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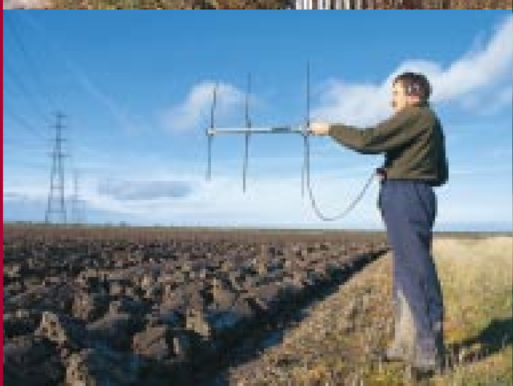
# Guidance on understanding and managing soils for habitat restoration projects

English Nature Research Reports



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## Guidance on understanding and managing soils for habitat restoration projects

A report prepared for English Nature by Ian Bradley[1], Michelle Clarke[1], Helen Cooke[1], Jim Harris[1], Peter Leeds Harrison[1], Thomas Mayr[1], Willie Towers[2], John Rodwell[1] and David Gowing[3].

[1] Cranfield University at Silsoe
[2] Macaulay Institute
[3] Open University

Edited by Anna Wetherell, English Nature

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# Cover note

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| **Project officer** | Anna Wetherell , Environmental Impacts Team<br>anna.wetherell@english-nature.org.uk |
| **Contractor(s)** | Ian Bradley, Michelle Clarke, Helen Cooke,<br>Jim Harris, Peter Leeds Harrison, Thomas Mayr,<br>John Rodwell<br>Cranfield University at Silsoe<br><br>Willie Towers<br>Macaulay Institute<br><br>David Gowing<br>Open University |



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# Executive summary

The aim of this report is to raise awareness of key considerations relating to soil type and management in restoration projects, and also to raise awareness of existing detailed guidance that is available on the subject. Although important distinctions can be identified between "habitat restoration" and "habitat creation", the principles involved in managing soil in these circumstances are largely relevant for both purposes. Therefore, the majority of references to "restoration" used in this report relate to both habitat creation and restoration projects. Post industrial sites (eg mines and quarries) are considered specifically as is agricultural land.

The report emphasizes that understanding soil conditions on a site is critical to deciding project objectives and to achieving successful and sustainable results. Based on this, objectives can also be guided by developing links between habitats in the wider landscape and on considering appropriate species and vegetation communities to enhance local and national biodiversity. Setting restoration sites within their wider landscape context helps make linkages with suitable stretches of existing habitats beyond the perimeter of the site possible. These can be aesthetically valuable in developing integrated landscape designs but they also have an ecological purpose in allowing the migration of plant and animal species whose natural colonisation can aid the development of viable habitats. Such an approach also enables clusters of separate restoration sites to be understood and managed within a coherent wider context and with economies of scale.

The key message in terms of managing soil for habitat restoration projects is to try and work with existing conditions before altering the site. This will minimise the initial and long-term costs involved. Such restoration, if it is to be successful, requires a full understanding of the physical and chemical properties of the soil, along with its plant, animal and microbial communities – collectively known as the soil ecosystem. There is a complex set of interrelationships between living and non-living components, driving the structure and function of soil ecosystems. The process of soil formation is never ending; there will always be a dynamic interaction between water, air, biology and minerals. Materials, whether solid or in solution, arriving from elsewhere, will continue to drive and shape the changing nature of the soil.

The diverse range of physical, chemical and biological processes that affect soil formation and modify soil properties will respond to climate change. The effect of climate change will be to modify the rates of soil processes and lead to changes in soil properties, with a range of implications for soil development and the way in which soils can be used.

In all projects there will be important sources of information and data that need to be considered, but both the amount and type of data must be site and project specific. For example, a highly disturbed site, whether as a result of physical and/or chemical changes, will require much more data than a relatively undisturbed site. Similarly, there will be many more factors to take into account for a large-scale development than a small, local initiative. In general, the more information that is collected prior to work beginning on the site the better the chance of success.

In devising a restoration project it is important to consider whether there is a need to restore only the vegetation, the soil, or whether the whole ecosystem needs restoration, as the objectives of the project will affect the restoration methodology. The current site conditions will be the primary driver of the objective and a management plan that takes into account design, establishment, initial after-care and medium and long-term management, is therefore essential. It should highlight potential problems of carrying out work too quickly (the quality of the resulting habitats should be more important than a short-term fix) or in the wrong order.

## Contents

# 1 Introduction

Defra's recently published Soil Action Plan for England contains a range of actions to be pursued by partner bodies (Defra, 2004). The overall vision of the Soil Action Plan is to ensure that the country's soils will be protected and managed to optimise the varied functions that soils perform for society. Action 43 states that: 'English Nature will publish guidance on the use of soil information in the restoration of wildlife and wildlife habitats'. The aim of this report is therefore to help implement this action.

Habitat restoration programmes are now a major component of overall nature conservation operations in England. The UK Biodiversity Action Plan sets restoration targets for priority habitat types; the development planning system encourages restoration activity to some extent through mitigation and compensation provisions; and there has been a very significant increase in funding availability for restoration programmes. These funding sources include a growing agri-environment programme, EU structural funds, lottery and similar funds, sustainability funding from environmental taxes, and other sources.

The aim of this report is to raise awareness of key considerations relating to soil type and management in restoration projects, and also to raise awareness of existing detailed guidance that is available. It concentrates on soil aspects of restoration. Other considerations will need to be taken into account before restoration can be started, for example archaeology, contamination, planning restrictions, etc.

The report looks at key aspects of soil and outlines the properties that need to be examined and considered as part of the planning stage of restoration projects (Chapters 2 & 3). Some key considerations with regard to climate change and potential conflicts are indicated in chapter 4, while chapter 5 looks at options where soil restoration is required. Chapter 6 considers the particular case of heavily modified agricultural soils. An extensive reference list is provided at the end of the document to identify key sources of further information and guidelines specific to a range of scenarios and habitats.

## 1.1 What is soil?

Depending on the context, the word 'soil' has very different meanings. A simple definition of soil is "the material that plants grow in, and which provides them with physical support and nutrients". There are other more specific views of soil. To the engineer, soil is the finely divided and relatively loose 'rock' material at the Earth's surface (often called 'overburden' and considered an inconvenience because it has to be removed). Geologists call this layer the 'regolith', and they frequently begin their investigations below it. The hydrologist looks on the soil as if it were a large 'sponge' storing water to supply streams and rivers. The farmer and gardener often think of the soil simply as the top few centimetres – the depth of ploughing or cultivating for the farmer, and a spade or garden fork depth for the gardener.

Soil is formed through a number of processes. It is initially derived from the underlying rock, or parent material, which breaks down as a result of physical and chemical weathering and provides mineral content to the soil. Biological processes, such as the growth of plants and lichens, add organic matter. This organic matter is broken down by macro and micro invertebrates, fungi and bacteria (soil fauna), which also act to mix up the mineral and organic matter. Precipitation (rainfall and snow) provides water which carries material and chemicals through the soil, resulting in leaching and variations in soil profile with depth.

Time is therefore another important factor in soil formation. Management of soil, for example through agricultural practices, modifies soil and affects soil processes. There are links between soil and the atmosphere, for example the exchange of carbon dioxide and other gases. These processes can be important for limiting pollution and ameliorating climate change, as well as being important for life. Soil ecosystem services are explored further in section 1.4.

The cross section of soil from the surface to the underlying rock is called the **soil profile**. A soil profile often has a number of distinct layers within it. These layers are known as **horizons**. It is possible to make many subdivisions and classifications of soil by using these horizons – the simplest being **topsoil, subsoil** and **parent material**. Examples of these are illustrated in figure 1.


| **Brown soil** | **Gley soil** | **Podzol** | **Peat soil** |
|---|---|---|---|
| Topsoil<br>*over*<br>Subsoil<br>*over*<br>Drift parent material | Topsoil<br>*over*<br>Subsoil<br>*over*<br>Drift parent material | Topsoil (organic)<br>*over*<br>Subsoil<br>*over*<br>Shale or sandstone parent material | Topsoil (organic)<br>*over*<br>Subsoil<br>*over*<br>Drift parent material |
| Well drained | Poor drainage | Impeded drainage | Very poor drainage |
| Deep | Deep | Moderately deep | Deep |
| Lowland | Lowland | Upland or lowland heath | Lowland fen or upland bog |

**Figure 1** Example of four soil profiles

**Topsoil,** as the name suggests, is the material at the top of the soil profile and is usually coloured dark brown or black. The topsoil may simply consist of rock material that has been chemically and physically broken down and changed, and well mixed with the decomposed remains of plants. There may also be a layer at the surface of fresh plant litter which has yet to be incorporated into the soil. The topsoil is that part of the soil most affected by the activities of living things. Most roots are found in this layer, together with abundant plant and animal life, from relatively large animals such as moles and earthworms, to microscopic bacteria and fungi.

**Subsoil** consists chiefly of altered rock fragments. It contains very little plant material, although live roots and some soil plant, animal and microbial life occurs. Within the subsoil, mineral materials are actively broken down and altered, plant nutrients are released, and the size of the soil particles altered. Soil material which has been transported from the topsoil may accumulate here. Considerable reorganisation of soil material may also occur in the subsoil. This reorganisation may involve the binding together of soil particles to form aggregates, which can often be seen when the subsoil is exposed.

**Parent material** is the material from which the soil has developed, and generally consists of weakly consolidated material or almost unaltered rock. This zone of the soil is least affected by soil forming processes. The depth at which the parent material occurs depends very much upon the nature of the underlying rock (for example the ease with which it can be broken down and altered), as well as the length of time during which soil formation has been taking place.

Eight key soil parameters that are of importance for plants and the kind of vegetation that can develop in a particular situation are:

- **soil texture and structure**
- the **nutrient status** - how much nitrogen, phosphorus and other nutrients are present in the soil and how available they are to plants
- **soil chemistry and pH** - whether the soil is alkaline, neutral or acidic and the dominant mineralogy
- **depth** – including whether it is to a hard or contrasting layer or a feature that presents a physical barrier, for example to water percolation
- **organic matter**
- **moisture** - how wet the soils are, how free-draining or impeded, how susceptible to flood or drought
- **porosity and permeability –** how easy it is for water to move through the soil and for it to hold air and other gases
- **soil fauna** – including macro- and micro-invertebrates, fungi and bacteria

These parameters are explored further in Chapter 2.

## 1.2 Restoration

The English Nature Habitat Restoration Monitoring Project (Thomas, 2000) distinguishes between *habitat restoration* and *habitat creation* in the following way:

**Restoration:** "*the positive management of existing semi-natural habitat to improve its nature conservation value*"

**Creation**: "*the establishment by planting, seeding, natural regeneration etc of new areas of semi-natural habitat on land which had formerly been managed for other purposes (for example arable, industrial uses, gravel pits)*".

However, the principles involved in managing soil for habitat restoration or habitat creation are largely relevant for both purposes, therefore the majority of references to "restoration" used in this report relate to both of the above situations. In essence, restoration is applied where soils have been significantly disturbed.

**The key message in terms of managing soil for habitat restoration projects is to understand and work with existing conditions, rather than unnecessarily altering the site.**

This principle will help to minimise the initial and long-term costs involved in the restoration project, assist with defining and attaining the goals, as well as limiting the amount of further work required in subsequent years. Such restoration, if it is to be successful, requires an understanding of the physical and chemical properties of the soil along with its plant, animal and microbial communities – collectively known as the **soil ecosystem** (Sections 1.4 and 2).

Time is a critical factor in habitat restoration. It may not be possible to produce a site which achieves **all** of the desired objectives in the short term; some processes simply take a long time to develop (such as the re-establishment of pore networks, bulk density and soil biological characteristics). There are, however, management strategies and techniques available which can enhance the rate at which some of these processes take place, should this be appropriate. For instance, in mineral extraction sites (quarries, etc.) if the topsoil and subsoil are separated during the initial stripping of the overburden, their subsequent restoration will be an easier task (see chapter 5 for more information). It is important to make provision for the development of these beneficial characteristics, by means of a long term monitoring and adaptive management programme. This is going to be increasingly important in the face of climate change affecting moisture and temperature regimes experienced on site, which in turn will affect which plant species, for example, will tolerate the new conditions. The potential impacts of climate change on soils are discussed further in section 4.2.

## 1.3 Vegetation

Vegetation consists of the living plants which form the green fabric of different habitats – the trees, shrubs, herbaceous plants, ferns, mosses, lichens and liverworts which can be sustained under different environmental conditions in a particular place and time. These form the habitat. Soil conditions make up one environmental component that both limits and sustains plant growth and the development of vegetation, along with climate and biotic effects – the influences of other living things, like animals and particularly humankind.

In any restoration project, desk based background surveys or investigations of soil and local vegetation (potentially followed by field assessment of these factors), including how they vary across a site, will be an important early stage in understanding what plants can grow there and which vegetation types can realistically be sustained (Section 3). It is also essential to understand what has happened previously on the site, in particular for ex-industrial sites where contamination may have occurred.

Soil parent materials are a key determining factor in the properties of soils, but there are also important interactions between soils and the climatic and biotic influences in a particular locality. There are also interactions with the vegetation itself which, as well as using nutrients and water in the soil, contributes organic matter as plants die and decay. Soils and the vegetation they sustain, together with the associated fauna in a habitat, form integrated dynamic systems (ecosystems) with strong interdependencies and feedbacks.

## 1.4 Soil ecosystem services

The ecosystem services performed by soil are derived from the physical, biological and chemical processes that occur within it (Holdren & Ehrlich, 1974; Ehrlich & Ehrlich, 1981; Costanza and others 1997). These services are of particular importance in the regulation of the soil, air and water environment, both at a local level and also on a global scale. The importance of soil in maintaining a healthy environment is being increasingly recognised. Soil ecosystem services in the context of this report include:

- Water filtration
- Water storage
- Dilution and degradation of leachates and pollutants
- Maintenance and enhancement of soil carbon
- Regulation of river flows and groundwater levels
- Maintenance of healthy rivers and channels
- Maintenance and regeneration of habitats and biodiversity
- Waste absorption, breakdown and recycling
- Regulation of climate through soil organic matter content and emission and absorption of greenhouse gases
- Insect pest control
- Maintenance and provision of genetic resources
- Provision of shade and shelter
- Maintenance of soil health
- Media for growth of vegetation
- Nutrient storage
- Energy storage

# 2 Soil characteristics and their implications for habitat restoration

Fundamentally, soil consists of a mixture of mineral grains that have been derived from the rock deposits of the earth, organic matter resulting from the decomposition of vegetation, living organisms of great diversity and numbers, varying amounts of water containing nutrients in solution, and finally varying amounts of air.

Soil is a dynamic component of the environment, and soil development is a continuous process, operating at various rates during the different stages. Soils are often subject to continuous weathering and erosion, and the eroded materials eventually form the parent material for future soil development. Conversely, rock hitherto buried beyond the reach of weathering processes will also form the parent material of future soils when exposed at the surface.

Soils have many important functions. Perhaps the best appreciated is the function to support the growth of agricultural and horticultural crops. Soil is the mainstay of agriculture and horticulture, forming as it does the medium in which growth and ultimately the yield of food producing crops occurs. The soil's natural cycles go a long way in ensuring that the soil can provide an adequate physical, chemical and biological medium for crop growth and also for maintaining natural and semi-natural vegetation – forests, grasslands and moorlands. It is its function in supporting natural and semi-natural vegetation that is the key focus of this report.

## 2.1 Soil classification

Soil profiles are produced by many different soil processes operating at different rates and in different combinations leading to soil properties and characteristics that need to be taken into account in any restoration scheme. It has long been recognised that soils vary from place to place, sometimes within very short distances. Various ways have been devised to describe and communicate these differences.

Soil profiles (ie the combination of topsoil, subsoil and parent material) can be grouped according to their properties into soil series and soil groups. The names of soil series reflect where they were first described (for example "Evesham"), and soil groups indicate technical descriptions, for example brown earths, podzols, typical stagnohumic gley soil. Soil series reflect the underlying geology, from which the soils were formed.

