other sinks and sources arising from land use change and forestry activities (Colls 2006).

3.101 In all cases it is important to consider the wider multi-functionality of soils. Soils are a non renewable resource and it is important to recognise and protect their wider functions (eg in environmental regulation such as run off, water flow and aquifer recharge, as carbon stores and for their impact on global warming, as a habitat for soil biodiversity etc) (Defra 2004). There is also increasing evidence about the importance of plant-soil microbial associations in influencing plant diversity. For these reasons it is important to ensure that damage to soil is minimised during habitat restoration and re-creation and consequently it is usually better to understand and work with existing conditions rather than unnecessarily altering the site (Bradley and others 2006).

4 Site experience in the UK

Methodology

4.1 The extent to which heathland restoration and re-creation have altered soils, or not, has been explored through a questionnaire sent to site managers and advisors across the UK. The original list of recipients was generated through Natural England's internal heathland network and the web-based 'heathnet' discussion forum. More contacts have been added through personal knowledge within PAA, especially through the National Trust. This gave a total list of 66 contacts for over 80 heathland restoration/re-creation projects.

4.2 A questionnaire was devised that sought information on various aspects of heathland restoration and re-creation in order to make judgements on the extent to which different techniques had been adopted. A copy of the questionnaire is presented in Appendix 2. The questionnaire was e-mailed to all contacts. A second e-mail was sent prompting a response after which those who had not replied or stated that they could be contacted were telephoned. A total of 26 questionnaires were completed covering a wide range of restoration and re-creation projects of varying size in a variety of geographical locations. This is an adequate level of response although a higher return would have been preferable and enable a more rigorous analysis.

The results

4.3 The responses give an overview of the types of projects and methods used for lowland heathland restoration and re-creation in England and Wales. Due to a commitment made to site managers, their identity and the name of particular projects have been kept confidential. The information obtained is summarised in Appendix 3.

General information

Location of projects

4.4 Responses to the questionnaire were received from site managers involved in projects across England and Wales (Figure 2). Twenty-two responses related to projects in England, which were distributed across the country from the south, south east, south west, and the Midlands to the north east. The northern most project was in County Durham. There were four Welsh projects, all of which were in Pembrokeshire.

Year(s) of works being undertaken

4.5 All projects have been subject to work over the last ten years. The longest standing heathland project is in Nottinghamshire and covers an area of approximately 26 ha. It commenced in 1985 when the site was acquired, with ongoing annual management in the intervening years. Twelve of the projects started within the last five years, three of which were less than twelve months old at the beginning of this survey. One 30 ha re-creation project in Shropshire is in its final stages of planning and is due to commence in the autumn of 2007.

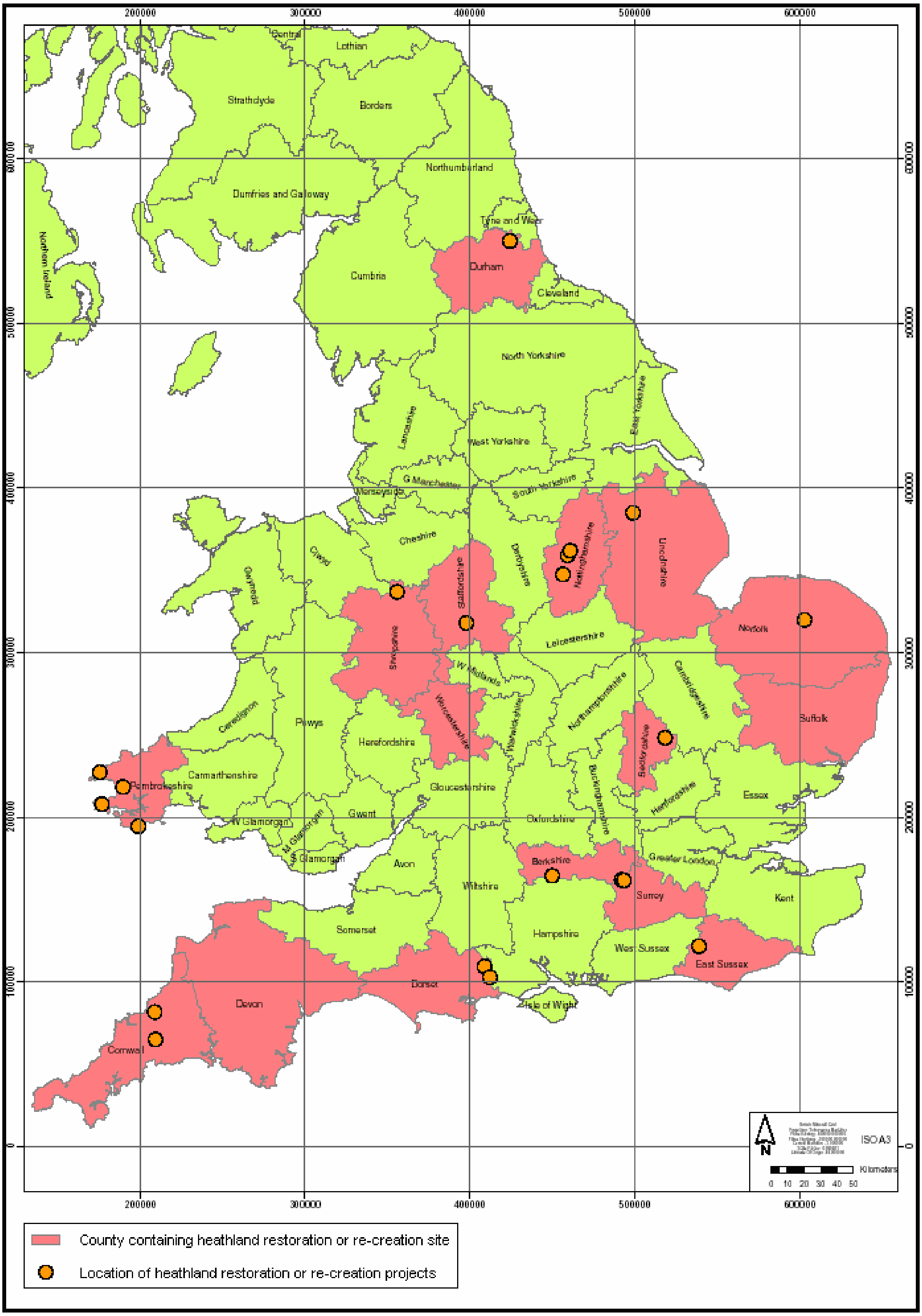

Figure 2 Counties with heathland re-creation or restoration and location of projects (those included in the questionnaire)

Size of project area

4.6 The sizes of the project areas have been classified into three categories; large (>50 ha), medium (11-49 ha) and small (<10 ha). Six projects were classed as large, eleven as medium and nine as small. The smallest project area was 0.1 ha with the largest covering 5000 ha. The latter respondent provided a generic response to the questionnaire over the phone, based on examples of restoration and re-creation projects across Dorset.

Project objectives

4.7 The projects were broadly termed as restoration, re-creation or management/maintenance (as defined in paragraph 1.4-1.6) of existing heaths, or a mixture of these types. Ten projects were classed as restoration projects, ten as heathland re-creation and the remaining six were a combination of project types.

Target habitat type

4.8 Lowland heathland and acid grassland were the predominant target habitat types for projects. The National Vegetation Classification (NVC) target was dependent on geographical location and the characteristic local vegetation type. In eight of the projects (30%) wet heath was being encouraged, and in the majority of these this was the priority target habitat type. Good quality mires were also listed as a target. The projects targeting wet heath were evenly distributed across the country. Coastal and dune heaths/grassland were favoured for some of the projects.

4.9 Some of the responses did not include a target NVC, but where an adequate description of the desired vegetation type has been provided, a target NCV has been extrapolated. The NVC target types were:

- U1 – Festuca ovina – Agrostis capillaris-Rumex acetosella grassland;
- H1 – *Calluna* vulgaris – Festuca ovina heath;
- H4 – Ulex gallii – Agrostis curtisii heath;
- H7 – *Calluna* vulgaris – Scilla verna heath;
- H8 – *Calluna* vulgaris – Ulex gallii heath;
- H9 – *Calluna* vulgaris – Deschampsia flexuosa heath;
- H10 – *Calluna* vulgaris – Erica cinerea heath;
- M16 – Erica tetralix – Sphagnum compactum wet heath;
- M23 – Juncus effusus/acutiflorus – Galium palustre rush-pasture;
- M25 – Molinia caerulea-Potentilla erecta mire;
- MC5 – Armeria maritima – Cerastium diffusum ssp. diffusum maritime therophyte community;
- SD8 – Festuca rubra – Galium verum fixed dune grassland; and
- SD10b – Carex arenaria dune community

4.10 In most instances, site managers were developing a mosaic of heathland habitats typical of the region in which the project was taking place. The target type was based on the habitats of the surrounding area, as they were the source of the brash and/or seed. The project objectives for a site in Pembrokeshire were the creation of a mosaic of heathland (H7) and calcareous grassland (CG7). No patterns in the distribution or frequency of NVC target type emerged from the responses received.

Vegetation and land use prior to the project

4.11 Given the diverse nature of the projects it is not surprising that a wide range of previous vegetation types and land use activities were reported. For re-creation projects, former agricultural land (arable, dairy and mixed) and conifer plantations were being converted back to heathlands. There were nine re-creation projects on land that has been used, at least in part, for agriculture and had been subject to varying degrees of agricultural improvement. Eight projects were on areas that had been, at least in part, forested; one had been used for gravel extraction and three used by the military. One was a former airfield, whilst other respondents did not specify the military use, other than the majority of the activity was associated with World Wars I and II. Two re-creation sites were common land with grazing.

4.12 Two project areas under restoration had been afforested, but heathland species were still present under the trees. Five sites had been subject to some use by the military, but no further details of the extent of these activities were given. All of these projects had issues with degradation by scrub enchroachment of the target habitat type, including European gorse, woodland encroachment and invasion by bracken. Two restoration sites were Common land with military use.

4.13 Drainage for agricultural improvement was a major issue on one site in Dorset where wet heath was the priority restoration target. Drain blocking was the main measure adopted. The respondent reported that in these areas heathland establishment was more rapid than in areas where drier heaths were the target. The respondent assumed that this might have been due to the lower nutrient load in wetter soils and that peat and *Sphagnum* development aided the establishment of the heather plants.

4.14 The land use of the sites prior to the restoration/re-creation projects could have had an effect on the soils and historic environment. Activities included ploughing, addition of fertilisers and lime, military movements and construction on the site; drainage (for agricultural improvement) and woodland operations (ploughing and other ground preparations for conifer planting). Only one out of the 26 projects had no previous activities on the site, because it was common land and had been subject to light grazing only.

4.15 Some land uses may ostensibly be highly destructive but closer scrutiny shows that the soil interest has not been totally compromised and despite some disturbance there may be vestigial features of value. For example, in the case of land previously owned and used by military authorities, it is possible that tank manoeuvres, heavy vehicle tracking and munitions explosions have resulted in extensive ground damage. However, military land may also have been used for activities less likely to disturb soils. It has been found that demilitarised land, where farming, construction development and visitor access have been restricted, now supports species-rich habitats of significant conservation value. This being the case, the potential for a concomitant rich geodiversity of soils may be high.

Ground preparation methods

Preparation activities

4.16 Soils and archaeology are considered later on in this chapter but, for the most part, they did not constrain the methods used for the ground preparation works. However, in some cases, the project area was reduced due to soil or archaeological issues.

4.17 The methods employed by site managers depended on the type of project, the vegetation and previous land use of the project area. Generally, restoration projects, for example, restoring degenerate heath into a favourable condition after scrub encroachment, would have less potential impact on the soils and historic environment than projects where significant soil removal or inversion were adopted.

4.18 In the following section the methods employed for ground preparation are discussed. The frequency of use of the different ground preparation methods is shown in Figure 3.

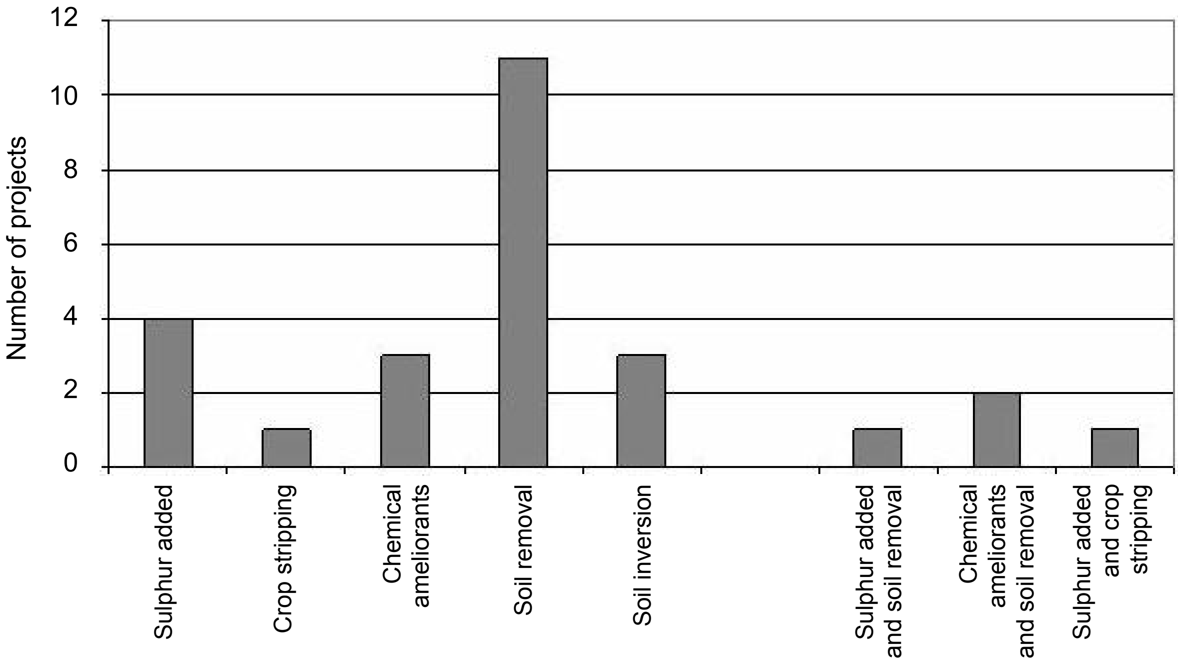

Figure 3 Ground preparation techniques: left side, individual techniques; right side, combination of techniques

Sulphur addition

4.19 Sulphur addition was used exclusively on sites previously used for agriculture, and where the conversion from arable and improved grassland was the project objective. Four (15%) of the projects used sulphur addition as part of the ground preparation methods prior to vegetation establishment. This method was exclusively used on sites improved through the application of fertiliser and where the pH had been altered over time. A project that is planned to start in 2007 will experiment with various levels of sulphur addition after inverting the soil (to a depth of one metre) across the whole of the site. Sulphur is to be applied at quantities of 1 or 2 tonnes/ha and the rate of vegetation establishment is to be monitored and compared with a control receiving no sulphur. The case study below (4.20) describes an example of this treatment.

Case study: A project where sulphur was added

4.20 A site in Suffolk, where experimental soil inversion was used, applied either a 50% or 75% mixture of soil with acidifying peat rich in pyrites. No information was provided as to which concentration gave the best results for vegetation establishment. However the respondent was keen to point out that soil fertility was the biggest problem and that if the starting soils were not ideal or at least in their broadest terms ‘fairly’ suitable for heathland vegetation it is very difficult to correct this. Managers of sites with the ‘wrong’ soils should consider whether or not the time and expense involved in creating the ideal soil conditions in terms of nutrient and pH should be entertained for heathland re-creation.

Nutrient stripping by cropping or grazing

4.21 Cropping as a method of nutrient stripping was only used once. Annual grasses were sown on the project site and then ploughed in. The respondent considered this an effective method of reducing the nutrient levels, although this contradicts the findings of the literature that cut vegetation must be removed from the site to achieve those levels. On one project where conversion from arable to heath was the objective, no phosphorus or ammonia was added to the crop in the final year before conversion into heath. Sulphur addition was also an integral part of the ground preparation in this project.

4.22 One of the respondents used grazing with sheep as an alternative method to nutrient stripping through cropping. He was of the opinion that the sheep were effective at reducing the amount of nutrients entering the heath/acid grass system because a proportion of the nutrients weas locked up in the animals. This would be most successful if the sheep were removed from the site and folded elsewhere at night (a traditional management practice used to improve the arable land in the past where animals were folded). It is not known how long it might take for such nutrient stripping to take place.