A soil map is a spatial inventory of soil profiles. Traditional soil mapping is conducted with an auger and spade at intervals throughout the landscape. The intervals between inspections can be according to a pre-determined grid (grid-survey) or, more often, are based upon the judgement of the surveyor who uses their knowledge of the inter-relationship between soil type and landscape, geology, vegetation, etc to determine where to make inspections. Auger borings are supplemented by excavated profile pits at determined points in the landscape. These profile pits are used to demonstrate lateral changes in the soil as well as vertical ones, and are important for the full description of soil types and for the taking of soil samples for chemical, physical and, less commonly, biological laboratory analysis. In this way a picture is built up of the soil in a region and its relationship to the landscape in which it lies.

Soils can be mapped at a range of scales from very detailed at 1:1,250 to 1:5,000 by which the pattern of soils in individual fields can be identified, through to a scale of 1:250,000 which provides a more generalised picture of the soils of a county or region. The soils in all parts of the UK have been mapped at 1:250,000. Published maps with more detail are held by the National Soil Resources Institute (England and Wales), Macaulay Institute (Scotland) and the Department for Agriculture and Rural Development (Northern Ireland), together with large archives of un-published maps and data. A synthesis of this data in England and Wales is provided via the 'Soilscapes' mapping, available online at www3.landis.org.uk/soilscapes.

Most soil mapping is based on a soil's physical and chemical characteristics. It is increasingly recognised, however, that biological processes are critical in creating and maintaining a healthy soil ecosystem, including, for example, the cycling of nutrients.

## 2.2 Soil texture and structure

The aim of any classification scheme is to convey information to a common framework, however simple or complicated that framework may be. Most restoration schemes, of whatever scale, will be interested in the following issues:

- whether the soils are sands, silts or clay, ie texture (but note *soil* textures are not the same as geological particle size classes even though the names are similar) (see figure 2);
- whether is the soil is predominantly mineral, organo-mineral or organic (less than 20, 20-50, more than 50% organic matter respectively);

- whether the soil is always or seasonally wet or dry (drainage and hydrology);
- whether the soils is shallow or deep to a hard layer;
- whether the pH is acid, alkaline or neutral.

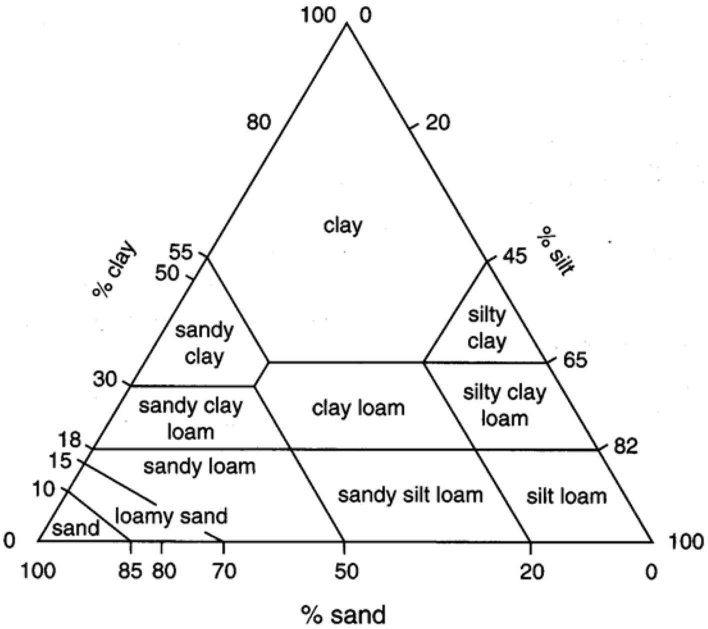



**Figure 2** Soil texture diagram

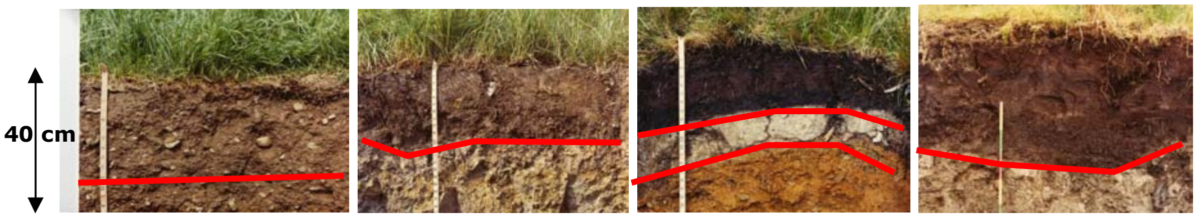
Recent guidance publications on soil management from Defra (Defra 2006) group soils as follows: sandy or light silty, medium, heavy, chalk and limestone soils and peaty, reflecting some of the parameters listed above. These are the same groups used for recommending fertiliser applications to agricultural and horticultural crops (MAFF 2000).

Biological processes can be important for the development and maintenance of soil texture and structure. These can include the physical burrowing and breaking down of organic material by earthworms and other macro-invertebrates, and also the 'glue' (glomalin) excreted by some bacteria and fungi, especially mycorrhiza, that assists soil to form peds (fine aggregates of soil material).

## 2.3 Soil moisture

Water is chiefly held within the soil profile in holes and cracks of varying sizes; some of very small diameter are full of water under most normal conditions, other larger holes and cracks become filled as water percolates through the soil after rainfall (see Figure 3). This water is slowly taken up by plant roots. The largest holes and cracks are full of water only briefly as water begins to percolate through the soil after rainfall which enables water to pass through the soil and drain away.

Drainage and depth to the water-table and consequently the length of time that a soil is saturated or unsaturated with water are vital parameters for plant growth. The suitability for most crops and many other plant species decreases when drainage conditions become impeded, but conversely some species are put at a competitive advantage by waterlogged soil. For example, tree crops with a deep root system are typically more sensitive to poorly drained conditions than annual crops with shallower root systems.




| | Brown soil | Gley soil | Upland podzol | Peat soil |
|---|---|---|---|---|
| **Topsoil** | | | | |
| Air | 15-25% | 10-20 | 5-15% | 5-10% |
| Water | 40-60% | 35-45% | 50-70% | 70-80 |
| Mineral | 45% | 20-50 | 15-20% | 15% |
| Organic matter | 2-8% | 4-10% | 80% | 80% |
| C/N ratio | 10-15 | 20 | 20 | 20 |
| **Subsoil** | | | | |
| Air | 10-25% | 5-10% | 15% | 15% |
| Water | 40-50% | 30-40 | 50% | 40-50% |
| Mineral | 40-50% | 55-65 | 35% | 30-40% |
| Organic matter | 2-3% | 1-3% | 8% | 1-2%% |
| C/N ratio | NA | NA | 12 | NA |
| **Subsoil** | | | | |
| Air | | | 15% | |
| Water | | | 40-50% | |
| Mineral | | | 35-50% | |
| Organic matter | | | 2.5% | |
| C/N ratio | | | NA | |

**Figure 3** Typical soil properties

## 2.4 Soil nutrients

The most important nutrient requirements in plant production are nitrogen, phosphorus and potassium. Nitrogen is an essential component of proteins and chlorophyll and therefore an adequate supply is vital to sustain high levels of crop production. However, natural ecosystems often become adapted to exist with low availability of these nutrients in the soil, particularly phosphorus. Potassium requirement is related to nitrogen uptake, larger quantities being needed when nitrogen usage is high as in intensive grasslands. Techniques to increase or decrease soil fertility for habitat creation are discussed in Parker (1995).

Considerations for soil nutrients during initial investigations for restoration potential should include:

- What is the appropriate habitat for the nutrient levels (and other parameters) present? For example, intensive agriculture may have increased the nutrient levels as a result of fertiliser application.
- Are the nutrient levels present appropriate to establish and sustain the planned habitat?

- Have previous land management practices affected the expected nutrient levels of the soil? For example, urban/brownfield sites may have been stripped of their nutrients and may be unsuitable for maintaining some ecosystems.

## 2.5 Soil acidity

Under the climatic conditions of the UK, soils become progressively more acid, particularly in areas of high rainfall through the dissolution and subsequent leaching of calcium. However, it is not only calcium that can be lost in this way and this and other minerals (such as magnesium, sulphur and trace elements) may need replacing by the addition of fertilisers. All plants have different degrees of tolerance to acid conditions that are well documented in the literature but the activity of micro-organisms is also altered (not necessarily detrimentally) by changes in acidity. This can lead to, for example, an accumulation of partly decayed plant materials and eventually peat, or in grassland leaving a mat of plant litter. Soil acidity is also a determining factor for habitat types, for example the range of grasslands, heathlands and woodland.

## 2.6 Soil depth

Soil depth is generally described as the thickness of loose soil available for root growth above a limiting layer (if any) which is impermeable to roots and percolating water. Adequate soil depth is vital for the anchoring of plants and provision of a favourable environment for plant root growth.

Rooting depth, the part of the overall depth that is exploited by roots, is a crucial parameter in soil productivity because it reflects the reserves of water and nutrients actually used by roots. The relationship between rooting depth and productivity is commonly described according to the law of diminishing returns, ie the shallower the soil the less scope there is for flexibility in restoration targets. However, it can be better for a number of habitats – shallow, poor soils can be more biodiverse in habitat and species.

## 2.7 Man-induced soil disturbance

The rate and duration of soil formation is controlled by the complex interaction of soil forming factors. One major factor, often rather surprisingly omitted from the consideration of soil development, is human influence which has also had a dramatic effect on soil development and distribution. Man is readily thought of as an agriculturalist or urban developer, but we also affect the soil by

- extracting minerals from beneath it;
- contaminating the soil through industrial processes;
- polluting the soil through airborne deposition
- erosion following inappropriate management
- inappropriate use of agro-chemicals – changing nutrient concentrations and pH and impacting on soil biology;
- draining and flooding;

- depletion of soil organic matter through continuous arable cropping and intensive grassland management;
- compaction – traffic and animals, not just in waterlogged conditions.

## 2.8 Soil biology

Soil biology is increasingly recognised as being of fundamental importance to soil processes and function. It is also, however, little understood at present. It has been estimated that there is more diversity within the soil than there is above ground, but we are only just beginning to gain an appreciation of the range of species which live there and their distribution in relation to habitat, soil type and climatic factors.

Soil fauna is generally divided into macro- and micro-invertebrates, bacteria and fungi. Each group provides key functions within the soil. In addition, plant root systems (the rhizosphere) and algae aid in the transfer of nutrients, water and gases (such as carbon dioxide) between the soil, atmosphere and vegetation. These interactions are fundamentally important and a key factor in soil restoration. See Bardgett 2005 for further discussion of this subject.

# 3 Matching habitats to site conditions

English Nature Research Report 260 (Dryden, 1997) provides the basis for where to locate projects through a number of very valuable habitat creation fact sheets. However, for any habitat restoration project to be successful, it is important to understand the existing soil conditions and the kinds of vegetation and habitats these can sustain. Restoration projects should not attempt nor expect to recreate ancient woodland for example, but to use the existing properties and distribution of soils (which are the result of centuries if not millennia of change caused by forest removal, grazing, cultivation, climate change and environmental pollution) to guide opportunities and outcomes for habitat restoration.

## 3.1 Soil and data considerations for habitat restoration

In order for a project to be as successful and efficient as possible, there are a number of considerations that need to be taken into account even before restoration objectives can be set.

**What relevant information do I need before carrying out a project?**

In all projects there will be important sources of information and data that need to be considered, but both the amount and type of data must be site and project specific. For example, a highly disturbed site, whether as result of physical and/or chemical changes, will require much more data than a relatively undisturbed site. Similarly, there will be many more factors to take into account for a large-scale development than a small, local initiative. These considerations form the basis of a feasibility study that should be carried out for any habitat restoration project. This stage is likely to be primarily desk-based but, if necessary, may also include a pilot site survey prior to the more detailed soil survey described below. The more information that is collected prior to work beginning on the site the better the chance of success. A summary of data sources and methods of collection is presented in Table 1.

Firstly, a **desk-based study** should look at the history of the site and potential impacts on restoration options. It is essential that an understanding of soil types and their characteristics is part of the decision-making process (ie the objectives of restoration must be defined based on what is possible on a particular site). The desk-based study must also look at the history of the site, influencing factors (such as archaeology, water courses or groundwater impacts), its context and linkages within the wider environment, local BAP targets and characteristic habitats in the surrounding area.

It is important to determine early on whether the soils on site are essentially original, undisturbed, or altered (for example nutrient enriched) due to management techniques, or, at the other extreme, absent and essentially sub-soil or overburden materials, such as those found in opencast mine sites. If the original soils are absent, and therefore all that is available is mineral material (ie "soil-forming material"), this may offer opportunities for establishing stress tolerant vegetation communities.

**Table 1** Sources of information

| Property | Desk study from published data | Field survey | Simple test | Complex test | Equipment |
|---|---|---|---|---|---|
| **Texture** | Soil maps and reports | Number and depth of samples depends on the size of the site and the complexity of the soil and landscape patterns – Defra Technical Advice Note 20 recommends 1 every 10 to 25 metres | Hand assessment in field | Lab assessment | Sampling equipment |
| **pH** | Soil maps and reports | | Simple field test kit | Lab assessment | Simple field kit |
| **Nutrients** | Little published data – National Soil Inventory data as benchmark | | None | Lab assessment | Sampling equipment, bags and labels, analysing equipment |
| **Depth** | Soil maps and reports | | In-field measurement with spade or auger | In-field measurement with scanner | Spade, auger or scanner |
| **Moisture** | Guide data only in published reports | | No reliable simple field test | Lab measurement using volume tins | Tubes or scanner |
| **Water table** | Guide data only in published reports | | Observation of auger hole in wet weather, otherwise no simple test | In-field measurement with tubes, | Tensiometer or scanner.<br><br>Spade, bags and labels, analysing equipment |
| **Contaminants** | Site specific – site history | | None | Lab assessment | Sampling equipment, bags and labels |
| **Porosity (bulk density as surrogate)** | Soil maps and reports | | In-field visual assessment of compaction | Lab assessment using volume tins | Volume tins, spade |

**What type of field survey will be required?**

It is important to note that not all projects will require detailed soil surveys, providing the appropriate data sources have been consulted and potential impacts taken into account.

An initial decision must be made as to whether to investigate the site by means of a map-based survey to give the spatial relationship between the different soils on the site and/or to concentrate on a number of key sites and investigate them in detail through sampling. This is the reason that knowing the history of a site is a critical first stage in habitat restoration. However, at a minimum on sites which have been significantly disturbed, soil samples should be collected every 10 to 25 metres and analysed. Ideally, a suitable soil survey should be carried out on a comparable site which already supports similar vegetation or the desired habitat. Again, this decision will be site-specific and should be part of the discussion process between all parties involved in the project along with external organisations, if required.

It is worth bearing in mind that the costs involved at this stage of the project may be significantly outweighed by the long term benefits in terms of future monitoring and management of the site, and especially success or failure of the project. The soil survey should form part of a wider detailed site survey and the length of time needed for this stage should not be underestimated. For example, if seasonal variations and patterns are likely to be important considerations, perhaps with regard to groundwater patterns, this could take up to 12 months. Particularly sensitive sites may also require data for monitoring both before and after restoration.

**Who else needs to be involved?**

There are a number of organisations that are available to give advice and offer practical support for the management of soils in habitat restoration projects. Some of these organisations may also be able to provide sources of data or can be used to find out where to access certain data. However, care should be taken to ensure the accuracy, timeliness and licensing restrictions of data obtained from external organisations. A list of some relevant organisations can be found in Section 10.

It is important to consider whether planning permission will be required for the restoration project. It can be worth involving the local authority at an early stage.

## 3.2 Which habitats can the soils support?

### 3.2.1 Soils and their plant communities

Different soil types sustain different kinds of vegetation with characteristic mixtures of plant species growing together in a distinctive structure. Ecologists use the term 'plant community' to describe such a recognisable kind of vegetation and group these together in major categories such as woodlands, heaths, grasslands, or tall-herb communities. Understanding the diversity of plant communities that can occur on the range of soils and climates found across Britain, and with different kinds of biotic impacts, needs an overview such as that presented in the legend to the Soilscapes map of England and Wales (NSRI 2006) (Table 2).

**Table 2** Examples of which habitats are associated with which soil types - Soilscapes legend (NSRI, 2006)

| Soil | Texture | Drainage | Fertility | Land cover | Habitats |
|---|---|---|---|---|---|
| Saltmarsh soils | Loamy | Naturally wet | Lime-rich but saline | Natural vegetation | Coastal salt marsh vegetation subject to tidal flooding |
| Shallow very acid peaty soils over rock | Peaty | Variable | Very low | Open moor | Rugged wet heather and grass moor with bare rock, and bog vegetation in hollows |
| Shallow lime-rich soils over chalk or limestone | Loamy | Freely draining | Lime-rich | Arable and grassland | Herb-rich Downland and limestone pastures; limestone pavements in the uplands; Beech hangers and other lime-rich woodlands |
| Sand dune soils | Sandy | Freely draining | Lime-rich | Natural vegetation | Sand dune vegetation ranging from pioneer dune systems through to low shrub |
| Freely draining lime-rich loamy soils | Loamy | Freely draining | Lime-rich | Arable with grassland at higher altitude | Herb-rich chalk and limestone pastures; lime-rich deciduous woodlands |
| Freely draining slightly acid loamy soils | Loamy | Freely draining | Low | Arable and grassland | Neutral and acid pastures and deciduous woodlands; acid communities such as bracken and gorse in the uplands |
| Freely draining slightly acid but base-rich soils | Loamy | Freely draining | High | Arable and grassland | Base-rich pastures and deciduous woodlands |
| Slightly acid loamy and clayey soils with impeded drainage | Loamy | Slightly impeded drainage | Moderate to high | Arable and grassland | Wide range of pasture and woodland types |
| Lime-rich loamy and clayey soils with impeded drainage | Clayey | Slightly impeded drainage | High | Arable some grassland | Base-rich pastures and classic 'chalky boulder clay' ancient woodlands; some wetter areas and lime-rich flush vegetation |

| Soil | Texture | Drainage | Fertility | Land cover | Habitats |
|---|---|---|---|---|---|
| Freely draining slightly acid sandy soils | Sandy | Freely draining | Low | Arable | Acid dry pastures; acid deciduous and coniferous woodland; potential for lowland heath |
| Freely draining sandy Breckland soils | Sandy | Freely draining | Mixed, low to lime-rich | Arable forestry and heath | Characteristic Breckland heathland communities |
| Freely draining floodplain soils | Loamy | Freely draining | Moderate to high | Grassland some arable | Grassland; wet carr woodlands in old river meanders |
| Freely draining acid loamy soils over rock | Loamy | Freely draining | Low | Grassland and rough grazing | Steep acid upland pastures dry heath and moor; bracken gorse and oak woodlands |
| Freely draining very acid sandy and loamy soils | Sandy | Freely draining | Very low | Heath and forestry | Mostly lowland dry heath communities |
| Naturally wet very acid sandy and loamy soils | Sandy | Naturally wet | Very low | Arable and horticulture some wet lowland heath | Mixed dry and wet lowland heath communities |
| Very acid loamy upland soils with a wet peaty surface | Peaty | Surface wetness | Very low | Moorland rough grazing forestry and grassland | Grass moor and heather moor with flush and bog communities in wetter parts |
| Slowly permeable seasonally wet acid loamy and clayey soils | Loamy | Impeded drainage | Low | Grassland with some arable and forestry | Seasonally wet pastures and woodlands |
| Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils | Loamy | Impeded drainage | Moderate | Grassland and arable some woodland | Seasonally wet pastures and woodlands |
| Slowly permeable wet very acid upland soils with a peaty surface | Peaty | Impeded drainage | Low | Moorland rough grazing and forestry | Grass moor and some heather with flush and bog communities in wetter parts |
| Loamy and clayey floodplain soils with naturally high groundwater | Loamy | Naturally wet | Moderate | Grassland some arable | Wet flood meadows with wet carr woodlands in old river meanders |
| Loamy and clayey soils of coastal flats with naturally high groundwater | Loamy | Naturally wet | Lime-rich to moderate | Arable some grassland | Wet brackish coastal flood meadows |

| Soil | Texture | Drainage | Fertility | Land cover | Habitats |
|---|---|---|---|---|---|
| Loamy soils with naturally high groundwater | Loamy | Naturally wet | Low | Arable grassland and woodland | Wet acid meadows and woodland |
| Loamy and sandy soils with naturally high groundwater and a peaty surface | Peaty | Naturally wet | Low to high | Mostly arable | Wet meadows |
| Restored soils mostly from quarry and opencast spoil | Loamy | Variable | Low to moderate | Grassland arable and trees | Variable |
| Blanket bog peat soils | Peaty | Naturally wet | Very low | Moorland rough grazing and forestry | Wet heather moor with flush and bog communities |
| Raised bog peat soils | Peaty | Naturally wet | Very low | Bog; grassland and some arable | Raised bog communities |
| Fen peat soils | Peaty | Naturally wet | Mixed, lime-rich to very low | Arable and horticulture | Wet fen and carr woodlands |

### 3.2.2 Describing plant communities

All British environmental agencies and NGOs, local authorities and consultancies now use the National Vegetation Classification (NVC) which provides a common language for describing plant communities and understanding their dynamic interactions with the environment. The NVC provides standardised and comprehensive information on the species composition and structure of British plant communities in all natural, semi-natural and major artificial habitats as well as their relationships to soil, climate and biotic influences, and their distribution across the country. The 'Habitat' sections of these plant community accounts provide a summary of the soil and other environmental conditions needed to sustain the vegetation. Wherever possible these sections make reference to the soil types described and mapped by the National Soil Resources Institute (NSRI) (Section 2.1). However, for some purposes, the NVC may be too specific and it may be necessary to consider broad habitat types for some purposes within the framework of NVC communities. Details of the NVC can be found in Rodwell (1991 et seq.).

### 3.2.3 Surveying the existing vegetation on a site

Understanding what plants and vegetation are already present on a site is vital before proposals for restoration are made and effected. It is important not to waste such existing resources or to ignore the natural processes that are already in train. Such understanding can help speed the establishment of viable habitats and 'going with the grain' is less costly and more sustainable. A standardised method for vegetation survey is provided in "The Handbook for Using the National Vegetation Classification" (Rodwell 2006) while www.ecoregen.org.uk shows a worked example of how to use this survey methodology in conjunction with GPS and GIS to produce a vegetation map of a restoration site. For species distribution, the National Biodiversity Network (www.nbn.org.uk) can provide valuable information about plants and animals across the country. This source also has a list of Local Records Centres that often have more detailed information about the area of your restoration site.

### 3.2.4 Going with the grain of natural processes

Because restoration sites often have unusual substrates disposed in difficult and unstable terrain (for example, derived from mining or quarry spoil) it is often thought that these need to be remediated by treatments or covered with top soil before any vegetation will develop. Shifting spoil and poisonous wastes can be highly inimical to plant growth as well as threatening to people and animals. However, it is clear that vegetation can often develop spontaneously in such situations – and at little or no cost to long-term establishment. Some artificial substrates, such as highly acidic sands or unconsolidated coal shales, also offer substrates that approximate to natural habitats which can readily sustain interesting plant communities. For example, at Darwen Parkway, one of Groundwork's 'Changing Places' sites, heath has developed on the steep slopes of abandoned sand pits (Rodwell & Dring 2000) while, at Grimethorpe Colliery in South Yorkshire, oak-birch woodland with wavy hair grass has spontaneously appeared within fifteen years of abandonment (Lunn 2001). In other cases, remediation can be much less complex and costly than expected. For example, at Lofthouse Colliery in West Yorkshire, treatment with spent mushroom compost enabled patches of heath to be established on coal shale from planted heather plugs (Speight, 1990). English Nature's Tomorrow's Heathland Heritage project (http://www.english-nature.gov.uk/thh) is working towards the restoration of large areas of heathland across

England such as the re-creation of heathland from the spoil heaps created by the china clay industry in Cornwall.

### 3.2.5 Predicting the potential vegetation types for a site

Classifications of plant communities like the NVC have strong predictive power enabling the identification of the kinds of vegetation that can be sustained in particular conditions. Therefore, a good map of soil types available from existing publications, or a map of soil conditions produced by site survey, will enable the prediction of the type of plant communities that can realistically be sustained there. Such understanding will also help limit expectations that, for example, chalk grassland cannot be produced on any site other than one which has shallow impoverished, highly calcareous soils; or that heaths can be sustained on deep, highly fertile soils that are occasionally flooded. One example of how the NVC has been successfully applied to provide simple predictive guidelines on which plant communities can be encouraged to develop in different situations is the Forestry Commission Bulletin on Creating New Native Woodlands (Rodwell & Patterson, 1994).

### 3.2.6 Choosing from potential options for a site

Various factors will influence which vegetation types, out of the range of realistic options sustainable on particular soils, might be a target for restoration. Conservation initiatives such as Biodiversity Action Plans (BAPs) highlight priority habitats and vegetation types which are nationally or regionally threatened (www.ukbap.org.uk). There can thus be considerable support and funding for projects and public kudos in targeting such priorities in restoration projects. The habitats and vegetation types which are the targets for particular areas can be found by logging on to local authority or county Wildlife Trust websites or obtaining the local BAP publications or via www.ukbap.org.uk . These will also often provide ways of relating the broad BAP habitats to the NVC, so that more detail about the vegetation types and factors needed to sustain them can be obtained. This will help realise a viable restoration project that is locally distinctive to a specific area.

### 3.2.7 Sustaining vegetation types after restoration

Very often, restoration involves an initial costly outlay for remediation and engineering to produce terrain amenable to the aesthetic and safety expectations of planners and landscape designers. Usually, there has been little endowment funding for ongoing management and often little understanding of the dynamic processes in train in such situations. In most cases where habitats are restored, succession is restricted through management and the implementation of the correct management is a vital part of any after-care programme. It is necessary to consider outcomes and choose objectives according to the site in question, for instance if no management occurs then will a natural succession to woodland be acceptable?

Some vegetation types require repeated interventions to sustain them and they will not retain their characteristic species composition and structure unless such management conditions are met. This is because they are transitional in terms of succession, and these habitats may require management intervention to maintain them, which may have occurred traditionally in the past (for example, in the case of heathlands or grasslands). The neat short turf of pastures, for example, is usually maintained by grazing; the tall colourful sward of meadows by some combination of grazing and mowing; the low shrubby cover of heaths by periodic cutting, burning or grazing, and so on. Without such interventions, vegetation proceeds in successions from one plant community to another. In the natural landscape, it is only in very exposed or otherwise uncongenial situations – very wet places, for example – that such successions are hindered. The 'Zonation and Succession' section in the plant community accounts in the NVC provides an understanding of the sequences of plant communities that are characteristic of particular soil types and the interventions necessary to halt successions at the desired stage.

## 3.3 Landscape scale context

Setting restoration sites within their wider landscape context helps make linkages with suitable stretches of existing habitats beyond the perimeter possible. These can be aesthetically valuable in developing integrated landscape designs but they also have an ecological purpose in allowing the migration of plant and animal species whose natural colonisation can aid the development of viable habitats. Such an approach also enables clusters of separate restoration sites to be understood and managed within a coherent wider frame and with economies of scale. This broader dynamic perspective forms the basis of the "Ecoscape" approach developed in Rodwell & Thorne (2004) and Rodwell and others (2005).

Conventional conservation policies have had mixed results in recent decades and in many cases have failed to prevent a decline in both species diversity and abundance as well as a degradation of habitat size and value. This can be partly attributed to the tendency to approach the conservation of habitats on a site-by-site basis which has overlooked the need for many species to be able to move between and beyond sites. This requires a landscape-scale approach, which undoubtedly is a more demanding task. English Nature's Living Landscape Project (Griffiths and others 2004) highlights the importance of linking habitats for both flora and fauna and increasingly views a more holistic approach the appropriate way forward.

Networks of sites and habitats need to be designed to match the requirements of specific species or groups of species and particular habitat types. Their form is likely to vary greatly, depending on local conditions. However, the components usually will include:

- Core areas, often sizable habitats, between which linkages may be required.
- Linkages, often in the form of corridors or "stepping stones" between habitats, such as a chain of wetland sites used by migrating birds. Corridors may be natural, including river or mountain chains, or they may be man-made features such as hedgerows. They are likely to vary in scale depending on the landscape and the species concerned. Important landscape-links are:
    - Floodplain – riparian links along river banks
    - Treeline and hedgrow links
    - Links along escarpments and valley sides
    - Links into urban areas, such as parks and paths.
- New or recreated habitats managed within a matrix to reinforce the network, for example by creating new links or stepping stones.
- Other elements, such as corridors *within* a habitat, and buffer zones adjacent to core areas.

- The need to consider 'permeability' of landscape to dispersal, which depends on types of habitats and species.

GIS can be a useful tool in analysing these various components on a spatial basis. In addition, landscape character assessment can be a useful tool (www.landscapecharacter.org.uk), as can linking in with local, regional and national Biodiversity Action Plans (BAP) (see www.ukbap.org.uk and www.nbn.org.uk).

Soils are not only important in determining the potential vegetation and habitat patterns at a particular site (as discussed in Section 2), but they also influence the distribution of potential habitats across a landscape. Consequently, a soil component has been incorporated in all currently existing landscape classifications. For example, the Soilscapes dataset from the National Soil Resources Institute is entirely based on soil properties, whereas Ecoscapes (English Nature), Natural Areas (English Nature), The Landscape Character of England (English Nature and the Countryside Commission) as well as Landscape Character Assessments (www.countryside.gov.uk/cci/guidance) incorporate a range of additional natural and cultural characteristics in addition to soil properties. All of them, however, allow an assessment of the position of an individual site with respect to the landscape as a whole. In addition, there are a number of models available which map the distribution of habitats within the landscape again relying on soil patterns as a key driver. Examples of such models include GBmove (Centre for Ecology and Hydrology) and the Ecological Site Classification (Pyatt and others 2001). www.commonground.org.uk may also be of interest.

Imaginative restoration projects will aim to create multifunctional sites where sustainable vegetation is integrated within some broader range of objectives and uses within the wider landscape. They will also draw on what is sometimes a wealth of resonances within the landscape to relate proposed future uses to valuable local history and memories about the meaning of the place. This can be a vital aid to local ownership of restoration projects among the wider community. To see how such an approach can be developed, reference should be made to Rodwell, Wildsmith & Cartwright (1998) and the associated National Urban Forestry Unit Case (2003).

# 4 Considerations for habitat restoration

Planning is an essential part of habitat restoration and recreation. The existing site conditions will be the primary driver of the project objectives. A management plan that takes into account design, establishment, initial after-care and medium and long-term management is therefore essential. It should highlight potential problems of carrying out work too quickly (the quality of the resulting habitats should be more important than a short-term fix) or in the wrong order. An important question to consider is "what is the impact on long term soil conditions and the ability of the soil to support particular habitats?". It is important to understand the conditions of the soil and habitats on site first so that what is 'valuable' is not lost. The initial project objectives should be flexible enough to be altered depending on survey results and on outcomes at different stages. For instance, is the aim to restore the soil and then the hydrology and ultimately what will be the impact on soil hydrology?

## 4.1 Conflicts between objectives?

There are a number of examples of where possible conflicts in objectives or wider impacts can be recognised. Some of these are outlined below.

### 4.1.1 Impacts on existing wildlife value

The initial surveys of the site should have included assessments of any existing vegetation. In general, new habitats should not be created on sites which already have significant existing wildlife value. Known examples include the planting of woodland on flower-rich grassland and digging ponds in the marshy corners of fields, where the existing habitat is of high value and will have taken a long time to develop. Another example, between native woodland and semi-natural grassland, has been highlighted by Hester and others (2003) in upland Scotland, where a key linkage point to develop a Forest Habitat Network was also a key site for an important moorland community.

Even apparently unfavorable habitats like improved, botanically-poor grassland can sometimes be very important for wildlife, for example by providing feeding habitat for badgers and wildfowl. It is therefore important to consider what a site already provides against proposals for what can be created anew. There can also be potential to add value to or supplement what already exists.

### 4.1.2 Water management for wetland restoration

A key consideration in wetland creation is the interaction between water and soil. For example, in wet grassland reversion, flooding land early to encourage birds to return as soon as possible usually acts against getting soil conditions back to a more natural state. Saturated soils contain less air and soil processes are significantly different. Raising water levels in stages can often be more beneficial, as it allows the soil and associated vegetation and fauna to respond to the environmental changes. The result will be a more sustainable solution in the long term. It may be essential to resist flooding the land immediately and to take a longer term view.

### 4.1.3 Major soil 'restoration' eg heathland

Heathland naturally occurs on acidic, well drained soils. Suitable conditions for heathland can also be produced by nutrient stripping/acidification via topsoil removal and sulphate application. However, this reduces soil carbon stock, increases erosion risk, compromises buffering capacity and has off-site water quality impacts. In addition, the heathland so produced may not be sustainable long term. It is therefore essential to consider whether the short term gains obtained by significant and major soil management techniques actually provide a long term solution, and whether the wider environmental implications of carrying out these works is desirable. Heathland recreation can take a long time and the transitional habitats are also of value.