4.23 Stems and/or roots were burnt in four projects.

Chemical ameliorants and herbicides

4.24 The reports showed that no chemical ameliorants were being used, other than one to assist in the clean-up of aviation fuel from one of the sites. These chemicals had no function in the ground preparation other than to remove pollutants.

4.25 Herbicides were used in many of the projects, mainly Asulox for bracken control and others for the control of invasive species such as South American crowberry *Empetrum rubrum*, Mountain laurel *Kalmia spp*. and mullein *Verbascum spp*.

Soil removal

4.26 Some form of soil removal was involved in 42% of the projects. This ranged from a shallow skim of soils (5-10 cm) to reveal the mineral layer, to more extensive and deeper extraction (30-40 cm). The nature of the soil removal operations were once again linked to the previous vegetation and land use. Deeper soil removal was noted in re-creation projects where arable and/or agricultural land was being converted to heath. Shallower, soil skimming operations were employed in restoration projects where the heath had become unfavourable due to scrub and grass invasion. The only exception was a restoration project on a degenerate heath that had been subject to 100% cover of bracken, and in this case up to 30 cm of litter and soil were removed.

4.27 With regard to soil removal, the biggest issue highlighted in the responses was the expense involved in this kind of ground preparation. Most of the removed materials were heaped/bunded around the site. Hedge banks were created in one of the projects. The disposal costs for soil removal are high and this, in some cases, limited the size of the project area.

4.28 No planning or waste disposal issues were reported.

Soil Inversion

4.29 Three (13%) of the projects had involved or will involve soil inversion (two were established projects, the other was due to commence in 2007). All the projects were on sites that had been subject to agricultural improvement. One was a horse paddock and the others were arable sites. A one metre deep plough was used on one of the sites and this is also planned for use on the project due to start in the autumn of 2007. The third project did not specify to what depth the soil was inverted. This method creates instantly nutrient-poor soils for the establishment of heathland vegetation, provided that the subsoil nutrient and lime levels are suitable, and lower than those in the topsoil. No other soil problems were any reported, although deep burial of organic matter (eg from topsoil) can result in anaerobic soil conditions; loss of soil stability can increase run-off and erosion.

Methods of restoration/re-creation of heathland vegetation

4.30 Ground preparation was the first stage in all restoration and re-creation projects. The methods employed in the establishment of the target vegetation are now considered and are summarised in Figure 4.

4.31 The questionnaire considered five different methods of establishing heathland vegetation following ground preparation. These are:

- natural colonisation;
- addition of seed;
- addition of seed holding brash;
- direct planting; and
- importation of rotovated material (containing a seed bank) onto the project site.

4.32 The latter was not reported as being used on any of the projects and is therefore not considered further. However, one of the projects exported stripped soils to another local site attempting heathland re-creation, but this second site was not reported in the responses. Ten projects relied on natural colonisation alone, while a further nine used natural colonisation in conjunction with other approaches. The other seven depended on introducing plant propagules.

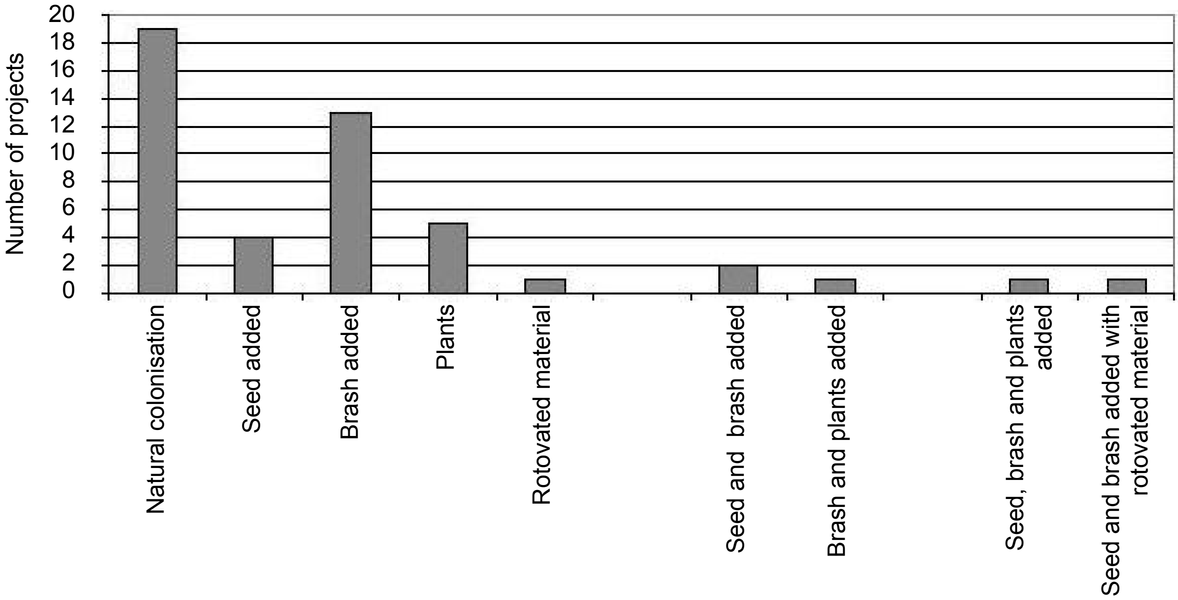

Figure 4 Techniques to improve vegetation establishment: left side, individual techniques; right side combination of techniques

Natural colonisation

4.33 The 19 sites that used natural colonisation were all restoration projects where a good seed bank resource was expected to be present, and the surrounding vegetation was the same as the target vegetation.

Seed added

4.34 Only four of the respondents reported using seeding as a method for vegetation establishment. This method was used on re-creation projects where there was a lack of suitable seed bank or nearby target vegetation. Heather seed was mixed, in one example, with bristle bent that was to act as a soil stabilisation crop. In one case, seeding was used after poor establishment of heather through spreading seed-holding brash over the prepared site.

4.35 Only one example of quantities of heather seed was reported and this was spread at a rate of 0.1 kg of heather seeds per hectare.

Seed-holding brash added

4.36 This method was used by 50% (13) of the respondents. In only one instance did this lead to poor heathland establishment and, in this case, additional seeding was undertaken as described above.

4.37 Heather bales, with seed in capsules still attached, were either cut from elsewhere on the site or imported and spread out over the project area. Quantities varied between sites and were dependent on the type of harvesting machine. It was reported that different quantities of brash were spread out on prepared areas. Figures varied from one tonne per hectare, to 10-15 cm depth of arisings, six tonnes per hectare, five bales per hectare and 2-5 cm depth of arisings. The results of the literature review and the experience of the land managers suggests that deeper layers could be reducing seed establishment as heather seed needs light to germinate. The size of the bales was not given – for five bales/ha to be sufficient, this must have been large round bales.

4.38 The reported results of the seeding show that most sites used heather seed as the main source of propagules, and only limited attempts were taken to introduce other species that might also form part of the heathland communities. The heathland being created is therefore likely to become more heather dominated for some years until other species find opportunities to establish and spread.

Direct planting

4.39 Direct planting was not favoured as a method of heathland establishment because of the cost and effort involved. Only four projects utilised this method. One introduced some gorse to the project area but one of the plantings failed. The reason stated was that the plants were too young, being less than a year old. An experimental plot on one of the sites was planted with 70 ling *Calluna vulgaris* and bell heather *Erica cinerea* plants. At two sites the public were invited to take part in planting heather as a way of encouraging community interest and involvement. At one of these sites the planting was not particularly successful. This was thought to be because the plants had remained in their nursery pots for too long. The plants that failed were two years old. Previous planting was more successful when one year old plants were used. The plants were grown on from cuttings of heather that were sourced on the site.

Archaeological and soil considerations

4.40 This section of the questionnaire aimed to examine whether projects had considered the impact of work on soils and archaeology. The results of the questionnaire responses are shown in Figure 5.

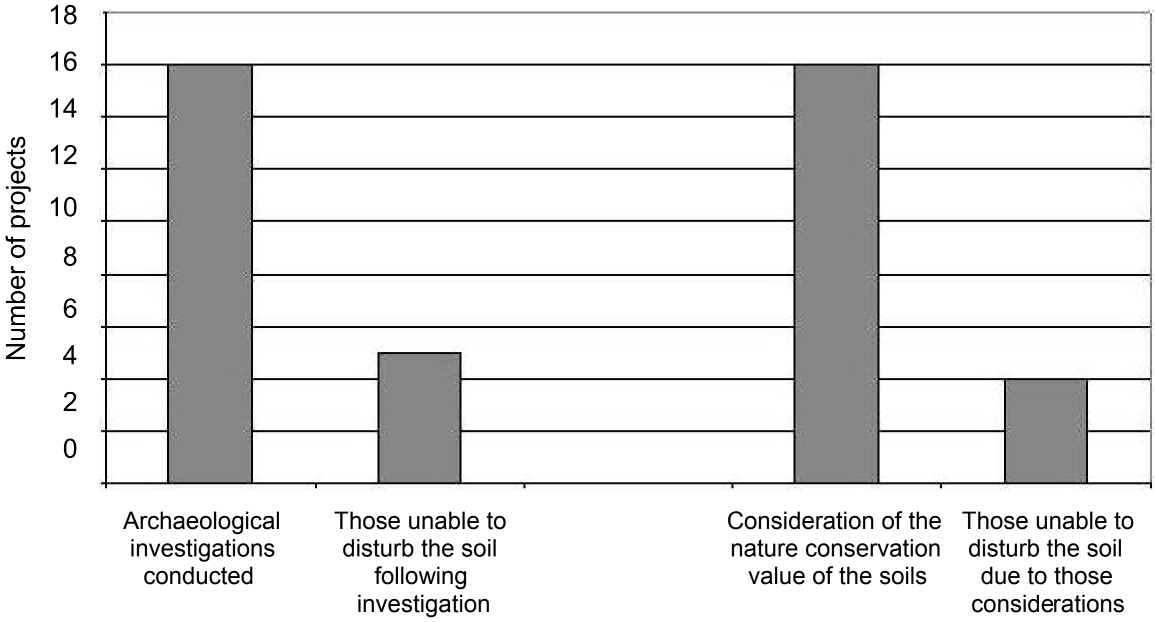

Figure 5 Archaeological investigations and/or consideration of the nature conservation of soils, and those in turn which were unable to disturb the soils

Archaeological investigations

4.41 Archaeological investigations prior to commencing the project were undertaken by 16 (61.5%) of the 26 respondents. In 12 cases the Historic Environment Record (HER) was checked, although it is far from complete. In seven instances (30% of projects) this was the only check made. If no interest was found then no further consideration of this issue was deemed to be required. The assumption was made that if the HER highlighted features of interest on the site then further investigations would take place. Where sites were not investigated for archaeology the respondents reported that those areas of interest were already known by the site managers and were avoided in the project.

Consideration of nature conservation interest of the soil conditions/characteristics

4.42 There were 16 positive responses where the nature conservation interest (biodiversity or geodiversity) of the soil had been considered before undertaking restoration/re-creation projects. However, site managers had not taken into account the soils in terms of geodiversity values for nature conservation. Information on the soils was limited, with many site managers having none - even on the textures, depth, acidity and nutrient content so essential for making decisions on the optimum approach for restoration or re-creation. Only one respondent provided detailed soil analysis results for their site.

4.43 Of those that had taken the soils into account at the inception of the project, their primary concern was about the suitability of the soil for restoration and biodiversity and not because of a concern for the intrinsic value of the soil itself. Soils were not disturbed that were valuable for reptiles; or because of problems with soil stabilisation or erosion by water and wind. The presence of a high quality soil profile, typical of the area in which the project was being undertaken, was not considered nor was the impact on the soils and their processes in terms of their wider functionality eg as a carbon store.

Outcome of the projects

Success of restoration/re-creation projects

4.44 Overall, success rates were generally good, with all but one project self-scoring as five or more out of ten. Only one project self-scored as one to two out of ten. The reason given was that an organic layer of between 100-200 mm was left after the upper soils had been removed. Where the entire organic layer had been removed and the mineral layer exposed, heather establishment was better and the project success was scored as nine out of ten. The respondent therefore suggested that this difference in the success of the project and vegetation establishment resulted from increased nutrients in the remaining organic layer. This point highlights the need for comprehensive details of the soils including a soil analysis down the whole profile before undertaking projects.

4.45 The degree of disturbance of the soils seemed to be an important factor in determining the success of the project. On some of the sites, more ground disturbance resulted in a quicker the rate of heather establishment. This was reported from one site where Rhododendron roots had been pulled out of the soil causing considerable disturbance. This was probably related to the removal of the litter layer, although without knowledge of the nutrient levels/soil type the success may have been related to this rather than soil disturbance per se.

4.46 The choice of machine for ground preparation was also critical in the establishment of vegetation. On one site a bulldozer was used to scrape the soil. However, establishment was slow due to ground compaction and the prepared bed was very uniform, something which the site manager wanted to avoid. In subsequent years a 360° excavator was used to prepare the ground. This resulted in an uneven and non-compacted bed as the machine could prepare the ground and reverse out of the site. Establishment of heathland vegetation was more rapid in these areas and good micro-niches also developed in the uneven bed.

Problems encountered

Inability to disturb soils due to nature conservation interest or archaeology

4.47 Six respondents (23%) reported that they were unable to disturb the soil due to the nature conservation interest on the site, the archaeology or the fragility of the soils themselves.

Nature conservation interest

4.48 Reptiles were present in bracken-covered areas with on one of the sites, which were to be stripped and allowed to colonise naturally with heather and associated vegetation. The presence of the reptiles led to the project being abandoned. On other projects, soils were also left undisturbed due to their value for invertebrates, notably bees and wasps.

Archaeology

4.49 Four respondents were unable to use their preferred method of ground preparation due to archaeological interests found within the project area. The presence of archaeological interest either led to a change in the location of the project area or in the ground preparation methods. One respondent reported that the altered ground preparation methods led to poor heathland establishment due to additional sulphur being added to compensate for the lack of soil removal (see case study below (4.50)) but the known areas of archaeological interest were avoided.

Case study: A project using sulphur instead of disturbing the archaeology

4.50 At a re-creation project on former agricultural land in Pembrokeshire, archaeological investigations were undertaken, the results of which limited the ground preparation methods. The area of interest was not subject to soil stripping whilst the remainder of the site was stripped to a depth of 200-300 mm. Sulphur was added to the whole site but where the soils were not stripped, double quantities were added to compensate for the lack of soil stripping. In these areas the rate of heather establishment was considerably poorer than in the stripped areas with less sulphur. Sulphur was added at quantities of between four and eight tonnes per hectare. In areas where extra sulphur was applied there was poor vegetation establishment, with bare soil and invasion by *Agrostis* species. The high sulphur applications led, in some areas, to a 'scorched earth' effect. In one of the 'scorched' areas the sulphur was subsequently rotovated into the upper soil layers to lessen the overall effect. This points to the fact the an understanding of soils and soil chemistry is needed before modifying the chemical status of the soils.

Fragility of soils

4.51 One respondent reported that soil disturbance was avoided because of their instability. The site consisted of sand over fen-peat and its inland dune system was considered to be vulnerable to wind erosion if the soil was unduly disturbed. Other site managers were aware of the instability of the soils within their project areas in relation to wind and water erosion, and these factors limited the ground preparation and heather establishment works. On one site a nurse crop of bristle bent *Agrostis curtisii* was sown with the heather seed to stabilise the soil after ground preparation works.

Reduction in the project area

4.52 Only one respondent reported having to reduce the project area as a result of nature conservation interest on the site. See paragraph 4.48.

4.53 Where an archaeological interest was found in the project area, respondents stated that changes in ground preparation methods were made rather than a change to the overall project area.

4.54 The practical constraints of soil disposal after stripping operations and removal of bracken litter were stated by many as a factor that limited the project area.

Factors leading to poor heathland establishment

4.55 Most projects were seen as being successful, with only a few reporting poor heathland establishment. Problems included: unsuitable soils; change in preferred ground preparation method due to soil/archaeological constraints; invasive species (mainly rhododendron and bracken); and financial constraints (the greater expense caused by using the preferred ground preparation method). One reported that the slow breakdown of bracken litter, without the use of machinery and livestock, limited the rate of heather establishment and habitat restoration.