### 4.1.4 'Landscape' restoration, agricultural land

Landscape scale restoration is often encouraged, for example via agri-environment schemes. Crop and/or grass planting encouraged by these schemes can lead to structural damage and water erosion on unsuitable soil types, for example as a result of mixed farming in the uplands. Arable cultivation for nature conservation as part of agri-environment schemes (ie cultivation for the specific purpose of encouraging plants and animals associated with arable land) can increase the risk of erosion (for example winter stubbles provided for birds on steep coastal land being spring ploughed whilst soils are still saturated). Cultivation can also deplete organic matter and the integrity of soil types characterised by organic horizons (such as shallow soils and podzols) are at particular risk as the organic horizon can be destroyed. The converse can also be true - for example, should the wet margin of a field be drained and brought back into cultivation or should it be developed under agri-environment schemes. The wider impacts of such schemes and proposals therefore need to be considered, along with timing of works.

#### 4.1.5 Forest habitat networks

Woodland is a popular habitat, both for the public and in restoration schemes. When considering new woodlands, however, it is important to consider the soil type. It is possible to plant trees on unsuitable soil types (for example on organic and organic-mineral soils, leading to carbon loss). Woodlands are just as reliant on their substrate as are other vegetation communities.

#### 4.1.6 Sand dune management

Preventing soil development/topsoil stripping in sand dunes helps maintain diversity of habitat type, in particular by maintaining early or pioneer habitats However, it also removes a potentially valuable resource in terms of a developing soil with a good organic layer, good structure etc. This can lead to reduced soil carbon stock and has effects on water and air interactions. The wider dune system therefore needs to be considered before making decisions, and priorities considered.

#### 4.1.7 Planning regulations

Planning regulations can be forgotten in major restoration projects. Planning permission may be needed and waste regulations should be considered if large scale stripping of soils is a serious option. It is essential that the appropriate regulations are observed. Defra TAN 31 advises that both planners and EA should be consulted when stripping is being considered. ( www.defra.gov.uk/rds/publications )

#### 4.1.8 Moorland management

Burning of vegetation in the management of moorland for grouse habitat is a widely used technique, but can be detrimental to soil hydrology, leading to erosion by water and loss of soil as well as dissolved and particulate organic matter. Significant alterations in management regime need to be carefully considered, and the impacts of both new and existing techniques looked at. Advice is available, for example from English Nature (Natural England).

#### 4.1.9 Choosing between options

Using the soil to determine a habitat change can provide a number of options. For example, on sandy soils, heath, Scots Pine or birch woodland may be options. It is essential to consider the wider landscape and needs of the local area. This can be where Biodiversity Action Plans and understanding wider habitat linkages and networks are useful in making decisions about objectives. Choosing one of these habitats may help with achieving local and national BAP targets, while a mosaic may link in well with the surrounding landscape, making surrounding habitats more sustainable.

## 4.2 The long term - climate change and its impact on soils

The diverse range of physical, chemical and biological processes that affect soil formation and modify soil properties will respond to climate change according to varying timescales. Properties such as bulk density, porosity, infiltration rate, permeability, nitrate content and composition of soil air can change on a daily basis, depending on the weather. In contrast, weathering of minerals and changes in soil texture can take place over a millennial time. The effect of climate change will be to modify the rates of soil processes and lead to changes in soil properties, with a range of implications for soil development, and the way in which soils can be used. Its potential impact on some of the major processes and properties is described in NSRI (2005).

Changes in soil moisture are recognised as the most significant results of climate change and also the least quantified. Areas predicted to have warmer temperatures and less rainfall will have less soil moisture, with potentially large implications for the crops that can be grown and the natural and semi-natural ecosystems that can be developed and then continue to exist. The temporal nature of changes in climatic variables is also particularly important, for example less soil moisture in summer, more soil moisture in winter. Areas that are likely to experience increased droughtiness may also find that buildings, roads etc, built to particular specifications relating to current conditions, have foundations which become unstable as soils dry out. In the urban, built environment, little has been done to study the effects of climate change on pollutant linkage, either through enhanced movement in contaminated substrates, or through flooding. There may be a need to develop further soil manufacture methodologies based on remediated and organic waste materials, given an increasing reliance on plant available water stored in the profile to support vegetation during the growing season. The ability of soils to hold and buffer contaminants and pollutants, particularly 'brownfield' soils may be affected by increases in temperature and changing rainfall patterns.

Soil organic matter is arguably the most important soil component in terms of responding to climate change, influencing soil structure, water holding capacity, soil stability, nutrient storage and turnover and oxygen-holding capacity, and it is a key part of food chain for soil fauna. These properties are fundamental in maintaining and improving soil quality. A decline in organic matter content also increases the susceptibility to soil erosion.

It is, however, difficult to predict what the effect of climate change will be on soil water at *regional* or *local* level, given the many different interacting influences on soil moisture levels. This difficulty is accentuated because soil water content is highly variable in space, with different impacts identified in different parts of the UK (Hollis and others 2005). Three major projects (RegIS, VULCAN and MONARCH) help inform what is likely to happen to existing habitats under climate change scenarios.

The aim of the RegIS project (Holman & Loveland 2001 www.silso.cranfield.ac.uk/iwe/projects/regis ) was to enable stakeholders to assess for themselves the impacts of future climate change on the agriculture, biodiversity, hydrology and coasts of East Anglia and the North West of England. In particular this involved the development, calibration and validation of simple models based upon simulations using existing impact models, which were then used to analyse the range of possible adaptive responses and the influence of future policy and socio-economic scenarios upon that response.

The future of the habitat appears to depend much more on the species under consideration than the soil. If the dominant species continue to find suitable climate space, as is the case in upland hay meadows, blanket and raised bog and cereal field margins, then it could be assumed that the habitat would continue in existence, but with a slightly different species composition. Salt marsh and fens, however, show a mixed species' response.

Some areas of salt marshes in East Anglia could also be lost to sea level rise and this, combined with the loss of potential climate space for some species, could mean that the habitat undergoes significant changes in the future. Lowland heathland in East Anglia should be able to maintain its species composition, but its existence is under pressure from agriculture (from atmospheric pollution, not from direct loss). The cereal field margin species, however, are more dependent on cropping practices, while the upland hay meadows would be affected by moves away from low intensity agriculture. Changing water levels are an issue for both blanket and raised bogs and fens, with changes for the latter habitat exacerbating simulated stresses from the direct effects of climate change for certain species. Climate change, therefore, has wide-ranging implications for both species and habitats in the two regions.

**VULCAN** (Vulnerability assessment of shrubland ecosystems in Europe under climatic changes) is an EU project investigating the effects of changes in the climate on the functioning of shrublands in order to support political decisions as well as management practices to sustain the quality of this habitat type in Europe (www.vulcanproject.com). Whilst risk assessments have been undertaken in other sectors for many years, they are only recently being utilised to aid conservation management. The work in VULCAN represents the first attempt to formulate a comprehensive risk assessment for shrub and heath lands at a European scale.

The **MONARCH** (Modelling Natural Resource Responses to Climate Change) (Berry and others 2005) programme has sought to advance the science and understanding of the potential impacts of climate change on biodiversity. This has been done by downscaling the resolution of the modelled climate and land cover suitability surfaces and has extended the scope of modelling to consider the role of land cover, the potential for dispersal and impacts on community structure (see www.english-nature.org.uk/science/climatechange/resources amongst others).

# 5 Other options – restoration of soil properties for habitat creation

There is a complex set of interrelationships between living and non-living components, driving the structure and function of soil ecosystems. The process of soil formation is never ending; there will always be a dynamic interaction between water, air, biology and minerals. Materials, whether solid or in solution, arriving from elsewhere, will continue to drive and shape the changing nature of the soil.

When considering a restoration scheme, objectives for the vegetation and faunal communities should ideally be based on the existing soils on site. However, these soils may be so degraded that soil restoration in some form is required. Deciding on objectives for the site will be important as this will determine what needs to be done in terms of how to handle and manage soils on site. However, restoration of soil properties should only be considered as a last resort. Where possible, attempts should be made to work with existing conditions.

## 5.1 The differences between inherent and in-situ properties

The *inherent* properties of the soil, for the purposes of this report, are those which persist when the soil is removed for analysis or handled during earthworks, and principally consist of the following:

- Textural class
- Organic matter content
- Chemical characteristics
- Mineralogy

The *in-situ* characteristics of the soil (which are changed, to varying degrees, when the soil is disturbed) include:

- Pore size distribution
- Soil structure
- Bulk density
- Hydrological characteristics
- Soil biology
- Horizontal and vertical distribution and extent

*In-situ* characteristics are usually the most readily changed – for example, by manipulation of the water table or drainage depth of the profile. Inherent characteristics, such as total nitrogen, are much more difficult to manipulate, and may take a long time to change. However, without this understanding, target plant communities may never be achieved. It is usually inappropriate to change fundamental characteristics such as pH unless it is aimed at restoring the soil to its original condition, for example by ceasing liming applications (there have been some attempts to speed this process up, by the addition of sulphur). In such cases it is more appropriate to choose species which suit the soil, topography and hydrology, not *vice-versa*.

In summary, it is important to determine what the current characteristics of the soils on site are, and what target ranges for inherent and in-situ characteristics are required to establish the target vegetation community.

## 5.2 The importance of soil biology

Without the action of living organisms there would be no such thing as soil. Primary colonisers of bare rock, such as lichens, secure a foothold in the rock and accelerate the process of weathering, leading to the production of finer materials and nutrients. This allows the establishment of more complex pioneer plants to also gain a foothold and therefore further accelerate the process. This continues with the process of succession, until the climax stages of vegetation are reached with its typical soil type. In many cases this is woodland or peatland, dependant on the moisture regime.

Central to the formation of soil is the process of *bioturbation* which involves the interactions between animals, plants, micro-organisms and mineral material. Through this process the fabric of the soil is altered by detachment, transport, ingestion, sorting and deposition both within, and on, the surface of the soil.

The soil biological community is therefore key to the sustainable function of soils. Earthworms generate and maintain structure; fungal symbionts are critical for establishment of certain plant species; and faunal groups such as ants may have an essential role to play in the life-cycle of other species, such as butterflies.

It is usually not possible to re-instate a soil community in a single step by a simple physical intervention or re-introduction. Therefore, it is essential to preserve it where possible and then design management options to manipulate conditions to encourage the establishment and integration of different biotic groups with the non-living components of soil. Examples of such strategies vary from direct innoculation with mycorrhizal spores, through to translocating intact blocks of soil to retain as much of the soil community as possible. Monitoring over time may be required to assess whether the development of a fully functional ecosystem has been achieved. Time is an important factor in soil development.

## 5.3 Soil sourcing where original soils have been lost

Where possible, it is desirable to conserve soil resources on site. When insufficient material of the correct sort is available, then it may be possible to **source materials off-site** or bring in amendments to add to the soil-making materials readily available. For example, there are opencast sites lacking in any top-soil materials, where sub-soils and overburden have been amended by the addition of sewage sludges or other biosolids, which have succeeded in establishing tree growth. There are various forms of guidance available for making this kind of decision, for example the ROOTS software (developed by English Partnerships and the Forestry Commission) and Defra (2004).

The control of **pH** on degraded sites is frequently a first step in the process of restoration, particularly when the handling procedures have caused the anaerobic decomposition of organic materials, or a soil substitute of inappropriate pH is used as "clean fill" (for example construction and demolition rubble). It would be better not to use these substrates in the first place, but often they are all that is available. For example, acid clays are often used as an impermeable cap on landfill covers, and the plants can experience a pH drop from around neutrality at the surface (due to the presence of construction and demolition rubble) to 3.5 in the thin depth of cover (no more than two and a half feet in most landfills). This puts a great stress on the plants ability to absorb nutrients whilst attempting to maintain internal solute gradients. pH can be altered by applying specific chemicals to the soil, eg lime to reduce the pH, and also via management of the soils. An additional factor in the control of pH which can have additional benefits on soil texture and structure, can be organic matter in the form of compost or well rotted manure.

Additional methods for the restoration of key soil properties are explored in Chapter 6. While focussing on heavily modified agricultural soils, these techniques have wider applications.

## 5.4 Soil restoration at extraction sites

Where minerals are extracted from a considerable depth, waste products are often piled in large heaps at the surface. A far more fundamental change in the soil occurs where the extracted material is only a few metres below the surface. This is how, for example, coal and gravel are extracted in parts of Britain. Extraction starts by removing the overburden of topsoil, subsoil, regolith and unweathered rock. What happens to the overburden depends upon the projected use of the site after extraction has been completed. This is another of the many choices facing the user of land. In some cases the excavated hole may fill with water and be used for recreation. Here the developer must dispose of the overburden in the best possible way, perhaps by selling the topsoil to developers and using other material as infill elsewhere. Alternatively the site may be returned to a condition similar to that which prevailed before extraction.

Habitat restoration following mineral extraction and soil handling is dealt with by www.goodquarry.com . This open-access web site is intended for anyone with an interest in minimising the environmental impact of surface mineral workings, including quarries, gravel and clay pits and opencast coal mines.

## 5.5 Soil handling, storage, and re-instatement procedures best practice

Any damage already caused by site history will be severely exacerbated by poor handling, storage, and re-instatement procedures. There is a considerable amount of evidence of the effects of soil handling procedures. Some general rules of thumb include:

- keeping soil handling to an absolute minimum with single operations being the most desirable;
- not moving soils when wet, and certainly not above their plastic limit;
- avoiding trafficking with heavy equipment;
- keeping stores as shallow as possible (this is particularly important for finer textured soils as they will become anaerobic quickly if quite close to the surface).

If soil has to be moved and stored, and this is sometimes unavoidable, then it inevitable that there will be impacts on the soil biological community. For example:

- invertebrate populations will be largely destroyed, and may take many years to recover;
- a narrow range of plant species will tend to persist in store as seeds, reducing the utility of the buried seed bank;
- there will be a build up of ammonium within the store, particularly in fine-textured soils, which will tend to be converted to nitrate on re-instatement – this may cause off site problems if not controlled by interceptor drains and storage lagoons; and,
- soil structure will be largely lost, with a concomitant increase in bulk density.

All of these effects will have to be addressed in the restoration programme, by a combination of cultivation and groundwork techniques. Even without storage, soil structure will have been adversely affected, and will need careful management. However, in some instances this may be an advantage – for example, on former arable sites, compact, poorly drained soils will make re-establishment of wetlands easier.

## 5.6 Other mechanical operations

Various techniques of soil loosening may be employed, aimed at reducing compaction at a gross level. Deep tine cultivation to rip the sub-soil/top-soil interface may be followed by ploughing and disking to achieve a seed bed. This can be critically important for establishing plant growth.

Once re-instated to the desired profile, poorly structured soils will require careful management with regards to the hydrology of the site and the re-integration of the top- and sub-soil layers, until soil structure approaching that of an undisturbed target site can be achieved. The principal methods used in this respect are mole drainage, semi-permanent drains and ditches. If wetlands are to be created, however, drainage infrastructure may still need to be retained, but its management amended.

## 5.7 Aftercare/long term considerations

Restoration of the soil system is often not a one-off operation. Regular monitoring will need to be carried out to check on the progress of the restoration. Further management may be required.

Management is likely to be required whatever the habitat created is and this can vary from grazing, cutting and burning, to water level management (see section 3.2). For example, in woodland this can include replacing dead trees, interventions in the under-story after canopy closure to establish a desirable ground flora, and inoculation with symbionts or whole communities from established plots.

# 6 Heavily modified agricultural soils and habitat restoration

Heavily modified agricultural soils, whether with a history of tillage for arable cropping or intensive use as productive grassland, cover a large percentage of lowland Britain and hence provide a large potential resource for habitat creation. Although intensive agricultural use may have impacted many of the soil's properties, the effects can often be mitigated or reversible given time, and habitats with nature conservation interest can be established. However, it is important in these situations to address the soil issues at the outset of the restoration process, because devoting resources to other aspects may be ineffective if the soil conditions are inappropriate for the target habitat. Although the primary focus of this section is on agricultural soils, the principles apply to a greater or lesser extent to all soils.