Other information

Cost

4.56 Costs for the works depended on the type of the project, previous land use, vegetation and the ground preparation methods employed. Costs increased with the level of invasive ground preparation. Soil stripping could be very expensive, with the majority of the costs being incurred from soil disposal. Where soils could be stored on site or moved to the outside of the area for habitat establishment (earth/hedge banks, bunds etc.), the reported costs decreased.

4.57 Costs per hectare varied. The lowest cost was £275/ha, which was a re-creation project on former conifer, agricultural and set aside land. The project area covered 100 ha and the ground preparation method was a deep soil strip to a depth of 400 mm. No information was provided on the destination of the stripped soil. The most expensive was an experimental project which equated to £29,000/ha. However, the project area was only 0.1 ha and the reason for the high cost was the need for soil removal. £2,000/ha was the average cost for the majority of the projects. Dorset Heaths projects have set costs at between £2,000 and £8,000/ha depending on the ground preparation works, previous land use and target habitat type.

Case study: An archaeological survey and heathland re-creation lesson

4.58 A site in Worcestershire completed a restoration exercise on a 1.5 ha agricultural field adjacent to existing heath. The site was formerly heathland which had been converted into a horse grazing paddock, dominated by cock's-foot grass *Dactylis glomerata* with a small corner patch of interesting flora. The field had been subject to enrichment and the ground preparation method chosen was soil inversion to a depth of one metre. Prior to undertaking the inversion a full archaeological survey was commissioned but no interest was identified. The archaeological survey cost three and a half times more (£2,300/ha) than the soil inversion and vegetation establishment. However, this drastic preparation process in an area of high potential for important archaeological remains requires a responsible approach. Soil survey/analysis can also be cost-effective – if nutrients are already low soil strip may be a waste of money.

Guidelines followed

4.59 The majority of the projects received guidance from the former English Nature (EN) and similar advice was given to all site managers. Where advice from EN was not sought, local knowledge and previous site experience with similar projects was used. The variations in environmental conditions in the UK mean that there is no single, universally applicable set of guidelines.

4.60 The National Trust Soil Protection Strategy (1999) was mentioned as having influenced the extent to which the soils could be disturbed and that future projects could be constrained if the Trust guidelines are followed.

4.61 The English Nature guidance on habitat restoration projects (Bradley and others, 2006) is only recently published and therefore was not available at the time these projects were planned.

Case studies

4.62 The following case studies provide details of three projects from inception to the current stage. Examples have been selected that cover the majority of the methods discussed above. Two are re-creation projects; one from agricultural land and one from a forestry site, the third example is of a restoration project.

Case study 1 – Re-creation from agriculture

4.63 The project area covered 6 ha in Cornwall and had been subjected to intensive slurry application. The project objectives were to re-create heath and maritime grassland from highly improved grassland. An archaeological survey was undertaken, including a check of the Sites and Monuments Record. Archaeological interests, in the form of two barrows, were found on the site which limited the extent of the project area. The soils were considered in terms of their nature conservation interest (biodiversity and geodiversity) and keeping the variability in depth of the soils. The preservation of micro-terraces was one of the key objectives. Soil analysis information was not provided. Soil stripping removed 8-15 cm of soil (soil depth was variable, 25-30cms on average) and the area was left to colonise naturally from the surrounding cliff side vegetation. The removed soil was used to create an earth-bank along the boundary of the newly created maritime grassland/heath. Planning permission was not required as the soil was only moved very locally to create earth banks lower than 2 metres. Other material was used to create a bund against unsightly agricultural buildings inland and did not need waste disposal consent. There was no significant run off or erosion. The land was flat (it was a wartime airfield) and it had also been arable some years before so would have been little different to that. The project was self scored as eight out of ten and cost approximately £2,000/ha.

Case study 2 – Re-creation from a conifer plantation

4.64 A 59 ha site in Bedfordshire consisting of conifer plantation and some sycamore and birch woodland was to be converted to a lowland *Calluna* dominated heath/acid grassland mosaic. The soil type was described as free-draining fine sands. Specific restoration works, avoiding ground disturbance on the 1.5 ha scheduled monument, were agreed with English Heritage. An archaeological investigation of all other parts of the site, including a check on the HER, concluded that ground works should be limited to the top 300 mm of mineral soil, and that tree roots must not be disturbed. The site had been heathland and acidic grassland up until ca1800, since which time several timber crops had been taken off the conifer-dominated area. Some 40 ha of plantations were felled over two winters, and lop and top mulched, or baled and removed. Some stumps were ground out, and litter and organic soils were removed to a depth of 100 mm to leave the mineral layer exposed. Following confirmation from The Environment Agency and local council that planning was not required, this organic waste was placed in banks adjacent to areas of retained trees, to decompose and scrub over. Seed was added to the mineral soils at a rate of 200 g heather seed/ha, bulked up with bran or sawdust to assist spreading. Some one year old gorse plants were planted. A follow-up spray of Asulox was used to control bracken re-growth. The outcome of the project was scored at ten out of ten for the re-creation works within the plantation. The net cost was approximately £275/ha (£90k had been obtained from selling the timber) and staff, fencing, grazing and other later costs are excluded.

Case study 3 – Restoration on area of neglected heath

4.65 This site in Pembrokeshire covers 14.6 ha and the project has been running for five years. The project objectives are to restore and maintain the dry heath and marshy grassland mosaic in favourable condition and any archaeological features present. The site had been subject to some localised machine workings to create a track across the site with some small-scale ground disturbance elsewhere. The soils were classed as peaty over clay, acidic with low fertility. No other information regarding the soils was offered and it is not known whether detailed analyses were made. Restoration consisted of the removal of above ground vegetation including bracken *Pteridium aquilinum*, Rhododendron and purple moor grass *Molinia caerulea*. Two small scrapes were dug and one or two small patches (0.3 ha) of heathland were burnt between 2001 and 2005 to assist with the restoration grazing.

4.66 Bracken control relied on trampling by cattle and horses. The restoration grazing was done by cattle (Dexters) at a rate of 0.14 Live Stock Units (LSU)/ha to 0.27 LSU/ha and the animals were kept on the site most of the year. Additional grazing by horses and ponies was undertaken in the summer months (May-Oct) at a rate of 0.14 LSU/ha. No other ground preparation methods were used. The area was left to recolonise naturally from the surrounding vegetation. Archaeological investigations were considered through consultation with the local archaeological trust. The site had been surveyed (desktop only) in the late 1990s and it was judged that no further surveys (including field surveys) were necessary due to the non-invasive nature of the site works. All of the objectives were met and the project was scored at ten out of ten. The cost of the project was £324/ha.

Conclusions

4.67 It appears from the number of completed questionnaires received, that current lowland heath restoration and re-creation projects cover a wide geographical area and a wide range of situations. The re-creation projects are mainly centred mainly on conversion of arable and conifer plantation to heathland, and restoration projects are being undertaken to return degenerate or derelict heath to favourable condition.

4.68 The degree of modification in relation to re-creation projects has been marked and the soils have been disturbed radically. In order to create the conditions for rapid heathland establishment, destructive ground preparation methods have sometimes been employed. The concerns over the deleterious impacts of the restoration and re-creation activities are often perceived to be small because the previous land use which destroyed the heathland may have already affected the soil and the historic environment. However, little consideration has been given to the wider value of soils and their functions, including the impact on the soil biota and ecosystem processes. Ploughing and forestry operations can be very damaging to the soils and can destroy any archaeological interest, at least within the plough layer. Although little information has been provided by respondents on soil type and soil analysis, it is important to understand the soil types and nutrient status on the site in order to consider the suitablility of the site and to inform on appropriate ground preparation methods and follow up management. The chances of successful and cost effective heathland establishment are improved if soil chemistry is understood.

4.69 Just under two thirds of the heathland restoration/re-creation projects considered the archaeological value of the site before starting (although in some cases this only involved a search of the HER and no interpretation by an experienced archaeologist). However, less evidence was found of any consideration of the intrinsic value and wider functionality of soils. Although many soils have already been damaged and any previous value lost after agricultural or other activities prior to heathland re-creation projects, there seemed to be a lack of awareness of the possibility of any other intrinsic interest or wider environmental value.

4.70 The development of a standard set of guidelines for these types of restoration/re-creation projects has to embrace a broad scope to cover site variation, as demonstrated by the responses to the questionnaire. This is pursued in the following chapters and in the best practice guidance document that forms the final part of this project.

5 Discussion

Effect of heathland restoration and re-creation on soil conservation

5.1 Features of heathland soils that may be lost through inconsiderate restoration practices include mature soils, often podzols, displaying distinctive horizonation that may have developed over many hundreds, even thousands, of years. Similarly, examples of palaeosols and cryogenic surface and sub-surface features may not be recognised, and therefore be destroyed. Whether these features are lost or saved depends on their inherent robustness and the level of disturbance the technique involves. All approaches will affect the soil to some extent as soils are an integral component of the ecosystem, inextricably linked to vegetation and engaged in a continuous exchange of material, gases and energy.

5.2 Of the techniques recognised in the literature review surface vegetation (herb layer) removal techniques are considered the least disturbing. They incorporate grazing, cutting, herbicide application and burning. Even these apparently less perturbing techniques will have some impact as, for example, cutting and the removal of arisings robs the soil of an input of organic matter and alters the nutrient dynamics. However, this form of management will not fundamentally change the soil system and represents very little threat to any soils provided it is used in isolation. Changes are subtle and hardly perceptible. Vegetation removal through grazing was practiced on one project which self-scored 8 out of 10.

5.3 Soil acidity and nutrient status amelioration techniques include cropping, acidification, application of elemental sulphur, the addition of bracken and pine chippings, and peat, all of which are aimed at reducing the soil pH and/or nutrient levels after agricultural use. Cropping to reduce the nutrient levels was reported to be used in only one project from the questionnaire sample, but is known to have occurred in a number of other large scale re-creation projects as described in Section 3. Soils that have been 'improved' for agriculture characteristically have elevated pH. Acidification has been practiced on four out of the 26 projects for which details were gathered to restore the relatively low pH of a heathland soil. The questionnaire revealed that the addition of sulphur was the only acidification method being employed and always in association with agricultural soils. No other methods were detailed and there was no use of chemical ameliorants. Not all projects provided self-scores for these techniques, but when they did, it was 5-7 for drier areas and 8 for wet heath.

5.4 The reduction in pH, however achieved, will have a significant influence on soil processes. Increased acidity has the effect of reducing the availability of some nutrients, increases the solubility of certain micronutrients and reduces microbial and macro-fauna activity. A low pH also tends to increase the solubility of NO_3 and the family of metals that include P, K and Mg where increased acidity is associated with further losses by chemical leaching. However, it is unlikely that the change in soil chemistry will bring about radical structural changes to the soil. If soil pH is high because of past intensive agricultural use, particularly arable production that requires ploughing, there is a good chance that most soil valuable characteristics have already been reduced or lost. Of the projects reviewed where sulphur has been applied, it was accompanied by soil inversion and ploughing and it is this practice that is likely to threaten any soil interest rather than the simple surface application of sulphur.

5.5 It has been shown that restoration of sites that were formerly heathland, but are now wooded as a consequence of natural succession or the establishment of commercial plantations have been more successful than attempts to restore heathland on arable land. This is thought to be because the soils have not undergone radical alteration, are less nutrient enriched and because soil processes that operate under heathland vegetation are similar to those of coniferous woodland.

Indeed, the point has been made that podzol soils are remarkably persistent and distinctive features such as sharp horizon boundaries and marked colour changes with depth can remain despite the change in vegetation and even climate. If an area of former heathland has experienced scrub encroachment and woodland development, it can be assumed that the ground has not been disturbed although there may be some disruption of horizonation in the soil profile related to penetration by tree roots. In the event of afforestation where planting ridges have been established and drainage ditches excavated, the degree of ground disturbance can be greater and there is a stronger likelihood that some soil conservation interest has been lost.

5.6 Eight projects from the sample involved the restoration from coniferous plantations and significantly wooded areas; in each case trees were felled and removed from the site. The method adopted for tree felling and removal is significant for the degree of ground disturbance. Harvesting operations can cause serious soil compaction, loss of soil features, erosion and rutting which in turn can lead to increased siltation and turbidity of water courses. Whole-tree harvesting (removal of the stem, branches and needles) using a cable crane (skyline) poses the least threat to soils as there is no ground trafficking. The repeated dragging along the same route can cause some wear but probably only affecting the litter layer. If tree removal is by skidders (tractors that lift the butt end from the ground and drag the crown along the ground) the potential for damage by tracking is increased. Felling and in situ branch and brash removal using a forward harvester (heavy machine mounted on track or wheels that can fell, lift, strip and cut wood to predetermined lengths) is the most likely to cause soil damage. The Forest Authority (Nisbet and others 1997) has published good practice guidance and classified soil types according to their susceptibility to ground damage. This can be used to inform the best approach when removing trees in preparation for heathland restoration or to avoid erosion where the soil surface has been cultivated. The self-scores were 7-10.

Table 3 The potential for ground damage and disturbance to soils

Risk category	Soil types (after Pyatt 1982)
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.

5.7 Soil disturbance and removal includes soil stripping, turf stripping, sod cutting, soil inversion, deep ploughing and rotovation. In 42% of the projects sampled, the removal of soil appears to be one of the most favoured techniques. In addition, soil inversion was also used in 13% of the projects (all on land which had previously been improved for farming). Over half the projects sampled, therefore, involved either the disturbance or removal of soils to some degree. Inversion could be to a depth of a metre (as in the Worcestershire example- case study 4.58), which is equivalent to forestry ploughing.

5.8 This approach has the highest potential to harm soil functions and intrinsic features of interest in the soil assuming that they have not already been damaged through agricultural or other activities. Because there were no pre-restoration soil investigations, it is difficult to assess if soils and surface features of value were lost. Many of the reviewed restoration approaches involved just such a level of disturbance. The projects which carried out these techniques scored 7-10.

5.9 In conclusion, in the absence of any soil investigations prior to heathland restoration it is impossible to judge whether examples of soils, surface and sub-surface phenomena of intrinsic value have been lost. What is apparent is that, provided the soil interest has not already been compromised by earlier land use practices, the restoration approach adopted is significant and some methods have a far greater potential to cause damage than others.

5.10 Those that can be considered the more benign (described and categorised in Table 2) involve vegetation management such as grazing, cutting and burning. Other methods that do not necessarily involve ground disturbance include those adopted to restore heathland soil acidity levels and/or reduce the nutrient levels, artificially elevated through the application of inorganic fertilisers. The addition of elemental sulphur to increase acidity, and nutrient stripping by cropping have proved popular and effective methods.

5.11 The alteration to the vegetation and acidity levels will bring about some sort of change in physical, chemical and biological processes but if these methods are used in isolation, that effect will be minimal and it is unlikely that any soil interest or function will be jeopardised significantly. However, if these methods are practiced in association with ground treatment that intrudes into the body of the soil (for example soil stripping, inversion and deep ploughing), then any soil interest may be lost and wider soil functionality damaged. There is, therefore, a potential conflict with the protection of soils (and sometimes the wider environment) as there seems to be wide agreement that these intrusive techniques produce the best results. Many of the restoration approaches under review involved just such a level of disturbance.

5.12 'Instant' results can be achieved by soil stripping/inversion but other techniques such as nutrient stripping by cutting, grazing or cropping need to be undertaken repetitively and/or over a longer timescale to be effective. This could have wide policy implications as perhaps we should recognise that as the land management processes that created heathland in the first place were gradual, then restoration is a gradual process too. We need to consider what is the sustainable approach in the longer term and consider the impact of meeting short term targets where they have other unintended adverse impacts on the natural environment such as soil.

Effect of heathland restoration and re-creation on archaeology

5.13 One of the functions of soil is to protect the buried heritage, and different methods of restoring or re-creating lowland heathland can clearly have very different impacts on archaeology. This section will take the several categories of techniques identified in the literature review and assess their current impact on the archaeological record, as evidenced from the questionnaire returns.

5.14 Those techniques considered under "surface vegetation (herb layer) management and removal techniques" (grazing, cutting, herbicide, burning) are near-neutral as regards the impact on archaeology. This was evidenced at the 14.6 ha Pembrokeshire site, where a mix of cutting and grazing was adjudged to have posed no threat to any archaeology that might be present. It is most unlikely that organic materials will have survived in archaeological deposits in dry heathland conditions, due to acidic and highly aerated soils. In this case even burning is unlikely to have much impact on the archaeological record although it might lead to the discoloration of some artefacts, such as flints and pottery. Indeed, it is quite possible that such activities might actually have a beneficial effect in some instances, by rendering archaeological features and/or artefacts more visible than under previous conditions of vegetation cover.