## 6.1 Issues

Seven aspects of agricultural soil which are likely to have been impacted by their past intensive use are addressed below:

### 6.1.1 Nutrient availability and pH

Soil chemistry is one of the most important factors to assess prior to embarking on a habitat restoration scheme. If nutrients are too readily available, only the most vigorous and competitive of plant species will prevail, thus creating species-poor vegetation lacking many of the components necessary to support a diverse fauna. Agricultural soils tend to be rich in all major nutrients (compared to soils beneath semi-natural habitats) and their pH tends to be greater than 6.0 as a result of past fertiliser, slurry, lime and/or slag applications. Fertiliser application can lower pH leading to the need to apply lime.

### 6.1.2 Soil structure and organic matter content

The air content of soils is critical for good ecological functioning in many habitats and this in turn relies on the presence of a range of pores sizes within the soil. Agricultural management, through a combination of mechanised tillage, trafficking with heavy loads and/or frequent trampling by livestock, often results in a reduction in pore size. This is exacerbated if the tillage results in soil aggregates being broken up exposing their organic fraction to oxidation by microbes. The resultant loss of organic fraction within the soil further destabilises its ability to maintain large open pores.

### 6.1.3 Water regime and drainage

Loss of soil structure through intensive tillage and loss of soil organic matter will reduce the infiltration rate of the soil and increase its risk of waterlogging following storm events. Farmers overcome this on susceptible soils through the use of an artificial sub-surface drainage network. This, however, only works if the soil itself allows water to infiltrate. If land is taken out of agriculture and the drainage infrastructure not maintained, then some soils that may not have been liable to waterlogging while under agriculture may develop a tendency to hold water on the surface, which can lead to overland flow and possible erosion.

### 6.1.4 Microtopography

Fine scale humps and hollows often characterise the soil surface beneath stands of semi-natural vegetation. They may be natural features from the last glaciation (pingoes, moraines etc), of animal origin (anthills, molehills, badger sets etc), or they may be historic features (earthworks, dewponds, drainage lines etc.). Intensive agricultural management usually involves these features being flattened by ploughing. Indeed specialist agricultural equipment may have been used to obtain a perfectly flat surface to maximise the efficiency of high-value crops such as salads. The result is a degree of uniformity that restricts the potential diversity of niches for target species to fill and therefore impedes the subsequent development of a species-rich vegetation.

### 6.1.5 Microbial communities

The diversity of microbial communities is enhanced by stable soil structure, high organic matter content and diverse vegetation. In intensively tilled soils, the soil structure and high organic matter content are diminished and the use of monoculture cropping, whether arable or grassland, diminishes the diversity of the vegetation. Therefore, it follows that heavily modified agricultural soils generally support an impoverished microbial community, which in turn may form a constraint to the re-establishment of diverse semi-natural vegetation as part of a restoration exercise.

#### 6.1.6 Soil fauna

Related to the point above, the community of soil animals (moles, earthworms, springtails, insect larvae etc.) is usually impoverished as a result of intensive agricultural management. Sometimes the animals have been targeted as “pests” (for example moles), deprived of their food source (surface plant litter in the case of many springtails) through mechanical churning of the soil (for example earthworms), or negatively impacted by agrochemicals (not only arable insecticides but also those such as avermectins which are applied to grazing animals and can be persistent in their dung and hence the soil).

#### 6.1.7 Seed banks

The soil is a rich source of plant propagules, but the species within the bank are usually dominated by those that specialise in colonisation of bare soils (arable weeds, rushes and creeping grasses, the latter being represented by sections of rhizome rather than seeds.) The target species of semi-natural vegetation often do not have a persistent seed bank. That is to say their seeds cease to be viable after just two or three years. This is particularly the case for species-rich grasslands and for woodlands. Even if the original vegetation were lost to agriculture only five years before, there is little hope that the plant community will reassemble itself from the soil’s seed bank. If the target is to allow a community to reassemble itself, dispersal from another local source needs to be encouraged.

### 6.2 Possible soil management options

At the start of a restoration scheme aimed at transforming a formerly intensive agricultural system into a habitat with semi-natural vegetation, each of the factors above should be taken into account and actions to ameliorate the soil environment taken where appropriate. It is worth considering, however, whether it is more appropriate instead to allow natural biological and geophysical processes to adjust the soil factors over time.

#### 6.2.1 Nutrient availability and pH

This is usually the most important constraint to habitat restoration (see Defra Technical Advice Notes (TAN) 21 and 26) ( www.defra.gov.uk/rds/publications ) and needs consideration in all cases. The target soil pH range for the desired habitat first needs to be established, followed by a decision on whether to allow natural regeneration or to intervene to reduce nutrients and pH. Sources such as Ellenberg Indicator Values (Ellenberg, 1988), the Habitat Creation Model (Gilbert and others 1996) or the “British Plant Communities” series (Rodwell, 1991 *et seq*.) should be consulted. Soil pH can be directly altered by chemical application (lime to raise pH or sulphur to reduce it) however the quantities required are dependent on the buffering capacity of the soil. Again the Habitat Creation Model or the Fertiliser recommendation handbook (MAFF, 2000) can give a guide based on soil type together with TAN 21 and 31.

In terms of soil nutrients, the first task is to assess the current status of the soil. Phosphorus availability is regarded as the most useful measure of soil fertility and the Olsen extraction method is the most frequently used to test it. Whilst nitrogen is often the most important single soil nutrient, its availability in the soil is so variable, both in space and in time, that nitrogen availability results are hard to interpret. Another reason for focussing on phosphorus is that excess soil available nitrogen is usually lost from the soil over a relatively short period following cessation of fertiliser application, whilst phosphorus is much more persistent and therefore a more intractable problem. To assess phosphorus availability, a representative sample from the site should be sent for analysis. A soil laboratory will provide a value for Olsen extractable phosphorus, which can then be compared to quoted ranges in the Habitat Creation Model or in ecological journals (for example Tallowin 1998).

Once the extent of any problem has been established, there are a number of possible avenues, bearing in mind that interim or transitional phases can be important parts of the process.

- Do nothing, if availability is close to the target range.
- If the availability is up to twice the target range, then harvesting biomass from the site is the simplest way of depleting the soil reserves of extractable phosphorus. A hay crop taken from a site will typically remove 10 kg of phosphorus per hectare. The rate at which the soil availability declines is a function of the soil's ability to buffer this loss from less soluble phosphorus pools. Clay soils often contain a large pool of poorly-soluble phosphorus, which may take decades to deplete through biomass removal, whilst sandy soils may be depleted in just a couple of years. Perversely the addition of nitrogen-only fertilizer can speed the process. Soil biological processes can also change the nutrient status of the soil. Applications of chemicals to the soil can affect these processes.
- If availability is considerably higher than twice the target, it is worth reviewing the project objectives to check whether they are appropriate to this site. More extreme interventions can be considered, if appropriate. Actions such as the stripping of topsoil, inversion of the profile or addition of chemicals to bind soluble phosphorus may assist. For instance, the practice of stripping the top 10 – 20 cm of topsoil to reduce N and other nutrient content has been used. However it can conflict with the objective of preserving as much of the original soil as possible. It may also need planning permission as part of the decision-making process that decides what to do with soil and there may be impacts on archaeology. An alternative technique being pioneered in the UK by the Landlife centre in Liverpool is the use of the "deep inversion plough" (www.woodland-wildflowers.org.uk/bng/bngindex.htm). This plough, developed in Denmark, inverts a layer up to 1 m deep, bringing the subsoil to the surface, and thus a reduced nutrient load. This has met with some success, but the long-term consequences of burying the nutrient rich layer and the danger of anaerobism and iron-pan formation are not yet clear. These actions will have significant impacts on soil biology and other soil processes.
- In high pH soils, lime can be used, whilst in low pH soils, aluminium or iron salts may be effective, but advice must be sought to avoid pollution of local water courses.

Some guidance on all these approaches can be found in the Habitat Creation Model (Gillbert and others 1996).

### 6.2.2 Soil structure and organic matter content

Damage to soil structure is not easy to reverse actively. It is best left to redevelop naturally, but there are some actions which can assist:

- Minimise any tillage operations or trafficking across the soil. Where agricultural operations are required, such as biomass harvest, ensure they are done when the soil is dry.
- Avoid stock trampling the soil whilst it is wet.
- Use a fine-rooted crop such as a mixture of meadow grasses or a deep-rooted crop to help structure the soil.
- If hard impermeable layers have developed in the profile as a result of ploughing (plough pans), then a sub-soiler can be used to break them up.
- Unless the target vegetation is a swamp or aquatic community, prolonged periods with surface water or saturated soil should be avoided. Drainage infrastructure should be maintained because well aerated soil restructures itself more rapidly than anaerobic soil.
- Subsoiling may help.

### 6.2.3 Water regime and drainage

Assisted drainage may be necessary whilst soils restructure themselves. It is often helpful to maintain the existing agricultural drainage infrastructure, at least for the initial period of habitat restoration. Once the water regime of the target vegetation has been established (Gowing and others 2002; Wheeler at al., 2005), then the drainage infrastructure can be modified appropriately. It should be borne in mind that few hydrological systems in the UK function "naturally", so it is necessary to consider water management in any restoration scheme.

### 6.2.4 Microtopography

Microtopographic variation can be readily re-established using land-forming machinery. However, before undertaking such work, one should consider the requirements of the target vegetation and the practicability of its subsequent management.

### 6.2.5 Microbial communities

Microbial communities require time to restructure just as the soil itself does – indeed the two things are closely connected. An interim vegetation of mixed grasses and herbs during a nutrient-stripping period may assist the microbial community to diversify, as will simply stopping artificial inputs.

### 6.2.6 Soil fauna

Cessation of pesticide and fertiliser application will allow the soil fauna to recover. Again a mixed grass and herb cover in the initial years will provide surface litter and encourage a return to more natural soil functioning. Grazing animals will help speed up the nutrient cycling and create more niches for soil fauna.

### 6.2.7 Seed banks

Seed banks are a potential problem as they will often produce non-target vegetation. Sowing a temporary grass cover and managing this through cutting (for biomass removal) or grazing (for soil fauna promotion) will also act to suppress the seed bank and persistent weeds (docks, thistles, nettles etc.) After an interim period, the initial grass cover could be removed and the target vegetation allowed to develop either through natural regeneration or by the introduction of seed sources from local sites (heather, green hay etc.). Other methods of assisting dispersal can include permitting flood waters to cover the site as they are an effective delivery mechanism for seeds or planting some pioneer shrubs (such as hawthorn). Such shrubs will grow quickly, providing roosts for birds who in turn can introduce a range of local seeds in their droppings.

# 7 Conclusions

The key message throughout this report is to try and work with existing conditions on site, rather than potentially unnecessarily altering the site when carrying out habitat restoration projects. Soil type and properties should be a key part of site research and surveys, and the information gained should form part of the decision making process for objectives.

A desk-based study should look at the history of the site and potential impacts on restoration options. It is essential that an understanding of soil types and their characteristics is part of the decision-making process and the objectives of restoration must be defined based on what is possible on a particular site. The desk-based study must also look at the history of site, influencing factors (such as archaeology, water courses or groundwater impacts), its context and linkages within the wider environment, local BAP targets and characteristic habitats in the surrounding area.

Restoration of the soil ecosystem is not a one-off operation. Regular monitoring and adaptive management will need to be deployed to check on the progress of the restoration and to correct any deviation from the desired restoration trajectory. Management is likely to be required whatever the habitat restored or created.

The following reference and further information sections provide more information on the topics discussed.

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# 9 Further reading

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COSTANZA, R., and others. 1997. The value of the world's ecosystem services and natural capital. *Nature,* 387: 253-260.

DE GROOT, R.S., WILSON, M.A. & BOUMANS, R.M.J. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41 (3), 393-408.
An academic paper presenting a conceptual framework and typology for describing, classifying and valuing ecosystem functions, goods and services. (Highlights the importance of soil retention and formation functions in regulating ecological processes and life support systems).

EHRLICH, P.R. & A.H. EHRLICH. 1981. Extinction: the causes and consequences of the disappearance of species. New York: Random House.

HOLDREN, J.P. & EHRLICH, P.R. 1974. Human population and the global environment. *American Scientist*, 62, 282-292.

### 9.2.4 Soil analysis

RURAL DEVELOPMENT SERVICE. 2003. Soil sampling and analysis for habitat re-creation and restoration in agri-environment schemes. *Technical Advice Note 20*, Defra. Available from: www.defra.gov.uk/rds/publications/technical/tan_20.pdf
A technical advice note providing guidance on the soil sampling methodology required to determine whether a site is suitable for habitat restoration and the appropriate target habitat.

RURAL DEVELOPMENT SERVICE. 2005. Soils and Agri-environment Schemes: interpreting soil analysis for habitat creation/restoration. *Technical Advice Note 31.* Defra. Available from: www.defra.gov.uk/rds/publications/technical/tan_31.pdf
A technical advice note covering the general interpretation of soil analysis result for Agri-environment schemes. (Highlights the importance of knowledge of soil properties in the consideration of sites for habitat re-creation or restoration, particularly soil nutrients).

SOIL SURVEY – mapping and analysis techniques:
*Soil Survey Field Handbook* (Ed. J.M. HODGSON) Third Edition
*Soil Survey Laboratory Methods* (Ed. B.W. AVERY and C.L. BASCOMB)
*Soil Survey Applications* (Ed. M.G. JARVIS and D. MACKNEY)
*Criteria for Differentiating Soil Series* by B. Clayden and J.M. Hollis
*Soil Survey Methods: A Review* by B.W. Avery
Available from: www.silsoe.cranfield.ac.uk/nsri/services/publicationslist.pdf

TRUDGILL, S. 1989. Soil Types: A field identification guide. *Field Studies*, 7 (1989), 337-363. Field Studies Council.
A key to basic soil types, written for use in the field.

## 9.3 Habitat restoration – general concepts

ANDERSON, P. 2003. *Habitat translocation - a best practice guide*. C600 London: CIRIA.
A comprehensive guide to habitat translocation including the planning, design, construction, management and ecological monitoring stages and the risks involved. *(Soil management issues are addressed in a number of different sections and include the ecological impact of translocation on soil, the effect of soils on choosing a receptor site, monitoring soils and specific techniques involved in habitat translocation).*

BAKKER, J.P. and others. 2000. How to define targets for ecological restoration – Introduction. *Applied Vegetation Science*, 3, 3-6.

BRADSHAW, A.D. 1996. Underlying principles of restoration. *Canadian Journal of Fisheries and Aquatic Sciences,* 53 (1), 3-9.
A general academic paper on the principles of restoration and the importance of focusing on the restoration of functions and processes. Provides a basic introduction to the terms used and issues to consider. *(Although not directly related to soil management within habitat restoration projects, some related issues are raised such as soil compaction and excess nutrients).*

DRYDEN, R. 1997. *Habitat Restoration Project: Fact sheets and bibliographies.* No. 260, Peterborough: English Nature.
A series of fact sheets and bibliographies produced for English Nature's Habitat Restoration Project. The report identifies the information needed to start a habitat restoration project and details on where to find further information. The subjects covered include general information about habitat creation, heathland, woodland, grassland, wetland, linking habitats and enhancing arable land. *(An easily accessible and clear document on planning and implementing habitat restoration projects with extensive bibliographies. The majority of sections highlight habitat-specific issues relating to soil condition and fertility but more in-depth documents would need to be consulted for more detailed information).*

GILBERT, O.L. & ANDERSON, P. 1998. *Habitat Creation and Repair.* Oxford: Oxford University Press.
A practical guide aimed at ecologists, landscape designers and developers addressing the issues surrounding habitat creation, including project planning, design and implementation. Separate chapters discuss specific habitats and relevant techniques. *(Useful section on soil factors to take into account when designing new habitat creation schemes, mainly relating to nutrient status. Brief discussion of habitat specific soil issues for grasslands, heath and moor, and wetlands).*

GRIFFITHS, G., and others. 2004. The Living Landscapes Project: landscape character and biodiversity. *English Nature Research Reports*, No 475. Available from: www.englishnature.net/pubs/publication/PDF/475.pdf
An English Nature Research Report describing the progress of a number of developments in the techniques of Landscape Character Assessment and its use in assessing the potential for habitat conservation and re-creation. (Incorporates the use of soil data in the methodology for landscape character mapping but is not discussed in great detail and is not directly related to habitat restoration projects).