5.15 The "Soil acidity and nutrient status amelioration techniques" (cropping, acidification, elemental sulphur, bracken and pine chippings, peat) were used on several sites. Cropping and elemental sulphur, in particular, were used exclusively in instances of conversion to heathland from arable. Some sulphur addition is being used in combination with soil inversion, which is considered below. Given that acidification by any of these various means is merely returning the pH of the soil to its historic conditions, there can be very little potential to cause archaeological harm, although sulphur addition could perhaps have some destructive effect. For example, metalwork from archaeological deposits (such as prehistoric, Roman-period or Anglo-Saxon graves) might have been affected through sulphur addition, which could also have had a serious impact had it occurred at Sutton Hoo prior to excavation of the 'ship-burial' in 1939 (eg Carver 1998).

5.16 Given its capacity to provide significant palaeobotanical evidence in a dateable context, the importation of acidic peat to a site has some potential to harm the archaeological record of the donor site. In the example described in this report, peat was taken from deep within the trenches excavated during construction of a power station. In other cases peat which is overlain by sub-soils deposited during the last glaciation are important repositories of vegetational history, climate and human activity information. The use of imported peat is likely, therefore, to involve risking the loss of archaeological information. So too does the importation of soil and litter from elsewhere, which might damage the donor site and easily contain archaeological artefacts which could be identified entirely out of context in their new location.

5.17 On a project site in Cornwall, acidification was used as an alternative to soil stripping where archaeological features had been identified and this was considered to have been an effective strategy. In Pembrokeshire, however, an area of archaeological interest was similarly reserved from soil-stripping but sulphur was added at twice the level of elsewhere on the site. This did not prove effective, leading to poor vegetation establishment, bare soil and invasion by *Agrostis* species. This suggests that the addition of sulphur should not be considered as an entirely dependable alternative to soil-stripping or inversion in areas where archaeological interest has been identified. Much will depend on pre-existing soil conditions across the area (and rates of sulphur application).

5.18 Cropping was only used on one site which apparently had previously been ploughed. Where heathland is being re-created on an area where ploughing has occurred, then cropping for re-establishing heath is unlikely to cause new archaeological damage, provided only that there is no change in the depth of plough used. The process could even have a useful effect, since freshly ploughed soil offers the scope to field walk and collect artefacts, an opportunity which does not occur where plant cover is dense across the ground surface. Cropping could, therefore, be used as part of the process of archaeological investigation of a site within the heathland re-creation process by offering fresh insights into any areas of archaeological interest within the project area, but only on previously disturbed land.

5.19 The archaeological impact of "Tree and shrub layer removal techniques" depends on several factors, including the recent history of land-use and the method adopted for tree removal. An archaeological assessment should clarify when and how to proceed.

5.20 Where land has been repeatedly deep-ploughed for conifer plantations, archaeological features are likely to have been destroyed wherever sites have gone unrecognised and unprotected. However, some artefacts, particularly flints or pottery, are normally preserved well within the soil. The number of times, therefore, that the site has been replanted will be a factor in archaeological survival. The scale of any archaeological features is also relevant: at Caesar's Camp, Berkshire, the ramparts and interior of the fort were still clearly visible when the decision was made to remove the trees on account, in part, of the damage they were doing to the archaeological record. Very few projects will encounter archaeological sites of this scale.

5.21 The method of tree removal is perhaps the central issue. At a 59 ha site in Bedfordshire, even though an archaeological survey revealed no significant interest, the decision was made to fell the plantation, remove the timber and tops and grind out the stumps, thus causing the minimal damage to any archaeology which might have been missed. Such techniques will always be preferable to bulldozing or the up-rooting of trees by other means, simply because of the lower levels of soil disturbance caused. Conifers are generally shallow-rooted but their fall normally involves the removal of a substantial root plate, comprising the bulk of the topsoil from that area. Where plantations can be felled without that level of disturbance to the soil profile, archaeology can only benefit. In fact, further forestry rotations could also damage archaeological interest.

5.22 As mentioned before, heathlands in general have a high potential for archaeological interest. In areas of dense scrub where it is impossible to see any archaeological feature or to survey the site, it would be safer to presume the presence of historic environment interest. Controlled burning or careful vegetation cutting could be an option in such cases, followed by a walk-over survey to inform subsequent heathland restoration methodology.

5.23 Whilst the removal of litter and the upper soil has some potential to displace archaeological artefacts from their proper context, it also has some potential to expose fresh soils to archaeological observation, prior to the development of heathland vegetation.

5.24 As reported earlier, soil disturbance and removal was carried out in 42% of the projects sampled and soil inversion was used in 13% on land which had previously been improved for farming. Where this occurred, an archaeological investigation either took place (often apparently meaning little more than consulting the local HER) or site managers felt confident that they were aware of any existing archaeology. While the consultation of the HER is obviously highly desirable, reliance on it or on existing knowledge in some other form does expose the limitations of the archaeological record, which is forever expanding due to new discoveries. The techniques of soil disturbance and removal are potentially highly destructive in an archaeological context.

5.25 It seems very likely that at least some of these projects could have involved a loss of archaeological remains and denied the opportunity to record new and previously unidentified sites of archaeological interest. Where this is a possibility, the site can be managed within the project brief by, for example, excluding specific areas from soil disturbance, or setting in motion some greater archaeological investigation. Also relevant is the transferral of archaeological material to a new site. However, soil transfer was used only rarely (one project out of the 26 recorded). However, given the frequency with which *in situ* soil disturbance and removal are being used, this is arguably where the principal focus of archaeological interest and activity should lie in both heathland restoration and re-creation projects.

5.26 In conclusion, the questionnaires reflected a high level of concern for archaeological issues within recent and/or current heathland restoration projects. However, the concern was not universal and there has been a tendency in some instances to consider consulting the local HER was a sufficient recognition of potential archaeological interest. Most projects have some capacity to facilitate a reconsideration of on-site archaeology to the overall enhancement of the site. This is particularly the case where thick vegetation, such as trees or bracken, is being cleared. In some cases this allows archaeological investigation of an area for the first time for many years, and this has been recognised in a minority of cases.

5.27 Soil disturbance or removal are clearly processes which are highly destructive of the archaeology (assuming that such interest has not already been lost to other activities such as ploughing). Although archaeological issues had been integrated into some of these projects, this review has highlighted a greater need for the assessment of archaeological interest before deciding on the appropriate restoration/re-creation method.

5.28 In the introduction to this report, it was suggested that the projects be divided into three in terms of scale: ‘large’, being above 50 ha, ‘medium’, 11-49 ha, and ‘small’, <10 ha. Of the questionnaire returns, six derived from large projects, 11 from medium-sized ones and nine from small. Clearly, archaeological interest was identified on a proportion of projects of all scales, from the 6 ha site in Cornwall with its two barrows upwards, so size was not a limiting factor. It might, however, reduce the flexibility available to the site manager to avoid destruction of identified archaeological remains.

6 Concluding comments

6.1 The questionnaire results suggest that nearly two thirds of heathland restoration practitioners that responded were aware of the need to protect any archaeological interest. However, project management practice did not always incorporate a full archaeological assessment to inform the restoration approach.

6.2 It is also clear that practitioners did not give the same regard to the multi-functionality and intrinsic scientific and nature conservation value of soils. Sixteen projects reported that they had considered the suitability of the soil but this was only in terms of supporting the target vegetation. There is a view that the soil is a 'platform', a means of establishing the heathland community but not of interest or wider environmental value in itself. Indeed, despite the assertion that the state of the soil was being considered in advance of restoration, there was very little or no evidence that information about the soil was being collected and, in most cases, not even acidity and nutrient status was investigated. Unfortunately, the lack of data has meant that this review could neither prove nor deny the loss of important soils of intrinsic value or that optimum methods or outcomes were being achieved. It also seems likely that the more intrusive methods are unintentionally damaging soil processes and functions; this may not be a sustainable approach in the longer term.

6.3 The key elements of the proposed EU Soil Framework Directive and Initial Regulatory Assessment, as proposed by the European Commission (Commission of the European Communities 2006), which may be of relevance for heathland restoration and re-creation are:

- A requirement for central and local Government to consider the impacts that new policies will have on soils whilst they are being developed (Article 3).
- A duty on all land–users to prevent or minimise harm to soils (Article 4).
- A requirement to reduce the risks relating to soil erosion, organic matter decline, compaction, salinisation, and landslides, by identifying risk areas, and deciding on a programme of measures to address these risks (Articles 6-8).
- A requirement to raise awareness of soils issues, report to the Commission, and exchange information (Articles 15-17).

6.4 The National Trust's Soil Protection Strategy (National Trust 1999), is one of a small handful of UK initiatives that do acknowledge the intrinsic conservation value stating '(We) should cherish the soil and its properties, both for the specific functions that the soil can fulfil and for the specific interest that the soil contains.' One respondent working on NT land mentioned that these guidelines had influenced their approach and limited the extent of ground disturbance. However, there has not been a widely accessible set of best practice guidelines to direct restoration practices so that soil and archaeological assets are protected. It is hoped that the suggestions made in this report can be refined and act as a template for the introduction of soil protection measures for heathlands and for a wide range of habitat restoration exercises.

7 References

AERTS, R., HUISZOON, A., VAN OOSTRUM, J.H.A, VAN DE VIJER, C.A.D. & WILLEMS, J.H. 1995. The potential for heathland restoration on formerly arable land at a site in Drenthe, The Netherlands. *Journal of Applied Ecology*, 32(4), 827-835.

ALLEN, S.E. 1964. Chemical aspects of heather burning. *Journal of Applied Ecology*, 1, 347-367.

ALLISON, M. & AUSDEN, M. 2004. Successful use of topsoil removal and soil amelioration to create heathland vegetation. *Biological Conservation*, 120, 221-228.

ALLISON, M. & AUSDEN, M. 2006. Effects of removing the litter and humic layers on heathland establishment following plantation removal. *Biological Conservation*, 127, 177-182.

ALONSO, I., HARTLEY, S.E. & THURLOW, M. 2001. Heather-grass competition on Scottish moorlands: interaction effects of nutrient enrichment and grazing regime. *Journal of Vegetation Science*, 12, 249-260.

ANDERSON, P. 2003. *Habitat Translocation: A best practice guide.* Constriction Industry Research and Information Association.

AUSDEN, M. & KEMP, M. 2005. Creating heathland by adding sulphur, and heather *Calluna* and bell heather *Erica* cuttings, at Minsmere RSPB Reserve, Suffolk, England. *Conservation Evidence*, 2, 30-31.

AVERY, B.W. 1980. Soil Classification for England and Wales (Higher Categories). *Soil Survey Technical Monograph No. 14*. Harpenden.

AVERY, B.W. 1990. *Soils of the British Isles*. CAB International.

BACON, J. 1996. Tussling with turves: a review of turf-stripping techniques. *Enact*, 4(2),12-16.

BARTON, D., GAMMACK, M., BILLETT, M.F. & CRESSER, M.S. 1999. Sulphate adsorption and acidification of *Calluna* heathland and Scots pine forest podzol soils in north-east Scotland. *Forest Ecology and Management*, 114, 151-164.

BERG, B.P., KNEISE, J.P., ZOOMER, R. & VERHOEF, H.A. 1998. Long-term decomposition of successive organic strata in a nitrogen saturated Scots pine forest soil. *Forest Ecology and Management,* 107, 159-172.

BOKDAM, J., GLEICHMAN,J.M. 2000. Effects of grazing by free-ranging cattle on vegetation dynamics in a continental north-west European heathland. *Journal of Applied Ecology, 37,* 415-431.

BOX, J., BRAMWELL, H., HILLCOX, P. & BODNAR, S. 1999. Heathland restoration in Sutton Park National Nature Reserve, with reference to changes in grazing practice and scrub clearance. *Journal of Practical Ecology and Conservation*, 3(2), 32-40.

BRADLEY, I., CLARKE, M., COOKE, H., HARRIS, J., HARRISON, P.L., MAYR, T., TOWERS, W., RODWELL, J. & GOWING, D. 2006. Guidance on understanding and managing soils for habitat restoration projects. *In*: A. Wetherell, ed. *English Nature Research Reports*, No. 712.

BRIG-BIODIVERSITY REPORTING AND INFORMATION GROUP. 2007. Report on the Species and Habitat Review. Report to the UK Biodiversity Partnership. URL://www.ukbap.org.uk/library/BRIG/SHRW/SpeciesandHabitatReviewReport2007Annexes4-6.pdf

BRITTON, A.J., MARRS, R.H., CAREY, P.D. & PAKEMAN, R.J. 2000. Comparison of techniques to increase *Calluna vulgaris* cover on heathland invaded by grasses in Breckland, south east England. *Biological Conservation*, 95, 227-232.

BRITTON, A., MARRS, R., PAKEMAN, R. & CAREY, P. 2003. The influence of soil-type, drought and nitrogen addition on interactions between *Calluna vulgaris* and *Deschampsia flexuosa*: implications for heathland regeneration. *Plant Ecology*, 166, 93-105.

BRITTON, A.J., PEARCE. I.S.K. & JONES, B. 2005. Impacts of grazing on montane heath vegetation in Wales and implications for the restoration of montane areas. *Biological Conservation*, 125(4), 515-524.

BROADMEADOW, M. & MATTHEWS, R. 2003. *Forests, carbon and climate change: the UK contribution*. Forestry Commission Information Note 48. Forestry Commission.

BRUNEAU, P. 2004. Soil – Nature's Cinderella. *Earth Heritage,* Issue 21, 14.

BULLOCK, J.M. & PAKEMAN, R.J. 1996. Grazing of lowland heath in England: management methods and their effects on heathland vegetation. *Biological Conservation*, 79 (1), 1-13.

BULLOCK, J.M. & WEBB, N.R. 1995. Responses to severe fires in heathland mosaics in southern England. *Biological Conservation*, 73, 207-214.

BUREK, C. 2005. England's first soil trail. *Earth Heritage*, Issue 24, 12.

CALVO, L. TARREGA, R. & LUIS, E. 2002. Regeneration patterns in a *Calluna vulgaris* heathland in the Cantabrian Mountains (NW Spain): effects of burning, cutting and ploughing. *Acta Oecologica*, 23, 81-90.

CARVER, M.O.H. 1998. *Sutton Hoo: Burial Ground of Kings?* London.

CHAMBERS, B.J., CROSS, R.B. & PAKEMAN, R.J. 1996. Recreating lowland heath on ex-arable land in the Breckland Environmentally Sensitive Area. *Aspects of Applied Biology*, 44, 393-400.

CHAPMAN, S.B., ROSE, R.J. & BASANTA, M. 1989. Phosphorus adsorption by soils from heathlands in southern England in relation to successional change. *Journal of Applied Ecology*, 26, 673-680.

CLAYDEN, B. & HOLLIS, J.M. 1984. Criteria for Differentiating Soil Series*. Soil Survey Technical Monograph No. 17.* Harpenden.

COLLS, A.E.L.C. 2006. The *carbon consequences of habitat restoration and creation*. Unpublished PhD Thesis: Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich.

COMMISSION OF THE EUROPEAN COMMUNITIES. 2002. *Towards a Thematic Strategy for Soil Protection.* COM (2002) *179 final*. Brussels: CEC. Available from: URL://ec.europa.eu/environment/soil/index.htm

COMMISSION OF THE EUROPEAN COMMUNITIES. 2006. Proposal for a Directive of The European Parliament and of The Council establishing a framework for the protection of soil and amending Directive 2004/35/EC. Available from: URL://ec.europa.eu/environment/soil/pdf/com_2006_0232_en.pdf

CPRE. 2000. *Valuing the land*: *Planning for the best and most versatile agricultural land*. London: Council for the Preservation of Rural England/Green Balance.

CURRIE, W.S., NADELHOFFER, K.J. & ABER, J.D. 2004. Redistributions of 15N highlight turnover and replenishment of mineral soil organic N as a long-term control on forest C balance. *Forest Ecology and Management,* 196, 109-127.

DARK, K. & DARK, P. 1997. *The Landscape of Roman Britain*. Stroud: Sutton.

DARVILL, T. & FULTON, A. 1998. *The Monuments at Risk Survey of England, 1995.* Main Report. English Heritage and Bournemouth University, 1998, 80-3.

DAVY, A.J., DUNSFORD, S.J. & FREE, A.J. 1996. Acidifying peat as an aid to the reconstruction of lowland heath on arable soil: lysimeter experiments. *Journal of Applied Ecology*, 35, 649-659.

DAY, J. 2005. Addition of sulphur to agricultural fields to restore heathland, Trehill Farm, Pembrokeshire, Wales. *Conservation Evidence*, 2, 100-101.

DEFRA. 2004. *The First Soil Action Plan for England: 2004-2006*. London: Defra Publications.

DEFRA. 2007a. *The Heather and Grass Burning Code.* Available from: URL://neintranet/content/technical/docs/HeatherGrassBurningCode_A6_for_web.pdf

DEFRA. 2007b. *The Heather and Grass etc Burning (England) Regulations 2007*. URL://www.opsi.gov.uk/SI/si2007/20072003.htm

DIAZ, A., GREEN, I., BENVENUTO, M. & TIBBETT, M. 2006. Are ericoid mycorrhizas a factor in the success of *Calluna vulgaris* heathland restoration? *Restoration Ecology*, 14(2), 187-195.

DIAZ, A., GREEN, I., EVANS, D. & BUCKLAND, P. 2007. Heathland creation techniques: ecological consequences for plant-soil and plant-animal interactions. *In*: Maren, I.E. & Nilsen, L.S. (eds). 10th European Heathland Workshop, Norway 24 June-1 July 2007, 146.

DIMBLEBY, G. W. 1962. The development of British heathlands and their soils. *Oxford Forestry Memoirs,* No. 23. Oxford: Clarendon Press.

DISE, N.B., MATZNER, E. & GUNDERSEN, P. 1998. Synthesis of nitrogen pools and fluxes from European forest ecosystems. *Water, Air and Soil Pollution,* 105, 143-154.

DODGSON, J.M. 1981. *The Place-Names of Cheshire*, V(I:ii). V*ol. LIV, 208-9*. English Place-Name Society.

DOLMAN, P.M. & LAND, R. 1995. Lowland heathland. *In*: W. Sutherland & D.A. Hill, eds. *Managing habitats for conservation*. Cambridge: Cambridge University Press.

DUNSFORD, S.J., FREE, A.J. & DAVY, A.J. 1996. Acidifying peat as an aid to the reconstruction of lowland heath on arable soil: a field experiment. *Journal of Applied Ecology*, 35(5), 660-672.

EMERY, M. 1992. Bell heathers and bulldozers? *Landscape Design, 1992*.

ENVIRONMENT AGENCY. 2004. *The State of Soils in England and Wales*. Available from: URL://www.environment-agency.gov.uk

ENVIRONMENT AGENCY. 2007. *Soils – a precious resource*. Available from: URL://www.environment-agency.gov.uk/subjects/landquality/1730389/

EUROPEAN COMMISSION. 2006a. *A strategy to keep Europe's soils robust and healthy*. Available from: URL://ec.europa.eu/environment/soil/pdf/com_2006_0231_en.pdf

EUROPEAN COMMISSION. 2006b. *Soil protection: the story behind the strategy*. Available from: URL://ec.europa.eu/environment/soil/pdf/soillight.pdf

EVANS, C.C. & ALLEN, S.E. 1971. Nutrient losses in smoke produced during heather burning. *Oikos*, 22, 149-154.

EVANS, J.G. 1975. *The Environment of Early Man in the British Isles.* London: Paul Elek.

EVANS, C.D., CAPORN, S.J.M., CARROLL, J.A., PILKINGTON, M.G., WILSON, D.B., RAY, N. & CRESSWELL, N. 2006. Modelling nitrogen saturation and carbon accumulation in heathland soils under elevated nitrogen deposition. *Environmental Pollution*, 143, 468-478.

FITZGERALD, C., MARTIN, D. & AULD, M. 1987. *The Sandlings Project: report of the Sandlings Project 1983/85*. The Sandlings Group.

FORESTRY COMMISSION. 2007. *Carbon Sequestration*. Available from: URL://www.forestry.gov.uk/forestry/infd-6vlkkm[3]

FORGEARD, F. & FRENOT, Y. 1996. Effects of burning on heathland soil chemical properties: an experimental study on the effect of heating and ash deposits. *Journal of Ecology*, 33(4), 803-811.

FOWLER, P.J. 1981. *The Farming of Prehistoric Britain*, 26, 49. Cambridge: Cambridge University Press.

FRANKLIN, O., HÖGBERG, P., EKBLAD, A. & ÁGREN, G.I. 2003. Pine forest floor carbon accumulation in response to N and PK additions: bomb 14C modelling and respiration studies. *Ecosystems*, 6, 644-658.

FRENCH, H.M. 2007 (3rd edition). *The Periglacial Environment.* John Wiley & Sons.

GALLET, S. & ROZE, F. 2001. Conservation of heathland by sheep grazing in Brittany (France): importance of grazing period on dry and mesophilous heathlands. *Ecological Engineering*, 1, 333-344.

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GALLET, S. & ROZE, F. 2002. Long-term effects of trampling on Atlantic heathland in Brittany (France): resilience and tolerance in relation to season and meteorological conditions. *Biological Conservation*, 103, 267-275.

GILBERT, O.L. & ANDERSON, P. 1998. *Habitat creation and repair*. Oxford: Oxford University Press.

GIMINGHAM, C.H. 1972. *Ecology of heathlands*. Chapman and Hall.

GIMINGHAM, C.H. 1992. *The lowland heathland management handbook*. English Nature Science Series. Peterborough: English Nature.

GRAY, J.M. 2004. *Geodiversity – valuing and conserving abiotic nature*. Chichester: Wiley & Sons.

GREEN, I., STOCKDALE, J., TIBBETT, M. & DIAZ, A. 2006. Heathland restoration on former agricultural land: effects of artificial acidification on the availability and uptake of toxic metal cations. *Water Air and Soil Pollution*, 178(1-4), 287-295.

HAGEDORN, F., SPINNLER, D. & SIEGWOLF, R. 2003. Increased N deposition retards mineralization of old soil organic matter. *Soil Biology & Biochemistry*, 35, 1683-1692. Sciences 5, 499-518.

HÄRDTLE, W., NIEMEYER, M., NIEMEYER, T., ASSMANN, T. & FOTTNER, S. 2006. Can management compensate for atmospheric nutrient deposition in heathland ecosystems? *Journal of Applied Ecology,* 43 (4), 759-769.

HAYCOCK, B. & TUDDENHAM, A. 2004. *Heathland re-creation work on Stackpole Head, Stackpole NNR: a report on the trial plots, established in winter 1999/2000*. Project sponsored by Pembrokeshire C. C., The Environmental Agency, Pembrokeshire Coast National Park, Country Council for Wales and the National Trust. Unpublished Report.

HOLLAND, E.A., BRASWELL, N.H., LAMARQUE, J.-F., TOWNSEND, A., SULZMANN, J., MULLER, J.-F., DENTENER, F., BRASSEUR, G., LEVY, H.I.I., PENNER, J.E. & ROELOFS, G.-J. 1997. Variations in the predicted spatial distribution of atmospheric nitrogen deposition and their impact on carbon uptake by terrestrial ecosystems. *Journal of Geophysical Research*, 102 (D15), 849-866.

HOLMES, P. 1993. Dersingham: a conservation case history. *Enact*, 1(2): 4-5.

HULME, P.D., MERRELL, B.G., TORVELL, L., FISHER, J.M., SMALL, J.L. & PAKEMAN, R.J. 2002. Rehabilitation of degraded *Calluna vulgaris* (L.) Hull-dominated wet heath by controlled sheep grazing. *Biological Conservation*, 107(3), 351-363*.*

JOINT NATURE CONSERVATION COMMITTEE. 2007. *Earth Heritage*. Available from: URL://www.jncc.gov.uk/page-1

JONES, R. & PAGE, M. 2006. *Medieval Villages in an English Landscape: Beginnings and Ends*. Macclesfield: Windgather Press.

KEIENBURG, T. & PRÜTER, J. 2004. *Safeguarding the heathlands of Europe: conservation and management of central European heathlands. Case Study: Lueneburger Heide nature reserve, north-west Germany*. HEATHGUARD, The Heathland Centre, Norway.

LAKE, S., BULLOCK, J.M. & HARTLEY, S. 2001. *Impacts of livestock grazing on lowland heathland in the UK.* English Nature Research Reports, No. 422. Peterborough.

LAL, R. 2005. Forest soils and carbon sequestration. *Forest Ecology and Management*, 220, 242-258.

LANDLIFE. 2006. *Topsoil inversion: breaking new ground in forestry*. Landlife National Wildflower Centre, Court Hey Park, Liverpool.

LASCELLES, B., JENKINS, D. & BOL, R. 2000. The role of 14 C dating in ironpan formation. *The Holocene*, 10, No. 2, 281-285.

LAWSON, C.S., FORD, M.A., MITCHLEY, J. & WARREN, J.M. 2004. The establishment of heathland vegetation on ex-arable land: the response of *Calluna vulgaris* to soil acidification. *Biological Conservation, 116,* 409-416.

LEWIS, C., MITCHELL-FOX, P. & DYER C. 1997. *Village, Hamlet and Field.* Manchester: Manchester University Press.

LOWDAY, J.E. & MARRS, R.H. 1992. Control of bracken and the restoration of heathland. III. Bracken litter disturbance and heathland restoration. *Journal of Applied Ecology*, 29(1) 212-217.

MACKNEY, D., HODGSON, J.M., HOLLIS, J.M. & STAINES, S.J. 1983. Legend for the 1:250,000 Soil Map of England and Wales. Harpenden: Soil Survey of England and Wales.

MAFF 1988. *Agricultural Land Classification of England and Wales: revised guidelines and criteria for grading the quality of agricultural land*. Available from: URL://www.defra.gov.uk/rds/publications/technical/ALC_BlueBook.pdf

MAFF. 1997. *Controlling soil erosion*. An advisory booklet for the management of agricultural land. London: MAFF Publications.

MAFF. 1998. *The Soil Code*. London: MAFF Publications.

MAFF. 1999a. *Controlling soil erosion*. An advisory leaflet for preventing erosion caused by grazing livestock in lowland England. London: MAFF Publications.

MAFF. 1999b. *Controlling soil erosion*. A field guide for an erosion risk assessment for farmers and consultants. London: MAFF Publications.

MAFF. 1999c. *Controlling soil erosion. A manual for the assessment and management of agricultural land at risk of water erosion in lowland England*. London: MAFF Publications.

MAFF. 2000. *Good Practice Guide for Handling Soils (Version 04/00*). Cambridge: FRCA.

MARRABLE, C.J. 2004. Ashdown Forest Grazing Action Plan. *English Nature Research Reports*, No. 602.

MARRS, R.H. 1985. Techniques for reducing soil fertility for nature conservation purposes: a review in relation to research at Roper's heath, Suffolk, England. *Biological Conservation*, 34, 307-332.

MARRS, R.H. 1987. Studies on the conservation of lowland *Calluna* heaths. II. Regeneration of *Calluna* and its relation to bracken infestation. *Journal of Applied Ecology*, 24, 117-189.

MARRS, R.H. 2002. Manipulating the chemical environment of the soil. In: PERROW, M.R. & DAVY, A.J., eds. *Handbook of ecological restoration volume 1: principles of restoration*. Cambridge: Cambridge University Press.

MARRS, R.H. & LOWDAY, J.E. 1992. Control of bracken and the restoration of heathland. II. Regeneration of the heathland community. *Journal of Applied Ecology*, 29, 204-211

MARRS, R.H., LOWDAY, J.E., JARVIS, L. & GOUGH, M.W. 1992. Control of bracken and the restoration of heathland. IV. Effects of bracken control and heathland restoration treatments on nutrient distribution and soil chemistry. *Journal of Applied Ecology*, 29, 218-225.

MARRS, R.H., JOHNSON, S.W. & LE DUC, M.G. 1998a. Control of bracken and restoration of heathland. VIII. The regeneration of the heathland community after 18 years of continued bracken control or 6 years of control followed by recovery. *Journal of Applied Ecology***,** 35(6), 857-870.

MARRS, R.H., SNOW C.S.R., OWEN K.M. & EVANS C.E. 1998b. Heathland and acid grassland creation on arable soils at Minsmere: identification of potential problems and a test of cropping to impoverish soils. *Biological Conservation,* 85, 69-82.

MARRS, R.H. & OWEN, K.M. 2002. Heathland and acid grassland creation on arable soils at Minsmere*. In:* J.C. UNDERHILL-DAY & D. LILEY, eds. *Proceedings of the sixth national heathland conference, Bournemouth, 17-19 September 2001*. Sandy: RSPB.

McCRACKEN, M., BULMAN, C., CAMP, P. & BOURN, N. 2005. *Heath Fritillary habitat management: a three-year experimental study at Halse Combe, Exmoor*. Report no. S05-44. Wareham: Butterfly Conservation.

MICHAEL, N. 1998. A comparison of the soil characteristics of lowland heathland which has been rotovated and turf stripped. *Journal of Practical Ecology and Conservation,* 2, 42-45.

MILNE, R. & BROWN, T.A. 1997. Carbon in the vegetation and soils of Great Britain. *Journal of Environmental Management,* 49, 413-433.

MITCHELL, R. & HARE, S. 1999. *Heathland creation on arable land at Minsmere: a summary of the research and results 1990-1998 and the costs involved*. RSPB.

MITCHELL, R.J., MARRS, R.H., LE DUC, M.G. & AULD, M.H.D. 1997. A study of succession on lowland heaths in Dorset, southern England: changes in vegetation and soil chemical properties. *Journal of Applied Ecology*, 34, 1426-1444.

MITCHELL, R.J., MARRS R.H., LE DUC, M.G. & AULD, M.H.D. 1999. A study of the restoration of heathland on successional sites: changes in vegetation and soil chemical properties. *Journal of Applied Ecology*, 36(5), 770-783.

MOHAMED, A., HÄRDTLE, W., JIRJAHN, B., NIEMEYER, T. & VON OHEIMB, G. 2006. Effects of prescribed burning on plant available nutrients in dry heathland ecosystems. *Plant Ecology, 189(2),* 279-289.

NADELHOFFER, K.J., EMMETT, B.A., GUNDERSEN, P., KJØNAAS, O.J., KOOPMANS, C.J., SCHLEPPI, P., TIETAMA, A. & WRIGHT, R.F. 1999. Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests. *Nature,* 398, 145-148.

NATIONAL TRUST. 1999. *National Trust Soil Protection Strategy*. Available from: URL://www.nationaltrust.org.uk/main/w-soil_protection_strategy.pdf

NERC. 2006. *Soil Biodiversity Programme: biological diversity and ecosystem function in soil*. Available from: URL://soilbio.nerc.ac.uk/

NIEMEYER, M., NIEMEYER, T., FOTTNER, S., HÄRDTLE, W. & MOHAMED, A. 2007. Impact of sod-cutting and choppering on nutrient budgets in dry heathlands. *Biological Conservation*, 134(3), 344-353.

NISBET, T., DUTCH, J. & MOFFAT, A. 1997. *Whole-tree harvesting: a guide to good practice.* Forestry Authority.

OVERBURY, T. 1995. *Discussion document on turf removal and disposal techniques from heathland*. Contract No: ENPACT III.: Internal report by The Royal Agricultural College to English Nature's Lowland Heathland Programme.

OWEN, K,M. & MARRS, R.H. 2000. Creation of heathland on former arable land at Minsmere, Suffolk, UK: the effects of soil acidification on the establishment of *Calluna* and ruderal species. *Biological Conservation*, 93, 9-18.

OWEN, K.M., MARRS, R.H. & SNOW, C.S.R. 1996. Soil acidification and heathland establishment on former arable land. *Aspects of Applied Biology*, 44, 385-392.

OWEN, K.M., MARRS, R.H., SNOW, C.S.R. & EVANS, C.E. 1999. Soil acidification – the use of sulphur and acidic plant materials to acidify arable soils for the recreation of heathland and acidic grassland at Minsmere, UK. *Biological Conservation*, 87, 105-121.

PAA. 1994. Caesars Camp Iron Age Fort Berkshire: heathland establishment trials. Penny Anderson Associates Ltd. Unpublished Report.

PAKEMAN, R.J. & MARSHALL, A.G. 1997. The seedbanks of the Breckland heaths and heath grasslands, eastern England, and their relationship to the vegetation and the effects of management. *Journal of Biogeography,* 24(3), 375-390.