HARRIS, J.A. 2003. Measurements of the soil microbial community for estimating the success of restoration. *European Journal of Soil Science*, 54, 801-808.
A review paper of the principles and methods involved in assessing land degradation by measuring the soil microbial community.

HARRIS, J.A., BIRCH, P. & PALMER, J. 1996. *Land restoration and reclamation; principles and practice.* Harlow: Longman Higher Education. ISBN 0-582-24313-0.

HARRIS, J.A. 1999. The Pedosome: Keystone of Ecosystem Construction. *Ecological Restoration,* 17, 1 & 2; 39-43.

HARRIS, J.A., GROGAN, P. & HOBBS, R. 2005. Restoration ecology and the role of soil biology. *In*: BARDGETT, R., USHER, M. & HOPKINS, D. *Biological diversity and function in soils.* Cambridge: Cambridge University Press.
This book chapter illustrates below-ground measurements commonly made in reclamation programmes and provides a general introduction to the role of soil biodiversity in restoration ecology. (Outlines the importance of soil biota in different types of land degradation and discusses potential mechanisms of plant-soil biota-ecosystem interrelationships drawn from wider literature on facilitation and inhibition).

HOBBS, R.J. & HARRIS, J.A. 2001. Restoration ecology: Repairing the Earth's damaged ecosystems in the new millennium. *Restoration Ecology*, 9, 239 - 246.

MARRS, R.H. 1993. Soil fertility and nature conservation: theoretical considerations and practical management solutions. *Advances in Ecological Research*, 24: 242-301.
A useful overview.

LUNN, J. 2001. Wildlife and mining in the Yorkshire coalfield. *British Wildlife,* 12, 318-26.
A review of the wildlife value of brownfield sites in post-mining landscapes and how natural patterns and processes can be used to improve sustainability in restoration.

MITCHLEY, J., BURCH, F. & LAWSON, C. 1998. Habitat Restoration Project: Development of monitoring guidelines. *English Nature Research Reports,* No 284.
An English Nature Research Report describing the development of a methodology for monitoring the extent to which restored habitats are likely to contribute towards enhancement of biodiversity in two trial areas in southern England. (No direct relevance to soil management issues but separate sections on specific habitats and target species).

MITCHLEY, J., BURCH, F., BUCKLEY, P. & WATT, T.A. 2000. Habitat Restoration Monitoring Handbook. *English Nature Research Reports*, No 378.
A handbook describing the monitoring programme developed by English Nature to record the establishment and development of restored habitats in the context of the Biodiversity Action Plan. This document highlights the necessary considerations in the following stages of the monitoring methodology; preparing habitat restoration monitoring prescriptions, preparing field recording forms and carrying out habitat restoration monitoring.

NSRI. 2006. *Soilscapes Viewer.* Available from: www5.landis.org.uk/soilscapes/

NATIONAL URBAN FORESTRY UNIT. 2003. *Urban Forestry in Practice*. Case Study 40. Wolverhampton.
An illustration of how the Outwood project (Rodwell, Wildsmith & Cartwright 1998) provides best practice guidelines for community led-habitat restoration.

PARKER, D.M. 1995. *Habitat creation - a critical guide.* English Nature.
A comprehensive report by English Nature addressing all aspects of habitat creation, including planning, objectives and relevant data sources. Includes a number of comprehensive checklists for various stages of the project and case studies. Separate chapters address specific habitats; grassland, woodland and scrub, heathland and moorland, peatlands (fens and bogs), urban sites. *(Describes the importance of including soil considerations in the planning process, such as soil type and soil fertility. Habitat specific sections highlight relevant soil management issues).*

PASTOROK, R.A., and others. 1997. An ecological decision framework for environmental restoration projects. *Ecological Engineering*, 9 (1-2), 89-107.
An academic paper highlighting the importance of careful planning and monitoring of ecosystem restoration projects and presents an ecological planning framework for such projects. (No direct relevance to soil management issues but a useful document addressing the importance of setting appropriate objectives, consideration of uncertainties in site processes, guidelines for project design and feasibility, monitoring and adaptive management of restoration projects in general).

PYATT, G., RAY, D. & FLETCHER, J. 2001. *An ecological site classification for forestry in Great Britain.* Bulletin 124. Edinburgh: Forestry Commission.
A description of the Ecological Site Classification Decision Support System (ESS-DSS) methodology for identifying the ecological potential of sites for different tree species and woodland communities in Britain. (The 3 principal factors incorporated in the system are climate, soil moisture regime and soil nutrient regime and this report describes the importance and factors involved with these. A comprehensive document for forestry but some principles may be useful for planning habitat restoration projects, with large sections of the report focussing on soil considerations).

RODWELL, J.S. & DRING. J. 2000. *Using the National Vegetation Classification for Changing Places.* Lancaster University Unit of Vegetation Science report for Groundwork UK.

RSPB. 2001. *Futurescapes: large-scale habitat restoration for wildlife and people*. Sandy: The Royal Society for the Protection of Birds.
Highlights the need for, and benefits of, habitat restoration in the UK and provides case studies of a range of habitats, including lowland heathland, wet grassland and ancient woodland. (Provides a checklist of best practice for restoration projects, including the consideration of soils).

SCOTTISH NATURAL HERITAGE. 2002. Soil restoration and nature conservation. *Information and Advisory Note*, Number 150. Available from:
www.snh.org.uk/pdfs/scottish/soils1.pdf
An accessible document describing the general principles and guidelines for successful restoration of soil for nature conservation. Also highlights problems associated with soil restoration. *(Much of the content can be related to soil considerations needed for planning and implementing habitat restoration projects)*

SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL. *The SER International Primer on Ecological Restoration.* Available from:
www.ser.org/pdf/primer3.pdf
An introductory document on ecological restoration, incorporating definitions, explanations of concepts, monitoring and planning restoration. *(Not directly related to soil but a useful overview of restoration principles).*

SPEIGHT, L.B. 1990. *Lofthouse Colliery Heather Trials*. Wakefield: Ecological Advisory Service Report.
An example of how semi-natural vegetation might be restored on brownfield colliery waste with low-intervention and sustainability costs.

SUTHERLAND, W.J. 2002. Restoring a sustainable countryside. *Trends in Ecology & Evolution*, 17 (3), 148-150.
A general document addressing agri-environment schemes and large-scale habitat restoration projects. (Not specific to soil management but highlights restoration issues relating to agricultural land, including climate change).

THOMAS, R. 2000. English Nature Habitat Restoration Project: Final Report. *English Nature Research Reports,* No 377. Available from:
www.english-nature.org.uk/pubs/publication/PDF/ENRR377_1.pdf
www.english-nature.org.uk /pubs/publication/PDF/ENRR377_2.pdf
www.english-nature.org.uk /pubs/publication/PDF/ENRR377_3.pdf
www.english-nature.org.uk /pubs/publication/PDF/ENRR377_4.pdf
www.english-nature.org.uk /pubs/publication/PDF/ENRR377_5.pdf
The final report for English Nature's Habitat Restoration Project, summarising the work of the project between 1996 and 2000. The project was set up to review the extent of wildlife lost from the countryside and trial methods to restore and create new habitats.

THOMPSON, T.R.E. 1979. Soil Surveys and Wildlife Conservation in Agriculture Landscapes. *In*: JARVIS, M.G. & MACKNEY, D. *Soil Survey Applications*, 184-190. Harpenden: Soil Survey of England and Wales.
Paper reviewing aims for conservation by various bodies involved and potential contribution of soil survey data. (Includes a brief introduction to the application of soil survey data to the creation of new habitats, highlighting relevant issues and a number of important references

for further information. However, more detailed and up-to-date information may be more appropriate).

TOMER, M.D. & JAMES, D.E. 2004. Do soil surveys and terrain analyses identify similar priority sites for conservation? *Soil Science Society of America Journal,* 68, 1905-1915.
An academic paper examining the correlation between soil survey delineations and terrain parameters that could be used for similar purposes in resource assessment and targeting conservation measures. (Incorporates a range of data sources, specifically soil survey data, for targeting conservation).

### 9.3.1 Toolkits

BENDING, N.A.D., and others. 2003. The development of intuitive software ("ROOTS") to provide a decision support system for the production of custom built specifications for the creation of woodland on disturbed land. *In:* MOORE, H.M., FOX, H.R. AND ELLIOTT, S.. Land Rec.
A paper describing the development of a computer-based decision support system software ("ROOTS"), supported by English Partnerships and the Forestry Commission. The software was designed to produce custom-built specifications for planting and establishing tress in new woodlands on individual sites. (Soil data is used as a primary factor in the decision-support system, requiring the user to input site attributes and soil properties (physical and chemical) collected during site survey. The software also highlights the importance of soil properties on plant growth).

GILBERT, J.C., and others. 1996. *The habitat creation model: a model to assess the viability of converting arable land into semi-natural habitat.* Project CSA 2373 Report to the Ministry of Agriculture, Fisheries and Food, London.
Project report for MAFF-funded project to develop a computer model designed to identify semi-natural habitats appropriate for restoration on different soils and within different climatic areas of England and Wales. Describes the approach and development of the model, including management techniques for habitat restoration and associated costs. (Uses national coverage of soil data and addresses management techniques used to achieve the amelioration of soil conditions prior to habitat creation and long term management of the vegetation, including economic analysis of such techniques).

## 9.4 Habitat restoration – habitat specific

RODWELL, J.S. 1991 et seq. *British plant communities*. Cambridge: Cambridge University Press.
The standard systematic and comprehensive description of the vegetation types of all natural, semi-natural and major artificial habitats in the UK, providing modular accounts of 293 plant communities arranged under major habitats heads in five volumes.
*Volume 1 – Woodlands and scrub*
*Volume 2 – Mires and heaths*
*Volume 3 – Grasslands and montane communities*
*Volume 4 – Aquatic communities, swamps and tall-herb fens*
*Volume 5 – Maritime and vegetation of open communities*

RODWELL, J.S. 2006. *National Vegetation Survey Handbook*. Peterborough: JNCC

### 9.4.1 Wetlands & peatland

GOWING, D., GILBERT, J. & SPOOR, G. 1997. *Conservation of peat soils on the Somerset Levels and Moors.*
Part of a series of investigations into the conservation of peat soils on the Somerset Levels and Moors. This report addresses the annual variation in peat level across an area subjected to a range of water table regimes and summarises the results of the experiment.

GOWING, D.J.G., and others. 2002. *The water regime requirements and the response to hydrological change of grassland plant communities.* Project BD1310 Final report to Department for Environment, Food and Rural Affairs, London.

Morris, J., and others. 1997. *Wet fens for the future: feasibility study phase 2 - a study of the economics, social and soil management implication of creating new wetlands in fenlands.* School of Agriculture, Food and Environment.
A report detailing Phase 2 of the multi-organisation led 'Wet Fens for the Future' initiative. Provides a strategic overview of wet fen creation with particular reference to farming systems, alternative land use, socio-economic impacts and selected soil management issues. (Highlights the chemical, physical and hydrological implications for soil as a result of rewetting agricultural land for wetland creation).

NEWBOLD, C. & MOUNTFORD, O. 1997. Water level requirements of wetland plants and animals. *English Nature Freshwater Series*, No. 5. Peterborough: English Nature.
A guide to the known water level requirements of a range of wetland plants and animals, including effects of drought and seasonality. (Water level requirements based on soil water tables and/or depths of water).

SPOOR, G., GILBERT, J.C. & GOWING, D.J.G. 1999. *Conservation of peat soils on the Somerset Levels and Moors.* Research Report to English Nature, Taunton.
Part of a series of reports addressing the conservation of peat soils on the Somerset Levels and Moors. This report covers water level management recommendations to conserve peat soils. (Not directly relevant to soil management in habitat restoration projects but highlights issues surrounding peat degradation and the conservation of peat soils without the loss of natural habitat).

TREWEEK, J.R., JOSÉ, P. & BENSTEAD, P. (eds.) 1997. *The wet grassland guide. Managing floodplain and coastal wet grasslands for wildlife.* Sandy: The Royal Society for the Protection of Birds.

WHEELER, B.D., and others (Eds.) *Ecohydrological guidelines for lowland wetland plant communities.*
A collection of guidelines focusing on the ecohydrological requirements of communities contributing to features designated as being of European importance under the Habitats Directive and on plant communities supporting breeding or wintering birds of European importance. (Not directly related to soil management issues but addresses some of the issues influencing the hydrological regime of wetlands, such as compaction of soils).

### 9.4.2 Grassland

CRITCHLEY, C.N.R., and others. 2002. Association between lowland grassland plant communities and soil properties. *Biological Conservation*, 105, 199-215.

CROFTS A. & JEFFERSON R.G. 1999. The lowland grassland management handbook 2nd edition. Peterborough, UK: English Nature/The Wildlife Trusts.

GIBSON, C.W.D. & BROWN, V.K. 1991. The nature and rate of development of calcareous grassland in Southern Britain. *Biological Conservation*, 58 (3), 297-316.
An academic paper investigating the features of vegetation characteristic of successional stages from disturbed land to ancient semi-natural grasslands in southern Britain. (Minimal reference to soil but useful for considering restoration of disturbed land to calcareous grassland).

GOWING, D.J.G., and others. 2002. The water regime requirements and the response to hydrological change of grassland plant communities. Project BD1310. Final report to Department for Environment, Food and Rural Affairs, London.

JANSSENS, F. and others. 1998. Relationship between soil chemical factors and grassland diversity. *Plant and Soil*, 202 (1), pp.69-78

MARRS, R.H. 1993. Soil fertility and nature conservation: theoretical considerations and practical management solutions. *Advances in Ecological Research*, 24, 242-301.
A useful overview.

OWEN, K.M., and others. 1999. Soil acidification- the use of sulphur and acidic plant materials to acidify arable soils for the re-creation of heathland and acidic grassland at Minsmere, UK. *Biological Conservation*, 87, 105-121.

PYWELL, R.F., and others. 2002. Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. *Journal of Applied Ecology*, 39 (2), 294-309.
An academic paper examining the key ecological processes limiting the creation of diverse grassland communities on former agricultural land. (Addresses techniques for restoration and the effects on soil fertility across a wide variety of soil types and locations across lowland Britain).

SWETNAM, R.D., and others. 1998. Spatial relationships between site hydrology and the occurrence of grassland of conservation importance: a risk assessment with GIS. *Journal of Environmental Management*, 54 (3), 189-203.
An academic paper presenting a methodology using GIS to quantify the distribution of the nature conservation resource and links this to a hydrological model and database of plant water-regime requirements. Highlights the potential risk for characteristic and scarce vegetation communities as a result of deliberate management to raise water tables. (A technical article highly relevant for soil hydrology considerations in wet grasslands and potential conflicts over the management of the habitat).

TREWEEK, J.R., JOSÉ, P. & BENSTEAD, P. (eds.). 1997. *The wet grassland guide. Managing floodplain and coastal wet grasslands for wildlife*. Sandy: The Royal Society for the Protection of Birds.

WALKER, K.J., and others. 2004. The restoration and re-creation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. *Biological Conservation,* 119 (1), 1-18.
An academic paper reviewing the techniques employed to restore and re-create grasslands on agricultural land in the UK, particularly those used to overcome high soil fertility and seed-limitation. (Provides an in-depth review of literature on soil-related techniques and issues, such as soil fertility and the effects of land management, focussed solely on the restoration of grassland on agricultural land).

### 9.4.3 Heathland

AERTS, R.; and others. 1995. The potential for heathland restoration on formerly arable land at a site in Drenthe, The Netherlands. *J.Appl.Ecol*., 32, 827-835.

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

CLARKE, C.T. 1997. Role of soils in determining sites for lowland heathland reconstruction in England. *Restor.Ecol*., 5 , 256-264

DUNSFORD, S.J., FREE, A.J., & DAVY, A.J. 1998. Acidifying peat as an aid to the reconstruction of lowland heath on arable soil: a field experiment. *J.Appl.Ecol*., 35, 660-672.

EGLINGTON, S. & HORLOCK, M. 2004. East of England Heathland Opportunity Mapping Project. Final Report.
A project report resulting from the development of a GIS-based modelling tool to identify priority areas for heathland re-creation in the East of England, taking into account environmental, social and economic factors. *(Highlights the importance and use of soil type to identify the maximum possible extent of land suitable for heathland re-creation).*

LARSON, P. 1999. Mineral development. A net contributor to heathland in the South-West. *Quarry Management*, March, 39-44.

MICHAEL, N. 1996. *How to select land which is suitable for the re-creation of lowland heathland: a guidance note for conservation advisors and landowners*. Peterborough: English Nature.