PAKEMAN, R.J., HULME, P.D., TORVELL, L. & FISHER, J.M. 2003. Rehabilitation of degraded dry heather [*Calluna vulgaris* (L.) Hull] moorland by controlled sheep grazing. *Biological Conservation*, 11, 389-400.

PETERSON, B.J. & MELILLO, J.M. 1985. The potential storage of carbon caused by eutrophication of the biosphere. *Tellus*. 37B, 117-127.

PICKESS, B.P., BURGESS, N.D. & EVANS, C.E. 1989. *Management case study: heathland management at Arne, Dorset*. RSPB/BirdLife international.

PLANNING POLICY STATEMENT 7: Sustainable Development in Rural Areas. 2004. HMSO. Available from: URL://www.communities.gov.uk/publications/planningandbuilding/planningpolicystatement2

POWER, S.A., ASHMORE, M.R., COUSINS, D.A. & SHEPPARD, L.J. 1998. Effects of nitrogen addition on the stress sensitivity of Calluna vulgaris. New Phytologist, 138, 663-673.

PYATT, D.G. 1982. Soil Classification. *Forestry Commission Research Information Note 68/82/SSN*. Edinburgh: Forestry Commission.

PYWELL, R.F., PAKEMAN, R.J., ALLCHIN, E.A., BOURN, N.A.D., WARMAN, E.A. & WALKER, K.J. 2002. The potential for lowland heath regeneration following plantation removal. *Biological Conservation*, 108, 247-258*.*

PYWELL, R.F., WEBB, N.R. & PUTWAIN, P.D. 1994. Soil fertility and its implications for the restoration of heathland on farmland in southern Britain. *Biological Conservation*, 70, 169-181.

PYWELL, R.F., WEBB, N.R. & PUTWAIN, P.D. 1995. A comparison of techniques for restoring heathland on abandoned farmland. *Journal of Applied Ecology*, 32(2), 400-411.

RACKHAM, O. 1986. *The History of the Countryside*. J.M. Dent and Sons Ltd.

RETALLACK. 2001. *Soils of the Past: An Introduction to Paleopedology*. 2nd Ed. Harper Collins.

RICHARDS, J. 2004. The Viking barrow cemetery at Heath Wood, Ingleby. *Antiquaries Journal,* 84, 23-116.

ROEM, W.J., KLEES, H. & BERENDSE, F. 2002. Effects of nutrient addition and acidification on plant species diversity and seed germination in heathland. *Journal of Applied Ecology,* 39, 937-948.

SCHINDLER, D.W. & BAYLEY, S.E. 1993. The biosphere as an increasing sink for atmospheric carbon: estimates from increased nitrogen deposition. *Global Biogeochemical Cycles,* 7, 717-733.

SLEUTEL, S., DE NEVE, S., SINGIER, B. & HOFMAN, G. 2006. Organic C levels in intensively managed arable soils – long-term regional trends and characterization of fractions. *Soil Use and Management*, 22, 188-196.

SMITH, R.E.N., WEBB, N.R. & CLARKE, R.T. 1991. The establishment of heathland on old fields in Dorset, England. *Biological Conservation*, 57(2), 221-234*.*

SMITHERS, R. 2006. Woodland creation as a biodiversity conservation strategy. *Conference proceedings - New woods, new lives, new landscapes – creating woodland for our future*. Manchester: The Woodland Trust, Manchester*.*

SNOW, C.S.R., MARRS, R.H. & BROCKBANK, A. 1995. Presentation: *The Thurstaston Study: assessment of various bracken control treatments on the regeneration of Calluna dominated heathland on a bracken infested site in north-west England.* Society for Ecological Restoration Autumn Workshop.

SNOW, C.S.R. & MARRS, R.H. 1997. Restoration of *Calluna* heathland on a bracken *Pteridium*-infested site in North West England. *Biological Conservation*, *8, 35-42.*

STACE, H. & LARWOOD, J. 2006. *Natural foundations: geodiversity for people, places and nature.* Peterborough: English Nature. Peterborough.

SURREY HEATHLAND COUNTRYSIDE MANAGEMENT PROJECT. 1994. *Fourth annual report.*

SYMES, N. & DAY, J. 2003. *A practical guide to the restoration management of lowland heathland*. RSPB/BirdLife International.

TATE, K.R., GILTRAP, D.J., CLAYDON, J.J., NEWSOME, P.F. & ATKINSON, I.A.E. 1997. Organic carbon stocks in New Zealand's terrestrial ecosystems. *Journal of the Royal Society of New Zealand*, 27(3), 315-335.

THIRSK, J. 1987. *England's Agricultural Regions and Agrarian History 1500-1750*. London.

THIRSK, J. (ed.). 2000. *The English Rural Landscape*. Oxford: Oxford U.P.

THOMPSON, T.R.E. & TRUCKELL, I. 2005. *Protecting Hampshire's Soils: Development of a soil function-based methodology*. Report to Hampshire County Council and Defra. National Soil Resources Institute.

TIBBETT, M. & DIAZ, A. 2005. Are sulphurous soil amendments (S^0, $Fe^{(II)}SO_4$, $Fe^{(III)}SO_4$) an effective tool in the restoration of heathland and acidic grassland after four decades of rock phosphate fertilization? *Restoration Ecology,* 13(1), 83-91.

TOWNSEND, A.R., BRASWELL, B.H., HOLLAND, E.A. & PENNER, J.E. 1996. Spatial and temporal patterns in terrestrial carbon storage due to deposition of fossil fuel nitrogen. *Ecological Applications*, 6, 806-814.

UK BAP. 2006. *Revised UK Biodiversity Action Plan targets.*

UK NATIONAL FOCAL CENTRE. 2007. *CEH Critical Loads Modelling and Mapping.* CEH Monks Wood. Available from: URL://critloads.ceh.ac.uk/ .

VERGEER, P., VAN DEN BERG, L.J.L., BAAR, J., OUBORG, N.J. & ROELOFS, J.G.M. 2006. The effect of turf cutting on plant and arbuscular mycorrhizal spore recolonisation: Implications for heathland restoration. *Biological Conservation,* 129, 226-235.

VITOUSEK, P.M. & HOWARTH, R.W. 1991. Nitrogen limitation on land and in the sea: how can it occur? *Biogeochemistry*, 13, 87-115.

WALKER, K.J., PYWELL R.F., WARMAN E.A., FOWBERT J.A., BOGHAL A. & CHAMBERS B.J. 2004. The importance of former land use in determining successful re-creation of lowland heath in southern England. *Biological Conservation*, 116,289-303.

WALL, T. 1993. Burning issues. *Enact*, 1(2), 12-14.

WEBB, N.R. 1986. *The New Naturalist: Heathlands*. *In*: K. MELLANBY, S.M. WALTERS, R. WEST & E. HOSKING (eds.). London: R. Collins.

WEBB, N.R. 1994. The habitat, the biotope and the landscape . *Proceedings of the third annual IALE (UK) conference, held at Myerscough College, Preston, 13-14th September 1994*. IALE (UK).

WEBB, N.R. 2001. Heathlands and pastoralism: a historical perspective. *In*: J.C. UNDERHILL-DAY & D. LILEY (eds.) *Proceedings of the sixth national heathland conference, Bournemouth, 17-19 September 2001*. Sandy: RSPB.

WEBB, N.R. & HASKINS, L.E. 1980. An ecological survey of heathlands in the Poole basin, Dorset, England in 1978. *Biological Conservation*, 17, 281-96.

WELCH, G. & WRIGHT, M. 1996. Arable to heath: a progress report. *Enact,* 4(2), 10-12.

WETHERELL, A. 2006. Soils: raising the profile of a downtrodden asset. *Earth Heritage,* 26.

WILLEM, J.H., WILLEMS, H., KARS., DEAN, P. & HALLEWAS. 1997. *Archaeological heritage management in the Netherlands.* Uitgeverij Van Gorcum.

WILLIAMSON, T. 1993. *The Origins of Norfolk,* 167-168. Manchester: Manchester UP

WILTON-JONES ,G. & AUSDEN, M. 2005. Restoring heathland by conifer plantation removal at The Lodge RSPB Reserve, Bedfordshire, England. *Conservation Evidence*, 2, 84-86.

WOODROW, W., SYMES, N. & AULD, M. 1996a. *RSPB Dorset Heathland Project 1989-1995: a management case study*. RSPB/BirdLife International/Life.

WOODROW, W., SYMES, N., AULD, M. & CADBURY, J. 1996b. Restoring Dorset's heathland: the RSPB Dorset Heathland Project. *RSPB Conservation Review*, 10, 69-81.

WRIGHT, M. 1993. Bracken versus Brettenham. *Enact*, 1(2), 8-9.

Appendix 1 – Plates

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Plate A Top: Kielderhead, Northumberland. *Calluna*-dominated dry heath. Bottom: Kielderhead, an iron stagnopodzol with a bleached eluviated (Ea) horizon and distinctive yellowish brown ironpan (Bf) below

Plate B Top: Harbottle Hill, Northumberland. *Calluna*-dominated dry heath. Bottom: Harbottle Hill, an ironpan stagnopodzol with characteristic ash-grey Ea horizon below black humus. The B horizon has a thin organic-rich horizon (Bh) above a thin dark-brown ironpan (Bf)

© Helen Hamilton

Plate C Moorland north of Rochdale. A palaeosol podzolised soil beneath peat. The thin ironpan is clearly visible. Peat formation in upland Britain was instigated in about the mid-Holocene during a cool, wet period

Plate D Bradfield Moor, High Peak. Tree roots in life-position formerly growing in the buried original podzolised soil now exposed by peat erosion

Plate E The boundary bank of High Lodge Warren, near Thetford

Appendix 2 – The potential for heathland restoration and re-creation techniques to cause deleterious impacts to the soil and the historic environment – Questionnaire

Please complete a separate questionnaire for each site. If you have no time, please send us an email, and I will contact you to help fill out the form.

Please provide as much information as possible – the space will expand for lots of text, the size of the boxes is not necessarily an indication of how much you should write!

For the Yes/No questions please use strikethrough, leaving clear your answer, eg ~~Yes~~/No.

Many thanks for your help.

Mark Gash, Penny Anderson Associates Ltd. (mark.gash@pennyanderson.com)

Table A Questionnaire

General Information		
1. Site Name:	2. County and Location:	3. Grid Ref:
4. Site Ownership:	5. Contact Name: Address:	6. Tel Number: E-Mail:
Project Details		
7. Year(s) of works being undertaken:		8. Size of Project Area:

Table continued…

9. Project Objectives (re-creation/restoration):	
10. Vegetation Prior to Works (eg scrub / woodland / weeds):	11. Target Habitat Type (NVC if possible):
12. Land use prior to works (eg forestry, existing heathland (restoration project), mineral workings etc.)	
13. Previous activities that could have affected the soils and archaeology interest before your project (eg ploughing, forestry, agriculture, extraction, development, military use etc):	

Soil Information prior to recreation/restoration works (if known):		
14. Soil Type	15. pH	16. Nutrient Information

Actions taken to prepare the site for heathland restoration/re-creation; methods employed and where appropriate to what depth: eg

Vegetation removal (above ground) - which type - bracken, trees/scrub, *Molinia, Rhododendron*, etc
Removal of loose vegetation material such as branches and brash
Litter removal (type - eg pine needles/bracken, and depth)
Root/rhizome removal (to what extent, which species group - bracken, trees etc)
Turf removal (depth) (top layer of soil made of decaying litter and mineral particles
Topsoil removal (depth) (mostly mineral soil)
Inversion of topsoil (to what depth)
Rotovation or other cultivation of the soil
Where did you place all the removed materials

17. Please describe:

Table continued…

18. Was sulphur or other pH reducing material added – Yes/No	19. If yes in what quantities:
20. Was cropping employed as a method of nutrient stripping – Yes/No	21. If yes – For how long: With what: What sort of cultivation was needed:
22. Were any other chemical ameliorants used – Yes/No	23. If yes – What: How much: At what time:
24. Were any soils removed – Yes/No	25. If yes – To what depth:

Methods of restoration/re-creation of heathland		
26. Was the area left to colonise naturally: Yes/No	27. Was seed added: Yes/No	28. If seed was added, in what quantities and which species:
29. Was seed holding brash added: Yes/No	30. If brash added – in what quantities:	
31. Were plants planted – Yes/No	32. If yes, what size and/or age of plant, and what was the source (local, cuttings from plants on the site etc)	
33. Was rotovated material imported from elsewhere – Yes/No	34. If yes – How much:	

Table continued…

Archaeological and soils considerations	
35. Were archaeological consultations or investigations undertaken prior to any soil disturbance? Yes/No	36. If yes please give as much detail as possible and include how this impacted the project:
37. Were soil conditions / characteristics in terms of nature conservation interest taken into account pre-works? Yes/No	38. If yes please give as much detail as possible and include how this impacted the planning and implementation of the project:
39. Was there a check of the Sites and Monuments Record? Yes/No	40. If yes, what was the outcome?

Outcome of Project – Success	
41. On a scale of 1-10 (10 being highest) can you grade the outcome/success of the project:	42. Reason behind grade of success:

Table continued…

Problems encountered

43. Were you unable to disturb soils due to nature conservation/archaeology concerns? If yes, please state the reasons why:

44. Did you have to reduce the project area due to these concerns? – If yes by how much and state the reasons why:

45. Did the constraints of soil and/or archaeology have a detrimental effect on the outcome of the project? Ie was there poor establishment of vegetation due to not being able to employ your preferred ground preparation method etc?

46. Were there any other factors encountered that led to poor heathland establishment? If yes please state what and any methods employed to counter these:

And finally….

47. Project cost – total project cost (if available) or per hectare (at least in broad terms):

48. Were any guidelines followed – If yes what, were they followed and were they of any use:

49. This project is developing some new guidelines – What would you like to see included and in what format? Eg decision trees, bullet points, narrative, other?

50. Any other information not covered within the questionnaire that would be useful to other site managers, including whether the site is open to the public, how the site is managed, etc.