PUTWAIN, P.D. & RAE, P.A.S. 1988. *Heathland Restoration: a handbook of techniques*. Southampton: Environmental Advisory Unit, Liverpool University & British Gas.
A review of techniques available for the restoration of upland and lowland heath as well as providing a general introduction to heathland environments and the types of disturbance they are vulnerable to. (Covers topics such as heathland soil profiles, properties of heathland soils (chemical, physical and biological) and the use of heathland topsoil for reinstating vegetation).

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. *Biol.Conserv.*, 70, 169-181.

SYMES, N. & DAY, J. 2003. *A practical guide to the restoration and management of lowland heathland.* Sandy: RSPB.
A handbook offering practical guidance for those involved in the management and restoration of lowland heathland in the UK. The report emphasises the need for adequate survey, monitoring and management planning and presents suitable techniques. *(Brief description of lowland heathland soils but focuses more on vegetation-related management techniques. A good habitat-specific guide in general but soil-related content is limited).*
Walker,K.J. and others. 2004. The importance of former land use in determining successful re-creation of lowland heath in southern England. *Biol.Conserv.*, 116, 289-303

### 9.4.4 Moorland

HESTER, A.J., and others. 2003. *Support for the Moorland Forum: Predicting the potential distribution of key moorland habitats in the Cairngorms area.* Contract No: AB(AC201A)0203148, The Macaulay Institute.
A detailed technical report describing the development of a Moorland Habitat Suitability Model within the Cairngorms area to aid the work of the Moorland Forum established by Scottish Natural Heritage. Uses the same general principles as the Native Woodland Model developed by the Macaulay Institute. (The model uses National soils and land use data containing information on soil moisture, nutrient status, pH, landform, parent material, slope, altitude and current vegetation and incorporates decision rules based on regional soil-forming processes).

### 9.4.5 Woodland

BAILEY, N., LEE, J.T. & THOMPSON, S. (In press). *Maximising the natural capital benefits of habitat creation: Spatially targeting native woodland using GIS.* Landscape and Urban Planning. Corrected proof.
An academic paper addressing the conversion of agricultural land to woodland, incorporating both biodiversity and natural capital benefit considerations. (Highlights the importance of soil type in determining woodland suitability. Also addresses the possible effects on levels of woodland restoration on soil organic carbon and the different responses of various soil types).

HARRIS, J.A. & HILL, T. 1995. Soil biotic communities and new woodlands. *In:* R. FERRIS-KAAN, ed. *The ecology of woodland creation*, 91-112. John Wiley & Sons.

HUMPHREY, J., and others. 2000. *In*: Anon., *The restoration of wooded landscapes*. Heriot Watt University, Edinburgh. Edinburgh: Forestry Commission.
Proceedings of a conference on 'The Restoration of Wooded Landscapes' addressing the theme of native woodland restoration at the landscape scale. Includes sections on UK forestry policies, research and modelling tools, restoration planning and case studies. (No direct relevance to soil management issues but soil data used to identify potential restoration opportunities. Also a number of the papers relate to habitat networks and fragmentation).

LEE, J.T., BAILEY, N. & THOMPSON, S. 2002. Using geographical information systems to identify and target sites for creation and restoration of native woodlands: a case study of the Chiltern Hills, UK. *Journal of Environmental Management*, 64 (1), 25-34.

An academic paper describing a method for spatially targeting the restoration of ancient semi-natural deciduous woodland using a land use database. (Although not directly linked to soil management for habitat restoration, the paper highlights the inclusion and importance of soils data in targeting habitat restoration sites).

MORRIS, S.M., HILL, T.C.J., & HARRIS, J.A. 2003. Soil microbial communities. *In*: HUMPHREY, J., FERRIS, R., & QUINE, C. (Eds). *Biodiversity in Britain's Planted Forests: Results from the Forestry Commission's Biodiversity Assessment Project*, 31-40. Forestry Commission. ISBN 0 82238 608 8.

PETERKEN, G.F., BALDOCK, D. & HAMPSON, A. 1995. A Forest Habitat Network for Scotland. *Scottish Natural Heritage Research, Survey and Monitoring Report*, No. 44. Perth: Scottish Natural Heritage.
A report written for Scottish Natural Heritage introducing the concept of developing a forest habitat network to conserve and enhance the natural heritage of Scotland's forest resource through spatial connectivity. Also includes a number of case studies to demonstrate the local distinctiveness which is essential for the national network. (Direct relevance to soil management issues for habitat restoration limited but a useful text to highlight the importance and feasibility of linking habitats).

PYATT, G., RAY, D. & FLETCHER, J. 2001. *An ecological site classification for forestry in Great Britain.* Bulletin 124. Edinburgh: Forestry Commission.
A description of the Ecological Site Classification Decision Support System (ESC-DSS) methodology for identifying the ecological potential of sites for different tree species and woodland communities in Britain. (The 3 principal factors incorporated in the system are climate, soil moisture regime and soil nutrient regime and this report describes the importance and factors involved with these. A comprehensive document for forestry but some principles may be useful for planning habitat restoration projects, with large sections of the report focussing on soil considerations).

RATCLIFFE, P.R., PETERKEN, G.F. & HAMPSON, A. 1998. A Forest Habitat Network for the Cairngorms. *Scottish Natural Heritage Research, Survey and Monitoring Report,* No. 114. Scottish Natural Heritage.
A case study report for Scottish Natural Heritage focussing on the potential for a forest habitat network in the Cairngorms, including modelling the effects of habitat fragmentation and connectivity. (Direct relevance to soil management issues for habitat restoration limited but a useful case study to highlight the potential for linking habitats).

RODWELL, J.S. & PATTERSON, G. 1994. *Creating New Native Woodlands*. London: HMSO.
A Forestry Commission bulletin providing guidelines for planting tree and shrub mixtures appropriate to particular site conditions and soil types throughout the UK.

TOWERS, W., and others. 2004. *The potential for native woodland in Scotland: the native woodland model.* Perth: Scottish Natural Heritage.
Booklet describing the development and use of the Native Woodland Model developed by the Macaulay Institute to assist in the planning of native woodland expansion in upland Scotland. (Describes the use of soil data in the model, including parent material and base status of different soils; soil nutrient status, moisture regime and depth and landform features which influence proportions of different soil types within complex and heterogeneous landscapes).

### 9.4.6 Coast

ABP RESEARCH & CONSULTANCY LTD. 1997. *Design Scheme for Habitat Creation. R.584(a).*
Focused on intertidal habitat creation schemes but some guidelines on planning and undertaking restoration could be useful for habitat restoration projects in general. *(Takes into account substrate/sediment factors but mainly targeted towards coastal environments).*

TREWEEK, J.R., JOSÉ, P. & BENSTEAD, P. (eds.). 1997. *The wet grassland guide. Managing floodplain and coastal wet grasslands for wildlife.* Sandy: The Royal Society for the Protection of Birds.

## 9.5 Landscape and Biodiversity Action Plan links

### 9.5.1 Landscape linkages including GIS applications

BAILEY, N., LEE, J.T. & THOMPSON, S. (In press*). Maximising the natural capital benefits of habitat creation: Spatially targeting native woodland using GIS.* Landscape and Urban Planning. Corrected proof.
An academic paper addressing the conversion of agricultural land to woodland, incorporating both biodiversity and natural capital benefit considerations. (Highlights the importance of soil type in determining woodland suitability. Also addresses the possible effects on levels of woodland restoration on soil organic carbon and the different responses of various soil types).

BAILEY, N., CLEMENTS, T., LEE, J.T. & THOMPSON, S. 2003. Modelling soil series data to facilitate targeted habitat restoration: a polytomous logistic regression approach. *Journal of Environmental Management,* 67 (4), 395-407.
An academic paper addressing habitat restoration at a landscape scale and the use of GIS techniques and soil data to target restoration projects. (Presents a method for using soil data to predict habitat suitability using polytomous logistic regression).

BROOKER, L. 2002. The application of focal species knowledge to landscape design in agricultural lands using the ecological neighbourhood as a template. *Landscape and Urban Planning,* 60 (4), 185-210.
Academic paper describing the concept of the ecological neighbourhood, which uses size, spatial arrangement, area of influence and connectivity of existing landscape elements as a starting point for habitat restoration and re-vegetation. Case study of enhancing bird habitats in Western Australia. (Habitat suitability maps created using GIS based on patch size, patch proximity and soil type. Highlights importance of adding new habitats in soil types already supporting the existing vegetation).

BRYAN, B.A. 2003. Physical environmental modelling, visualization and query for supporting landscape planning decisions. *Landscape and Urban Planning,* 65 (4), 237-259.
An academic paper presenting a methodology for using a database of environmental parameters through visualisation and analysis. An interactive spatial decision support tool enables the user to identify all geographic areas with similar environments to a specified site, thereby indicating possible target areas for restoration. (A technical methodology incorporating a range of environmental data sources including soils information. The soil properties used include fertility, pH, rockiness, drainage and salinity).

DAWSON, D. 1994. Are habitat corridors conduits for animals and plants in a fragmented landscape?: A review of the scientific evidence. *English Nature Research Reports*, No 94.
An English Nature Research Report investigating issues connected with habitat fragmentation and reviewing already existing knowledge. Includes a vast reference list for sources of further information. (No direct relevance to soil management issues but provides a good background to habitat fragmentation and corridors).

EGLINGTON, S. & HORLOCK, M. 2004. *East of England Heathland Opportunity Mapping Project*. Final Report
A project report resulting from the development of a GIS-based modelling tool to identify priority areas for heathland re-creation in the East of England, taking into account environmental, social and economic factors. *(Highlights the importance and use of soil type to identify the maximum possible extent of land suitable for heathland re-creation).*

GRIFFITHS, G., and others. 2004. The Living Landscapes Project: landscape character and biodiversity. *English Nature Research Reports*, No 475. Available from: www.englishnature.net/pubs/publication/PDF/475.pdf
An English Nature Research Report describing the progress of a number of developments in the techniques of Landscape Character Assessment and its use in assessing the potential for habitat conservation and re-creation. (Incorporates the use of soil data in the methodology for landscape character mapping but is not discussed in great detail and is not directly related to habitat restoration projects).

HAINES-YOUNG, R., and others. (In press, corrected proof). *Modelling natural capital: The case of landscape restoration on the South Downs, England*. Landscape and Urban Planning.
An academic paper presenting the advantage of linking habitat suitability modelling to ideas about natural capital and landscape function, illustrated by a case study from the South Downs of England. (Not directly relevant to managing soils but highlights the importance of ecological and landscape functions in restoration projects).

KIRBY, K. 1995. Rebuilding the English Countryside: habitat fragmentation and wildlife corridors as issues in practical conservation. *English Nature Science*, No. 10.
A summary of discussions and publications from English Nature's Habitat Fragmentation Group. Covers basic information about habitat fragmentation including the effects of fragmentation, habitat and species sensitivity and methods of restoration. (No specific references to soil management issues but useful information for planning restoration projects and linking habitats).

LARSON, P. 1999. Mineral development. A net contributor to heathland in the South-West. *Quarry Management*, March, 39-44

LEE, J.T., BAILEY, N. & THOMPSON, S. 2002. Using Geographical Information Systems to identify and target sites for creation and restoration of native woodlands: a case study of the Chiltern Hills, UK. *Journal of Environmental Management*, 64 (1), 25-34.
An academic paper describing a method for spatially targeting the restoration of ancient semi-natural deciduous woodland using a land use database. (Although not directly linked to soil management for habitat restoration, the paper highlights the inclusion and importance of soils data in targeting habitat restoration sites).

LING, C., HANDLEY, J.F. & RODWELL, J.S. 2003. Multifunctionality and scale in post-industrial land regeneration. *In*: MOORE, H.M., FOX, H.R. & ELLIOTT, S. *Land Reclamation*. Rotterdam: Balkema.
This paper emphasises a multifunctional approach to landscape restoration and the integration of land uses in a landscape made up of assorted functions (economic, social, historical, cultural, ecological) into a cohesive sustainable whole. It stresses the particular potential of brownfield sites for biodiversity and nature conservation and provides one approach for developing green infrastructure in regeneration, particularly in conjunction with ecoscapes. (Not specifically soil-related but highlights multifunctionality of landscapes and restoration at different scales).

ODPM. 2005. Biodiversity and Geological Conservation. *Planning Policy Statement 9.* Norwich: TSO. Available from: www.odpm.gov.uk/pub/214/ConsultationonPPS9BiodiversityandGeologicalConservationPDF740Kb_id1148214.pdf
A brief guidance note setting out the planning policies on protection of biodiversity and geological conservation through the planning system. (No reference to soil but highlights the importance of habitat networks).

PETERKEN, G.F., BALDOCK, D. & HAMPSON, A. 1995. A Forest Habitat Network for Scotland. *Scottish Natural Heritage Research, Survey and Monitoring Report*, No. 44. Perth: Scottish Natural Heritage.
A report written for Scottish Natural Heritage introducing the concept of developing a forest habitat network to conserve and enhance the natural heritage of Scotland's forest resource through spatial connectivity. Also includes a number of case studies to demonstrate the local distinctiveness which is essential for the national network. (Direct relevance to soil management issues for habitat restoration limited but a useful text to highlight the importance and feasibility of linking habitats).

PORTER, K. & WRIGHT, R. 2003. *Working at a 'Landscape' Scale: the Role of English Nature.* GC P03 32. Peterborough: English Nature. Available from: www.englishnature.net/about/meetings/GCP0332final2.pdf
An English Nature General Committee of Council paper highlighting the importance of delivering nature conservation at a 'landscape' scale. (No direct relevance to soil management but issues raised regarding considerations for expanding nature conservation beyond individual sites).

RATCLIFFE, P.R., PETERKEN, G.F. & HAMPSON, A. 1998. A forest habitat network for the Cairngorms. *Scottish Natural Heritage Research, Survey and Monitoring Report*, No. 114. Scottish Natural Heritage.
A case study report for Scottish Natural Heritage focussing on the potential for a forest habitat network in the Cairngorms, including modelling the effects of habitat fragmentation and connectivity. (Direct relevance to soil management issues for habitat restoration limited but a useful case study to highlight the potential for linking habitats).

RODWELL, J.S. & THORNE, K. 2004. Future Landscapes for the Severn/Vyrnwy Land Management Initiative. Report for the Countryside Agency.

RODWELL, J.S., LING, C. & HEY, D. 2005. *Future landscapes and biodiversity for the Dearne Valley, Yorkshire.* Report for English Nature.

RODWELL, J.S., WILDSMITH, C. & CARTWRIGHT, R. 1998. Outwood Future Landscapes. Lancaster: Unit of Vegetation Science Report to WWF (UK).
An example of a community-led project for landscape restoration, involving ecological prediction of sustainable vegetation and habitats within the frame of cultural understanding and community aspirations.

RSPB. 2004. *An assessment of the value and practicality of habitat recreation opportunity mapping: A pilot study covering East Dorset, Purbeck and Christchurch*. Sandy: The Royal Society for the Protection of Birds.
www.rspb.org.uk/Images/habitatrecreationwithmaps_tcm5-83182.pdf
A technical report written by the RSPB presenting a case study of mapping re-creation opportunities for priority habitats to highlight the ease, practicality and value of representing biodiversity priorities spatially. (Not specifically related to soil but stresses the importance of incorporating soil/geology baseline data).

SWETNAM, R.D., and others. 1998. Spatial relationships between site hydrology and the occurrence of grassland of conservation importance: a risk assessment with GIS. *Journal of Environmental Management,* 54 (3), 189-203.
An academic paper presenting a methodology using GIS to quantify the distribution of the nature conservation resource and links this to a hydrological model and database of plant water-regime requirements. Highlights the potential risk for characteristic and scarce vegetation communities as a result of deliberate management to raise water tables. (A technical article highly relevant for soil hydrology considerations in wet grasslands and potential conflicts over the management of the habitat).

### 9.5.2 BAP links

MITCHLEY, J., BURCH, F. & LAWSON, C. 1998. Habitat Restoration Project: Development of monitoring guidelines. *English Nature Research Reports,* No. 284.
An English Nature Research Report describing the development of a methodology for monitoring the extent to which restored habitats are likely to contribute towards enhancement of biodiversity in two trial areas in southern England. (No direct relevance to soil management issues but separate sections on specific habitats and target species).