Appendix 3 – Questionnaire response matrix

Table B Questionnaire response matrix

Number	Size of project area (ha)	Project objectives	Vegetation prior to project	Land use prior to project	Previous activities	Preparation activities	Sulphur added	Crop stripping	Chemical ameliorants	Soils Removed (depth)	Natural Colonisation	Seed added (quantities)	Brash added (quantity)	Plants	Rotovated material	Archaeological investigations	Check of Sites and Monuments Record	Intrinsic value of soils	Outcome of project	Unable to disturb soils	Reduction in project area	Project cost
1	60	Rc	Improved grassland	Dairy Farming	Ploughing, levelled, slurry application	Turf stripping (8-15 cm)	N	N	N	Y (8–15 cm)	Y		N	N	N	Y	Y	Y	8	Y	N	c £2000/ ha
2	1300	Rs	Degraded lowland heath	Country Park. Army WWI	Mounding (conifers), military	Tree and scrub removal, bracken cutting and bailing. Removal of litter (up to 30 cm). Trial plots of inversion.	N	N	N	N	Y		Y- 22 Bales/ha	N	N	Y	Y	Y	7-8	Y	No data	-
3	100	Rc	Conifer/ arable set aside/mixed woodland	Set aside arable Forestry Shooting	Arable – ploughed, fertilised. Forestry, several crops and used for WWII military.	Conifer felling/bracken spraying. Lop and top mulched and baled. Litter removed (500 mm) to expose underlying sand. Tree stumps ground. Some turf stripping may occur in the future on the most nutrient rich areas.	N	N	N	Y (400 mm)	N	Y- 0.1kg heather/ha	N	Y - One yr old gorse plants	N	Y	Y	Y	10 – plantation	No data	No data	£275/ha

Table continued…

Number	Size of project area (ha)	Project objectives	Vegetation prior to project	Land use prior to project	Previous activities	Preparation activities	Sulphur added	Crop stripping	Chemical ameliorants	Soils Removed (depth)	Natural Colonisation	Seed added (quantities)	Brash added (quantity)	Plants	Rotovated material	Archaeological investigations	Check of Sites and Monuments Record	Intrinsic value of soils	Outcome of project	Unable to disturb soils	Reduction in project area	Project cost
4		Rs	100% bracken	Existing heath – common land/ LNR/ SSSI	WWII training. Poss medieval Ridge and Furrow	Bracken vegetation and litter removed. In the past rhizomes were disc harrowed. Material rotovated prior to removal for better saleability. Birch and gorse cleared and roots pulled then burnt.	N	N	N	Y- Few cm	Y	N	Y- Brash cut from site spread	Y- Failed plants <1Yo	N	Y	No data	Y	8-10	No data	No data	£3,500/ha
5	70	Rc	Arable	Arable	Deep plough, drainage, liming, herbicide and pesticide application	Fields ploughed then stripped to a depth of 200-300mm.	Y	N	N	Y 200 -300 mm	N	N	Y- 1tonne/ha approx.	N	N	Y	Y	Y(BD) N(GD)	No data	Y	N	£2,400/ ha
6		Rs	Rs = Dense bracken/ gorse Rc= 2ndry wood over military.	Nature conserv/ military.	Military since Napoleon. Much WWII activity.	Gorse cut and burnt or mulched. Shallow skim of top soil to reveal mineral layer. Soils either bunded or removed for a local heath creation project.	N	N	N	Yup to 30 cm bracken soils, 5-10 cm on shallow soils	Y	N	N	N	N	Y	Y	N	varied 9 in some 1-2 in others where an organic layer was left after skim	No data	N	-
7	4.4	Rc	Woodland	Forestry	Forestry	Removal of trees plus gorse and Rhododendron.	N	N	N	N	Y	N	N	N	N	N	Y	N	7	N	N	-

Table continued…

Number	Size of project area (ha)	Project objectives	Vegetation prior to project	Land use prior to project	Previous activities	Preparation activities	Sulphur added	Crop stripping	Chemical ameliorants	Soils Removed (depth)	Natural Colonisation	Seed added (quantities)	Brash added (quantity)	Plants	Rotovated material	Archaeological investigations	Check of Sites and Monuments Record	Intrinsic value of soils	Outcome of project	Unable to disturb soils	Reduction in project area	Project cost
8	26.2	Rs	Remnant heath with scrub, bracken and birch	Remnant heath	Small holding and had railway assoc. with mineral works.	Removal of birch and scrub. Bracken rolled using agricult roller & 4x4. No soils removed. *Kalmia* sp. (mountain laurel) invasion on to wet areas of heath. Cut and sprayed.	N	N	N	N	Y	N	N	N	N	N	Y	Y(BD)	7	No data	No data	£3000/ yr
9	120	Rc	Conifer plantation	Forestry	Forestry	Bracken control, removal of regenerating pine. Removal of timber. Some lop and top burnt.	N	N	N	N	Y	N	N	N	N	N	Y	Y	10	Y	N	£500 - £2,000/ha ungrazed £3,000 - £4,000/ha grazed
10	100	Rc	Conifer plantation	Forestry	Forestry	Bracken control, removal of regenerating pine. Removal of timber. Some lop and top burnt.	N	N	N	N	Y	N	N	N	N	N	Y	Y	8	N	N	£500 - £2,000/ha
11	197.2	Rs/Rc	Mosaic of Scots pine and heath	Late 1800's forestry. Heath since 1974. Some farming and gypsy camp	Drainage some shooting – cover crop; American crowberry	Tree removal. Crowberry cut, sprayed and completely removed. Soil removal (max 15 cm) down to mineral layer. Spoil stored on site and sprayed to eradicate crowberry.	N	N	Y	Y- max depth of 15 cm	N	Y- heather seed with bristle bent for soil stabil-isation.	Y- some spread but not quick uptake so seed added	N	-	N	Y	YBD	No data	N	N	£10k one off cost

Table continued…

Number	**Size of project area (ha)**	**Project objectives**	**Vegetation prior to project**	**Land use prior to project**	**Previous activities**	**Preparation activities**	**Sulphur added**	**Crop stripping**	**Chemical ameliorants**	**Soils Removed (depth)**	**Natural Colonisation**	**Seed added (quantities)**	**Brash added (quantity)**	**Plants**	**Rotovated material**	**Archaeological investigations**	**Check of Sites and Monuments Record**	**Intrinsic value of soils**	**Outcome of project**	**Unable to disturb soils**	**Reduction in project area**	**Project cost**
12	1.5	Rc	Horse paddock with rank grassland	Agricult	Enrichment	Soil inversion ≤1m.	N	N	N	N	Y	-	N	N	N	Y	Y	N	No data	No data	No data	invers - £1k Arch Con - £3.5k
13	122	Rs	Heath with bracken	Open public access	None	Flail and remove stemmy growth from mature heather plants. Scarification of litter layer with spike harrows <40 mm depth. Partial removal of litter <755.	N	N`	N	N	Y	N	N	N	N	N	Y	YBD	8	No data	No data	£300/ha
14	20	Rs/Rc	Scrub/gorse pine trees	Sand gravel extract.	Planting of pine	Removal of unwanted vegetation and litter removal using ryetec cut and collect flail. In some v sandy areas soil stabilisation undertaken but not v successful.	N	N	N	N	Y	N	Y	N	N	N	Y	Y	No data	No data	No data	£2,500/y (10 yrs)
15	19.7	Rs/Rc	Grassland/ woodland. Rs plot bracken	Common land	-	Restoration grazing by cattle. Bracken and re-creation grass sprayed off with glyphosate, soil stripped to 15 cm and piled adjacent to plot. Cattle excluded.	N	N	N	Y15cm	N	N	Y10-15 cm deep of mown arisings	N	N	Y	Y	N	8	No data	No data	£247/ha

Table continued…

Number	Size of project area (ha)	Project objectives	Vegetation prior to project	Land use prior to project	Previous activities	Preparation activities	Sulphur added	Crop stripping	Chemical ameliorants	Soils Removed (depth)	Natural Colonisation	Seed added (quantities)	Brash added (quantity)	Plants	Rotovated material	Archaeological investigations	Check of Sites and Monuments Record	Intrinsic value of soils	Outcome of project	Unable to disturb soils	Reduction in project area	Project cost
16	14.6	Rs	Gorse scrub with bracken/ bluebell. Willow scrub & hedgerows	Neglect heath	Some machine work to create track on site	Some fencing, small scale gorse clearance. 2 scrapes dug. Heath cut 1 ha/yr. Approx 0.3 ha burnt/yr (2001-04) to assist with restoration grazing. Restoration grazing cattle and horse.	N	N	N	N	Y	N	N	N	N	Y	Y	x	10	x	x	£324/ha
17	0.25	Rs	Gorse with extensive birch and pine regeneration	Common land	Military	Cutting and collect shrub using forage harvester. Removal of turf and topsoil (360^{0} excavator) various depths to reach mineral layer. Chemical treatment of gorse.	N	N	Y	Y	Y	N	N	N	N	Y	N	Y	7	No data	No data	£1575 for 0.25 ha
18	0.1	Rc	Plantation pine	Forestry	Military	Removal of turf and topsoil (360^{0} excavator).	N	N	N	Y	Y	N	Y	N	N	Y	N	Y	No data	No data	No data	£2350 for 0.1 ha
19	460	Rs/Rc	Defunct heath, secondary woodland. Acid grassland	Airfield	Airfield	Secondary woodland removed, logs taken, brash burnt. 360^{0} excavator soil scrape and bunded around the site – litter removed leaving thin soil layer. All hardstanding removed to leave gravel soils.	N	N	Y	N	Y	N	Y	N	N	Y	Y	Y	5 – 6	No data	No data	-

Table continued…

Number	Size of project area (ha)	Project objectives	Vegetation prior to project	Land use prior to project	Previous activities	Preparation activities	Sulphur added	Crop stripping	Chemical ameliorants	Soils Removed (depth)	Natural Colonisation	Seed added (quantities)	Brash added (quantity)	Plants	Rotovated material	Archaeological investigations	Check of Sites and Monuments Record	Intrinsic value of soils	Outcome of project	Unable to disturb soils	Reduction in project area	Project cost
20	15	Rs	Oak/birch scrub encroach. Extensive encroach by bracken	Common Land – grazed	NONE – common land	Bracken cut twice for two years. Litter removed mechanically (8-10 cm) to sub soil/organic layer (never deeper).	x	N	N	N	Y	N	Y6 tonnes per ha	N	N	N	N	Y	9	N	No data	£1,700/yr not inc machine hire
21	30	Rc	Arable weed	Arable	Ploughing and nutrient addition.	Soil inversion to depth of 1m (Landlife plough).	Y	N	-	N	N	Y	Y5 bales /ha	Y	-	Y	Y	N	No data	No data	No data	No data
22	5000	Rs/Rc	Reversion form pine	Forestry / existing heath, some agriculture.	Ploughing agriculture, forestry and drainage.	Shallow ploughing and spreading brash. Trees and rhododendron cause large scale ground disturbance. Drainage – blocking and infill of drains. Bracken litter scrapped to mineral layer – risings left to rot.	Y	Y	N	N	Y	Y Only for the arable area.	Y Usually to depth of 2-5 cm	N	Y	Y	No data	No data	5 – 6 for drier areas 8 wet heath	Y	Y	£2k - £8k/ha
23	10	Rs	Neglected heath with scrub and 2ndry woodland.	No formal use.	Firewood, sheep grazing some minor mineral extraction.		N	N	N	Y 10cm	Y	N	Y	N	N	Y	Y	N	8	N	N	c £5k total project cost

Table continued…

Number	Size of project area (ha)	Project objectives	Vegetation prior to project	Land use prior to project	Previous activities	Preparation activities	Sulphur added	Crop stripping	Chemical ameliorants	Soils Removed (depth)	Natural Colonisation	Seed added (quantities)	Brash added (quantity)	Plants	Rotovated material	Archaeological investigations	Check of Sites and Monuments Record	Intrinsic value of soils	Outcome of project	Unable to disturb soils	Reduction in project area	Project cost
24	42.6	Rc/Rs	Species poor grassland with fringe maritime heath.	Various including agriculture.	Deep plough to reclaim for agricult. Cultivate root crops.	Trial plots chosen to minimise impact on nature conservation and known archaeological interests. Max 20 cm soil removed.	N	N	N	Y Max 20cm	Y	N	N	Y Local sourced ling and bell heather 70 plants	N	Y	Y	No data	9	Y	No data	£29,500/ha
25	0.9	Rc	Arable	Arable	Plough/ Fertilise	Experimental inversion of topsoil.	Y	N	N	N	N	N	Y	N	N	N	N	No data	7	N	N	-
26	0.9	Rs	Oak/birch woodland with some remnant heath species.	Country Park, military WWII – 1970's.	Built structures, military, plantation with large scale felling 1940's, rabbits.	95% trees and scrub hand cleared and windrowed around the site, down slope from clearing.	N	N	N	N	N	N	N	Y	N	N	N	Y	8	No data	No data	£660/ ha approx

Key:

Rc – re-creation

Rs – restoration

Yo – year old

BD – biodiversity

GD – geodiversity

Appendix 4 – Outline guidance on the protection of soils of conservation value and of archaeological interest when re-creating or restoring heathlands

Introduction

1) This best practice guidance sets out the approach to take when planning the restoration or re-creation of heathland in relation to soils and archaeology.

Defining heathland restoration and re-creation

2) Heathland **restoration** involves reclaiming the heathland from other vegetation such as scrub, trees or bracken (improving the condition of existing heathland). Heathland **re-creation** involves a land use change, from conifer plantations, mineral extraction or agricultural land where heathlands occurred in the past (expanding the heathland extent).

The scope of this guidance

3) Soils that have developed for a long period without damaging activities may have intrinsic scientific value from a **geodiversity** viewpoint. The concept of geodiveristy encompasses not just the diversity of rocks and soils and their intrinsic scientific interest but also associated soil properties, processes and functions or services such as: food and fibre production, environmental regulation, habitat for plant and animal communities, source of raw materials, platform for construction, cultural heritage including the character of landscape and the preservation of archaeological remains (Stace and Larwood 2006). This document concentrates on this wider geodiversity value potential. Soil management and handling issues are also addressed through other guidance (for example, Defra's Code of Good Agricultural Practice for the Protection of soil URL://www.defra.gov.uk/farm/environment/cogap/pdf/soilcode.pdf or the Cross Compliance Soil Guidance available from Defra as a booklet) or the MAFF Good Practice Guide for Handling Soils URL://www.defra.gov.uk/farm/environment/land-use/soilguid/index.htm. Further advice can be found in Technical Information Notes (TIN035 - Soil sampling for habitat recreation and restoration in agri-environment schemes; TIN036 - Soils and agri-environment schemes: interpretation of soil analysis & TIN037 - Soil texture) available at URL://naturalengland.communisis.com/NaturalEnglandShop/
4) This guidance also covers any potential for **archaeological** interests to be present in heathland restoration and re-creation projects and shows how best to deal with them.

Best practice in relation to soils

5) Soil conservation has generally not been considered prior to heathland restoration and re-creation. This was because the practitioners had not been advised and it was not established as common and appropriate practice. This section provides guidance on the steps that can be

taken to assess the soil conservation status so that suitable working practices can be adopted and any soil interest guarded. The guidance is based on two main approaches: **desk-top study** and **site investigations**.

Desk-top study

6) Establishing the **previous land use** will provide an indication of the likelihood and the extent of soil modification through nutrient enrichment and disturbance. This will be related to the intensity, duration and type of land use. The past land use may be already known but if not, consultation with old maps, archival sources and document repositories may supply information and discussion with local land owners and managers should tell you more about the past use.
7) Reference to modern **geology and soil maps** is important in determining the physical setting of a site and an understanding of soil types and their characteristics and potential impacts on restoration options. The British Geological Survey (BGS) [URL://www.bgs.ac.uk] supplies maps at different scales of both the bedrock geology (formerly 'Solid') and superficial deposits (formerly 'Drift'). The 1: 625,000 maps have versions that illustrate the bedrock ie the superficial deposits removed, and the superficial deposits, ie the Quaternary, in two sheets: North and South. However, these may give a too broad view of the nature of onshore geology.
8) The most useful scale is **1: 50,000** that provides more detail, showing the extent and stratigraphy of the rocks at a district level, providing geological information important for the comprehensive assessment for a heathland restoration site. There are three versions available: 'Bedrock', 'Superficial Deposits' and 'Bedrock and Superficial Deposits'. The last two are probably the most useful as they illustrate the Quaternary and post-glacial deposits and cryogenic features are associated with the soft sediment and regolith deposits that can be affected by frost action under periglacial conditions. These include glacial sand and gravel, loess, peat, lacustrine clays and silts, alluvium, boulder clay, morainic drift and erratics. Artificial deposits such as landscaped, worked and made ground are also given. The 'Bedrock and Superficial Deposits' maps show both with equal emphasis and provide the best idea of surface deposits. Each map has an associated 'Geological Memoir[4]'. This consists of text, geological cross-sections, photographs and other detailed information. All of these maps are available in paper and most in digital form, suitable for printed output and use in a Geographical Information System (GIS).
9) The **Soil Survey of England and Wales** (1983)[5] has produced a box set of 1:250,000 maps and has a very useful legend booklet that describes soils and soil associations, which share similar characteristics generally cover extensive areas and are named after a representative type. Digital versions are available from [URL://www.silsoe.cranfield.ac.uk/nsri/services/natmap.htm]. A digital map 'Soilscape', showing the distribution of 27 different soil types, which covers the whole of England and Wales at a scale of 1:250,000, is available on the Multi-Agency Geographic Information for the Countryside (MAGIC) website [URL://www.magic.gov.uk]. However, these maps are not sufficiently detailed to give adequate information for a complete site assessment. None of these sources of information will tell you if the site is suitable but they will give an important background to the site and hint at possibilities. Other more detailed soil maps and accompanying memoirs are published at scales of 1:25,000, 1:50,000 and 1:63,360 scale for selected locations. These are available from the National Soil Resources Institute and provide additional detail for those locations covered.
10) Other 'geospatial' data (also helpful in examining site archaeology) that might prove useful includes **aerial photography**. This may be of sufficient scale and resolution to pick out surface patterns eg patterned ground. There are a number of commercial providers but if the restoration project is being completed in association with the Environment Agency, Natural England and other statutory conservation organisations, they usually have access to

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[4] These are being replaced by 'Sheet Explanations', as an A5 booklet and 'Sheet Descriptions', a more detailed A4 size report.

[5] Soil Survey of England and Wales. 1983. Soil Map of England and Wales (1:250 000). SSEW Harpenden.

comprehensive, UK-wide aerial photographs. Other data that may be prohibitively expensive but nevertheless useful, both in terms of the investigating soils, surface phenomena and archaeology, are Digital Terrain Models (three dimensional representations), Light Detecting And Ranging maps (LIDAR[6]), Ground Penetrating Radar (GPR) and measurements at the ground such as Magnetometry[7], Resistivity[8] and other non-destructive geophysical methods that have a proven successful application in locating buried archaeological features, which could also throw light onto aspects of soil conservation.

11) It is important to **make contact with 'expert' groups and individuals** to help in the assessment of site features. The site may be designated under UK statute as a Site of Special Scientific Interest (SSSI) and afforded protection. Approximately a third of the 4,000 SSSIs have a notified geological and or geomorphological interest and the citation can be read on the Natural England website [URL://www.naturalengland.org.uk]. Other sites of geological importance may be designated as Regionally Important Geological and Geomorphological Sites (RIGS). These are outside the framework for statutory protection but are, nevertheless, recognised as important earth science sites because of their research, educational, aesthetic and/or historical value. They are designated according to locally developed criteria as regionally or locally representative sites. If you want to see if there is a RIGS 'interest' at or close to the proposed heathland restoration area you have to consult with one of the county groups. There is not, as yet, a national database but the UKRIGS website [URL://www.ukrigs.org.uk] will provide contact details for the local RIGS group. Some Local Authorities have Local Geodiversity Action Plans (LGAPs), developed from the model of Biodiversity Action Plans (BAPs), where interested organisations contribute to a plan to conserve and enhance the geodiversity of a particular area. Contact with RIGS and LGAPs will help you obtain the specialist help required to make an assessment of the intrinsic interest of the soils and identify other geomorphological phenomena worthy of protection. Other 'expert' contacts may be found through the Quaternary Research Association [URL://www.qra.org.uk] and universities with Quaternary departments are listed at [URL://www.qpg.geog.cam.ac.uk/links/external/]. Soils expertise may be found via the British Society of Soil Science and its professional body, The Institute of Professional Soil Scientists [URL://www.soilscientist.org].

Site Investigations

12) The desk-top study should give an indication of what a ground investigation will show and allow a site investigation to be planned. Even if it suggests that there is very little interest on the site, it is still essential that the site is examined. Paragraph 10 above mentions a number of relatively sophisticated techniques but these will probably be used infrequently because of time, money and the specialist skills required operating the equipment and making sense of the results.
13) The number and depth of **soil samples** assessed depends on the size of the site and the complexity of soil and landscape patterns. Soil profiles may already be visible where a road or path has made a cutting, but care should be taken that this is representative of soils on the site. Provided it is not overgrown and/or an old exposure that has weathered, it provides a convenient way to look at the soil in profile. Alternatively , a better approach is to undertake an auger survey (see below) to determine the types of soils present and their relationship to topography, landscape features, existing habitats etc and then dig one or more representative soil pits. These are holes which are large enough to expose the **soil profile**, at least 1 m deep but may need to be much deeper. It is recommended that a number of pits are excavated across the site so that a comprehensive picture is obtained.
14) A more rapid assessment of soils can be made with a Dutch auger. This consists of a metal shaft with a coring head of varying size, but typically 7 cm wide and 18 cm long. A handle at the top allows it to be turned vertically into the ground to a desired depth. The plugs of earth that are captured in the coring head can be carefully removed and laid end to end to

[6] LIDAR uses lasers to accurately measure the elevation of the ground.

[7] Maps the magnetic properties of soil and subsoil.

[8] Measures the electrical resistance of the soil, which depends largely on the moisture content.

reproduce the equivalent of a vertical profile. It is not recommended that a soil assessment is completed solely using the auger as the method is quite destructive and fine detail easily lost.

15) It may also be possible to expose quite rapid changes in soil types over a short distance. This is called a '**catena**' where there is a sequence of different soils, generally derived from the same parent material but each owes its character to its position on a slope and the control this exerts on the height of the water table.
16) A mature podzol generally has distinct horizons, each with a different colour and other distinguishing attributes. However, lowland heath is not uniquely associated with podzol soils, especially those formerly in arable use, and there may be other, equally as interesting, types discovered. Remember that the **surface topography** may be of interest too.
17) Advice on assessment of site suitability in relation to **nutrient availability and pH** is needed as this is usually the most important constraint to habitat restoration (see Technical Information Notes 'TINs' 35, 36 & 37 as above). The target pH range for the desired habitat needs to be established. Soil pH can be reduced by sulphur applications; however the quantities required are dependent on the buffering capacity of the soil and may have negative effects on soil biodiversity. In terms of soil nutrients the first task is to assess the current status of the soil. Phosphorous availability is regarded as the most useful measure of soil fertility and the Olsen extraction method is the most frequently used to test this. The results can then be compared with quoted ranges (cf Gilbert & Anderson 1998) Further information on this subject and on collecting soil samples for nutrient analysis, how to interpret the results and how that impacts on choice of restoration methods can be found in Bradley and others (2006), and the mentioned TINs.
18) Bear in mind, **it is important to elicit the help of a specialist to undertake the survey and to interpret the results**.

Best practice in relation to Archaeology

19) Survey requirement needs to be related to the restoration methods used and the degree of soil disturbance (a full survey may not always be necessary if the soils will not be disturbed). Some heathland re-creation and restoration projects already take account of archaeology, both in the planning stage and later, all of which is to be welcomed. What follows is intended to reinforce good practice within the numerous agencies where this is already occurring and to encourage other agencies and land managers or project officers to raise their level of practice, to the mutual benefit of those primarily engaged with ecology and also with the archaeological record. This guidance is based on a **desk-top study, obtaining further expert advice** and **site investigations**.

Desk-top study

20) First consult the local **Historic Environment Record (HER)**. This is effectively an annotated list of known sites of archaeological interest kept by the responsible local authority (usually the County Council). An increasing number of these are available on-line, in which case they can be searched from any networked computer. Alternatively a phone call to the HER staff will normally produce a paper copy of the appropriate record at marginal cost, within at most a few weeks. Searches are generally based on parish or township names and National Grid references.
21) This enquiry will reveal the presence/absence of archaeological features of all sorts, whether Scheduled Ancient Monuments (so enjoying legal protection) or not, but the HER will only provide information regarding **archaeology which is known** to the archaeological community, as opposed to sites which have not yet been discovered and/or sites which are known to particular individuals or groups but which have not yet been revealed to the authorities.
22) The information from the HER will generally be sufficient to enable site managers to plan heathland restoration/re-creation projects and can be obtained directly or via an archaeological consultant.
23) Historic Environment Record (HER) staff will occasionally highlight a high probability of sites in the area even if a search of the HER itself reveals nothing. Even where nothing is known or

predicted, further archaeological expertise should be sought where damaging operations are planned, as discussed below.

24) Should a specific site or small number of sites be identified, then the easiest solution is often to design the project in such a way that it either avoids the main areas of archaeological interest altogether, or treats those areas with particular sensitivity, for example avoiding earth-moving activities in this particular vicinity. Remember to include a buffer zone to include the context of the site of interest.

Obtaining further archaeological advice

25) The key to what further archaeological investigation should be undertaken will be the type of activity which is planned. Where there is known archaeology on the site of a project, an **archaeologist should be part of the team designing the project**. Where projects are extending across large areas, it will normally be good practice to involve an archaeologist in the planning process. In other instances it will normally be good practice to invite an archaeologist to view and comment on the project design as it nears completion, and to advise regarding just how much archaeological input is required. In some instances county archaeological staff will be prepared to assist in the early stages, elsewhere the National Trust, for example, has its own archaeological staff. In other instances, liaison with county archaeological societies, the archaeological departments of local universities and local archaeological groups may provide initial help before deciding to contact archaeological contractors.

26) If removal of the surface vegetation is planned, but without the disturbance of the soil, this is archaeologically close to neutral and may not require any further archaeological input. It does, however, offer the opportunity for archaeological investigation of an area to take place, perhaps for the first time under conditions which are rather more suitable for the survey than, for example, when covered with bracken or scrub. Wherever possible the site should be made available to investigation by, for example, local authority HE staff or the local archaeological society.

27) **Liaise with local archaeological societies**. This is often a viable option which is virtually cost-free. This can provide further information not in the HER.

28) Alternatively, use of an archaeological consultant. A list of consultants is normally available from the Historic Environment Services of the County Council, although no advice will be given regarding which you should choose. There is also a list on the Institute of Field Archaeologists' web site at URL://www.archaeologists.net under 'Finding a Registered archaeological organisation'. Always ask several for estimates and visit the site with those interested in the commission before allocating the contract. Select the individual or organisation who/which best understands the needs of the project. Surface field-walking is comparatively cost-effective and not time-consuming.

29) A professional archaeological input is particularly necessary where ploughing and cultivation are to be used as part of the process of heathland restoration/re-creation. Field-walking after ploughing but before sowing will provide an opportunity to identify the location of many different types of human activity, from flint scatters from knapping sites through to burials and settlements of different kinds and periods. Once heathland plants have begun to take hold, this opportunity will have been lost, so this is an important and time-limited opportunity to assess the archaeology of the area of the project and identify any areas of interest.

Vegetation removal

30) Where trees and shrubs are to be removed, from the archaeological viewpoint this is virtually always best done by clearance with **a chain-saw followed by the grinding down of stumps**, leaving the root systems to decay in situ. This minimises the extent of soil disturbance, thus reducing the impact on any surviving archaeological features.

31) The removal of litter has considerable advantages to the archaeologist, who will be offered a far better view of the upper levels of the soil as a consequence, although considerable caution should be exercised where this is close to known remains. Archaeological field walking should be undertaken after the removal of litter. The methodology should ensure as minimal disruption of the soil surface as possible.

Disturbing the soils

32) **Full-scale soil inversion** is highly destructive of archaeological features, particularly if it is deeper than previous ploughing across the site, and should be undertaken only in association with an archaeological watching brief, to enable the site to be assessed effectively for hitherto unidentified archaeological evidence.
33) **Soil stripping** should equally be undertaken in association with an archaeological watching brief. Archaeologists will need access to surfaces at two stages, first when surface vegetation and litter have been removed and secondly when the topsoil has been stripped away. The earlier stage enables the archaeologist to identify the presence of any features and/or artefacts that may be visible in the upper soil; the second is so that they can observe any breaks in the top of the subsoil where human activity in the past has cut through, as for example where a grave has been cut.
34) **Where soil is being brought in from a donor site**, it is primarily the donor site which should receive archaeological attention to assess for the presence of artefacts within the body of the soil to be re-deposited and check for any traces of cuts in the subsoil as that is revealed beneath (as described above). Peat should be assessed for its potential to provide a column capable of examination as a record for the history of vegetation by a competent archaeologist or palynologist[9]. If the topsoil is to be removed at the receptor site to accommodate the transferred soil, the same process as for soil stripping above should be followed.
35) The stripped soils should be reused whenever it is possible. The First Soil Action Plan for England: 2004-2006 (Defra 2004) paragraph 72 states: In those cases where land is not to be returned to agriculture or forestry after use, soils surplus to requirements for site restoration including any necessary landscape work, should be re-used as effectively as possible. Concerns are emerging that good quality soils may be lost where a particular habitat creation could be achieved without using such soils. They should not be sent to landfill.

Learning from past experience

36) It is very difficult to foresee all the problems and challenges that may appear at each stage. Keeping good records of the activities performed, the costs and the success (or otherwise) of the project will be very helpful for future attempts. Incorporate a **monitoring system** to the project, looking at soil changes (eg nutrients/pH); vegetation regeneration; biodiversity achievements; negative indicators (eg weeds, erosion).

Summary

37) Please refer to Figure A ‘Heathland Restoration: Steps to Protect Soils & Archaeology’. The decision tree suggests how the condition and value of a site can be assessed prior to restoration and how this can inform the best restoration practices.

In short:

1) Establish the **former land use**. This can be done through research: archival sources, maps and asking land owners and managers. Knowing how the land has been used will give you an idea of the state of the soils and likely degree of ground disturbance and potential suitability for heathland habitat.
2) Complete a **desk-top study**. This can provide essential information about the site and clear pointers as to the soil and archaeological interests.
3) Thoroughly **survey the site, taking soil samples** to determine soil profileand nutrient/pH status. Get help from specialists and consult published advice, eg Technical Information Notes.
4) **Assess the value** in terms of the site’s bio/geodiversity and archaeology.
5) **Select restoration approaches** unlikely to damage soil and archaeological assets.
6) Set a **monitoring protocol** to evaluate progress and record unforeseen problems.

[9] One who studies plant pollen and spores. Pollen may be preserved many thousands of years and can be used to reconstruct past plant communities and by inference, climate and even human societies.

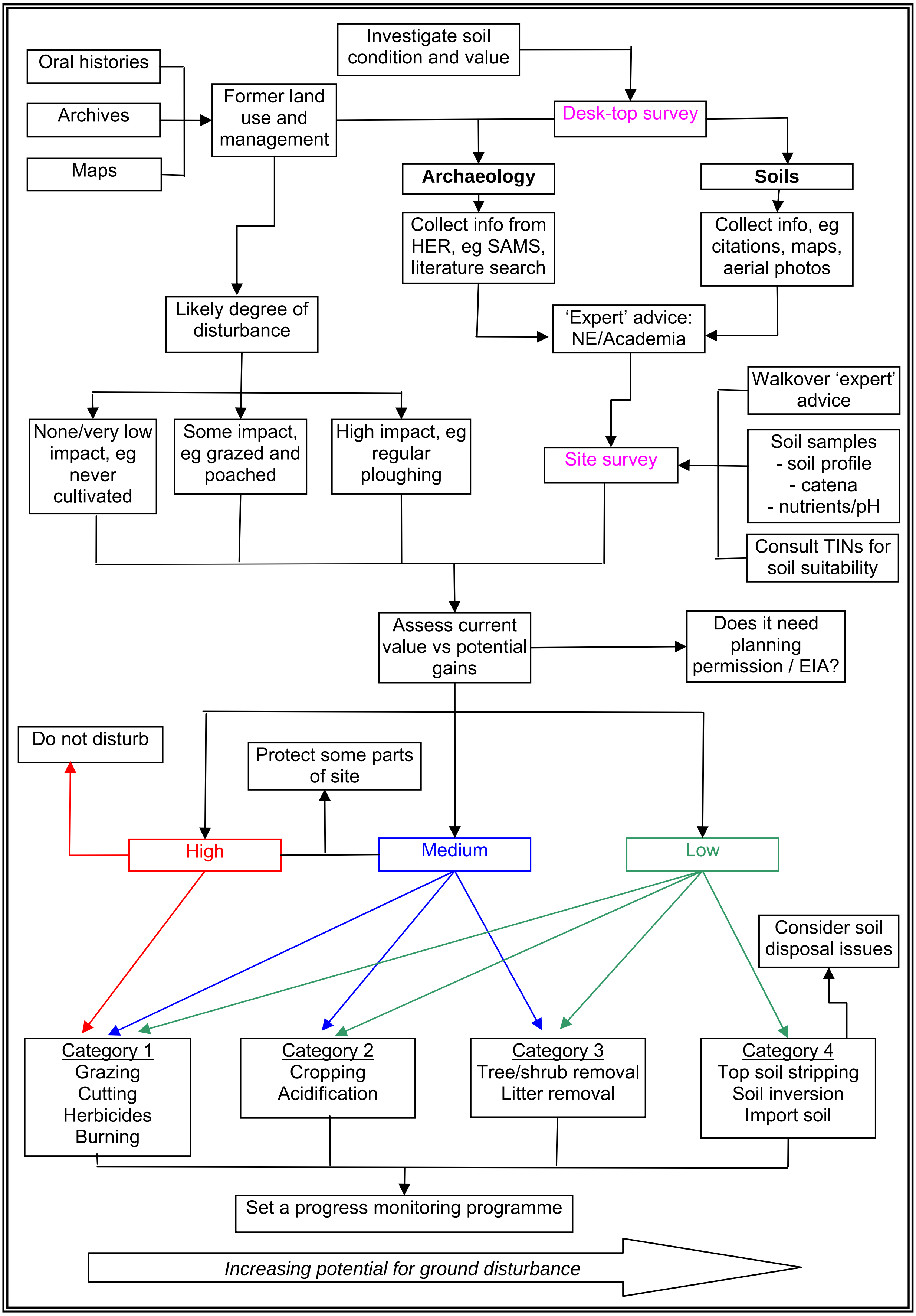

Figure A Heathland restoration/re-creation: steps to protect soils and archaeology

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