RSPB. 2004. *An assessment of the value and practicality of habitat recreation opportunity mapping: A pilot study covering East Dorset, Purbeck and Christchurch*. Sandy: The Royal Society for the Protection of Birds. Available from:
www.rspb.org.uk/Images/habitatrecreationwithmaps_tcm5-83182.pdf
A technical report written by the RSPB presenting a case study of mapping re-creation opportunities for priority habitats to highlight the ease, practicality and value of representing biodiversity priorities spatially. (Not specifically related to soil but stresses the importance of incorporating soil/geology baseline data).

THE WILDLIFE TRUST (no date). *Boulder clay woodland in Bedfordshire: A desktop study to identify possible restoration and creation sites*.
A project report resulting from an investigation into the impact of Biodiversity Action Plans on BAP habitats and species and the possibility of habitat restoration and creation for priority habitats across Bedfordshire, Cambridgeshire and Northamptonshire. (No specific relevance to soil management issues but identifies the key stages in targeting areas for habitat creation/restoration).

## 9.6 Climate change

BERRY, P.M., and others (eds). 2005. *Modelling natural resource responses to climate change: a local approach.* UKCIP. Available from:
www.ukcip.org.uk/resources/publications/documents/125.pdf

BISGROVE, R. & HADLEY, P. 2002. Gardening in the Global Greenhouse: The Impacts of Climate Change on Gardens in the UK. Technical Report. UKCIP, Oxford. Available from:
www.rhs.org.uk/news/climate_change/climate_technical.pdf
A technical report outlining the possible effects of climate change on UK gardens, including the impact on soil and plant growth. (Although content relevant to soil management is fairly limited, the report identifies soil moisture and fertility as important challenges for future research. An accessible document for local issues although not specifically focussed towards habitat restoration projects).

HOLMAN, I.P., and others. 2002. *REGIS - Regional climate change impact response studies in East Anglia and North West England*, Defra. Available from:
www.ukcip.org.uk/resources/publications/documents/Regis_tech_master.pdf
A technical report detailing the RegIS project, funded by Defra and UK Water Research Ltd as part of the UK Climate Impacts Programme, which attempted to predict future scenarios for two regions of the UK based on climate change and socio-economic trends. (Although not specifically soil-related, the study assessed the impact of climate change on biodiversity and the likely changes to important ecosystems.)

HESTER, A.J., and others. 2003. *Support for the Moorland Forum: Predicting the potential distribution of key moorland habitats in the Cairngorms area.* Contract No: AB(AC201A)0203148, The Macaulay Institute.
A detailed technical report describing the development of a Moorland Habitat Suitability Model within the Cairngorms area to aid the work of the Moorland Forum established by Scottish Natural Heritage. Uses the same general principles as the Native Woodland Model developed by the Macaulay Institute. (The model uses National soils and land use data containing information on soil moisture, nutrient status, pH, landform, parent material, slope, altitude and current vegetation and incorporates decision rules based on regional soil-forming processes).

HOLLIS, J.M., SAKRABANI, R.U. & HANNAM, J.A. 2005. *The development of a soil properties database for England and Wales for climate change impact studies.* NSRI project report to Defra for project CC0375.

NSRI. 2005. *The impacts of climate change on soil functions.* Defra report.
Final project report for a Defra-funded project to assess the impacts of climate change on soil functions, including a review of existing research and recommendations for future work. *(Includes a range of relevant topics including the effects of climate change on soil forming processes and properties, soil functions, and more specifically, soil adaptation measures related to biodiversity).*

ROUNSEVELL, M.D.A. & LOVELAND, P.J. 1994. Soil responses to climate change. Berlin: Springer-Verlag.
A collection of papers and discussions from a NATO Advanced Research Workshop to address the role of soils in mediating responses of ecosystems to predicted climate change and the rates of these responses. *(No direct reference to soil management issues for habitat restoration projects but covers related issues such as the effects of climate change on soil hydrology, erosion and nutrient status).*

Vulnerability assessment of shrubland ecosystems in Europe under climatic changes. Available from:
www.vulcanproject.com

## 9.7 Restoring ex-industrial sites (disturbed land)

DEFRA. 2004. Defra guidance for successful reclamation of mineral and waste sites. Available from:
www.defra.gov.uk/environ/landuse/reclamation/guidance-full.pdf
A concise guidance document consisting of factsheets and checklists aimed at promoting better understanding of the agricultural issues that affect the restoration of mineral and waste sites where the preservation of long-term agricultural potential of the land is of importance. It provides a working tool for the industry to focus on agricultural considerations and sustainability relating to the reclamation of mineral and waste sites. *(Section 3 specifically covers restoration of mineral and waste sites and includes a range of sub-sections directly dealing with soil management issues, such as soil storage, soil handling and soil replacement).*

DEPARTMENT OF THE ENVIRONMENT. 1996. The reclamation of mineral workings to agriculture. London: HMSO.
A research report providing guidance on the reclamation of mineral workings to agriculture. (Some detailed guidance on management of soil but specifically targeted towards restoring mineral workings to agriculture, however some guidance may be applicable for alternative habitat restoration projects).

ECOSCOPE WATSON, D. & HACK, V., (Eds.). 2000. *Wildlife management and habitat creation on landfill sites: a manual of best practice.* Muker: Ecoscope Applied Ecologists.
A manual providing best practice guidelines for landfill-related wildlife and ecology issues. A complete section provides practical guidance for habitat creation at landfill sites, separated into specific habitats; grasslands, woodlands and scrubs, heathlands, wetlands, agricultural landscapes. The report also provides a number of relevant case studies. (Includes a concise introduction and practical guidance for issues surrounding soil and establishment of vegetation in habitat creation projects. This covers such issues as soil depth, suitable conditions, soil testing, soil storage and preparation of the site).

ENGLISH NATURE, QUARRY PRODUCTS ASSOCIATION & SILICA & MOULDING SANDS ASSOCIATION. 1999. Biodiversity and minerals: Extracting the benefits for wildlife. Entec UK Ltd. Available from:
www.quarrying.info/natureconservation/pdf/biod.pdf
A fairly basic, but accessible, document providing guidance on the planning, operating, restoring and managing of mineral sites for biodiversity. (No direct relevance to soil management issues but a useful document for the mineral industry for considering biodiversity in planning and operation of mineral sites).

HARRIS, J.A. & BIRCH, P. 1989. Soil microbial activity in opencast coal mine restorations. *Soil Use and Management*, 5(4), 155-160.

HARRIS, J.A. & BIRCH, P. 1990. The effects of heavy civil engineering and stockpiling on the soil microbial community. *In:* P. HOWSAM, ed. *Micro-organisms in civil engineering*, 274-286. Proceedings of the Conference, FEMS Symposium No. 59. London: E. & F.N.Spon.

HARRIS, J.A., BIRCH, P. & SHORT, K.C. 1989. Changes in the microbial community and physico-chemical characteristics of soils stockpiled during opencast mining. *Soil Use and Management,* 5(4), 161-168.

LARSON, P. 1999. Mineral development. A net contributor to heathland in the South-West. *Quarry Management*, March, 39-44

LING, C., HANDLEY, J.F. & RODWELL, J.S. 2003. Multifunctionality and scale in post-industrial land regeneration. In: MOORE, H.M., FOX, H.R. & ELLIOTT, S. *Land Reclamation.* Rotterdam: Balkema.
This paper emphasises a multifunctional approach to landscape restoration and the integration of land uses in a landscape made up of assorted functions (economic, social, historical, cultural, ecological) into a cohesive sustainable whole. It stresses the particular potential of brownfield sites for biodiversity and nature conservation and provides one approach for developing green infrastructure in regeneration, particularly in conjunction with ecoscapes. (Not specifically soil-related but highlights multifunctionality of landscapes and restoration at different scales).

LUNN, J. 2001. Wildlife and mining in the Yorkshire coalfield. *British Wildlife*, 12, 318-26. A review of the wildlife value of brownfield sites in post-mining landscapes and how natural patterns and processes can be used to improve sustainability in restoration.

ODPM. *Minerals Planning Guidance 7: Reclamation of Mineral Workings.* Available from:
www.odpm.gov.uk/index.asp?id=1144193#P68_2106
A detailed document published by the UK Office of the Deputy Prime Minister to assess the contribution of reclaimed mineral sites to Government policy on sustainable development and mineral working. Includes guidance on advice on preparation of schemes of conditions for restoration, aftercare and after-use, the role of management in achieving successful site reclamation and financial provision. *(Highlights the importance of soil management considerations during restoration and aftercare of mineral workings. Includes a useful table describing the effects of disturbance on specific soil characteristics).*

SNIFFER. 2004. *Planning for soil: advice on how the planning system can help to protect and enhance soils*. UKLQ01.
An advice note to assist planning authorities in addressing soil issues. Describes the effects on soil that may occur at different stages in the development process and provides guidance for good practice. *(Not primarily related to habitat restoration but highlights the impact of various activities on soil functions, for example soil compaction and habitat creation, and provides guidance for good practice on considering soils within the planning system).*
*Speight, L.B. (1990) Lofthouse Colliery Heather Trials, Wakefield: Ecological Advisory Service Report.* An example of how semi-natural vegetation might be restored on brownfield colliery waste with low-intervention and sustainability costs.

WHITE, G.J. & GILBERT, J.C. 2003. *Habitat creation handbook for the minerals industry*. Sandy: RSPB.
A handbook focusing on habitat design and creation techniques to aid the creation of valuable habitat on land that has been worked for minerals for a range of Biodiversity Action Plan (BAP) priority habitats. *(Emphasis very much on habitat creation for the minerals industry rather than restoration of degraded habitats however there is a small section on managing soils including soil movement, storage and fertility).*

BRADLEY, R.I., and others. 2005. *Transferring best practice on soil handling.*
A guidance document relating to soil handling, reviewing existing good practice guidance and its applicability to the construction industry. Includes a draft outline of Best Practice Soil Handling for the Construction Industry. *(Primarily focussed on urban sites and the construction industry but many of the issues raised and processes involved could be applicable for habitat restoration projects, eg. surveying site soil resources and soil storage).*

DEPARTMENT OF THE ENVIRONMENT. 1996. *Guidance on good practice for the reclamation of mineral workings to agriculture.* London: HMSO.
Detailed guidance recommending best practice and techniques for efficient and sympathetic restoration of mineral workings to agriculture, including a series of checklists. (Contains a number of sections relating specifically to soil management issues, including soil stripping, storage, restoration of soils and aftercare. However, all are specifically focussed towards the minerals industry and the restoration of mineral workings to agriculture although some details may be relevant for habitat restoration on such land).

MAFF. 2000. *Good practice guide for handling soils*. Cambridge: FRCA.
A comprehensive guide to handling soil, primarily targeted towards the mineral and waste development industries. The document consists of 19 sheets which provide guidance and technical advice on issues such as soil stripping, storage and replacement. *(A useful guide for anyone involved in soil handling, but not specifically related to habitat restoration).*

SAKRABANI, R., ANDREWS, R. & WELLS, I. 2005. *British standards relating to soil.* Report for Defra, unpublished report, Cranfield University at Silsoe.
A report prepared for the Department of the Environment, Food and Rural Affairs reviewing British Standards relating to soil.

SHORT, K.C. 1993. Changes in the microbial community during the construction and subsequent storage of soil stockpiles: A strategist theory interpretation. *Restoration Ecology*, 1 (2), 88-100.

## 9.8 Agricultural land

DEFRA. 2005a. *Entry level stewardship handbook*. PB10355. London: Rural Development Service. Available from:
www.defra.gov.uk/erdp/pdfs/es/els-handbook.pdf

DEFRA. 2005b. *Higher level stewardship: farm environment plan (guidance handbook).* pb10383. London: Rural Development Service. Available from:
www.defra.gov.uk/erdp/pdfs/es/hls-fep-handbook.pdf

DEFRA. 2006. *Cross compliance guidance for soil management*. PB11162, London. Available from:
www.defra.gov.uk/farm/capreform/pubs/pdf/XCSoilGuidance2006.pdf

GILBERT, J.C., and others. 1996. *The habitat creation model: a model to assess the viability of converting arable land into semi-natural habitat.* Project CSA 2373. Report to the Ministry of Agriculture, Fisheries and Food, London.
Project report for MAFF-funded project to develop a computer model designed to identify semi-natural habitats appropriate for restoration on different soils and within different climatic areas of England and Wales. Describes the approach and development of the model, including management techniques for habitat restoration and associated costs. (Uses national coverage of soil data and addresses management techniques used to achieve the amelioration of soil conditions prior to habitat creation and long term management of the vegetation, including economic analysis of such techniques).

MAFF. 1998. *Code of Good Agricultural Practice for the Protection of Soil.* Available from:
www.defra.gov.uk/environ/cogap/soilcode.pdf
A practical guide published by the UK Government to assist farmers in preventing long term damage to their soils.
*(Although not specifically related to habitat restoration projects, provides detailed information on handling and restoring soil and guidance on practices to maintain and increase the ability of soil to support plant growth).*

MAFF. 2000. *Fertiliser recommendations for agricultural and horticultural crops.* RB209. London.

OWEN, K.M., and others. 1999. Soil acidification- the use of sulphur and acidic plant materials to acidify arable soils for the re-creation of heathland and acidic grassland at Minsmere, UK. *Biological Conservation*, 87, 105-121.

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., and others. 2002. Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. *Journal of Applied Ecology*, 39 (2), 294-309.
An academic paper examining the key ecological processes limiting the creation of diverse grassland communities on former agricultural land. (Addresses techniques for restoration and

the effects on soil fertility across a wide variety of soil types and locations across lowland Britain).

RURAL DEVELOPMENT SERVICE. 2003. *Soil sampling and analysis for habitat re-creation and restoration in agri-environment schemes.* Technical Advice Note 20. Defra. www.defra.gov.uk/rds/publications/technical/tan_20.pdf
A technical advice note providing guidance on the soil sampling methodology required to determine whether a site is suitable for habitat restoration and the appropriate target habitat.

RURAL DEVELOPMENT SERVICE. 2005. *Soils and Agri-environment Schemes: interpreting soil analysis for habitat creation/restoration*. Technical Advice Note 31. Defra, www.defra.gov.uk/rds/publications/technical/tan_31.pdf
A technical advice note covering the general interpretation of soil analysis result for Agri-environment schemes. (Highlights the importance of knowledge of soil properties in the consideration of sites for habitat re-creation or restoration, particularly soil nutrients).

SUTHERLAND, W.J. 2002. Restoring a sustainable countryside. *Trends in Ecology & Evolution*, 17 (3), 148-150.
A general document addressing agri-environment schemes and large-scale habitat restoration projects. (Not specific to soil management but highlights restoration issues relating to agricultural land, including climate change).

TALLOWIN, J.R.B. 1998. Use and effects of lime applications on semi-natural grasslands in Britain. *Countryside Council for Wales Science Report*, No. 261. Bangor: CCW.

ANDREWS, J. & REBANE, M. 1994. *Farming and wildlife: a practical handbook for the management restoration and creation of wildlife habitats on farmland*. Sandy: RSPB.

GILBERT, J.C., GOWING, D.J.G. & LOVELAND, P. 2003. Chemical amelioration of high phosphorus availability in soil to aid the restoration of species-rich grassland. *Ecological Engineering,* 19 (5), 297-304.
An academic paper highlighting the importance of phosphorus availability for the restoration of grassland. (Provides the findings of a study into reducing soil phosphorus levels through the application of aluminium sulphate in order to reduce phosphorus availability in soil and enable the establishment of species-rich grassland).

LAWSON, C.S., and others. 2004. The establishment of heathland vegetation on ex-arable land: the response of *Calluna vulgaris* to soil acidification. *Biological Conservation*, 116, 409-416.

PYWELL, R.F., and others. 2002. Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. *Journal of Applied Ecology*, 39 (2), 294-309.
An academic paper examining the key ecological processes limiting the creation of diverse grassland communities on former agricultural land. *(Addresses techniques for restoration and the effects on soil fertility across a wide variety of soil types and locations across lowland Britain).*

WALKER, K.J., and others. 2004. The restoration and re-creation of species-rich lowland grassland on land formerly managed for intensive agriculture in the UK. *Biological Conservation,* 119 (1), 1-18.
An academic paper reviewing the techniques employed to restore and re-create grasslands on agricultural land in the UK, particularly those used to overcome high soil fertility and seed-limitation. (Provides an in-depth review of literature on soil-related techniques and issues, such as soil fertility and the effects of land management, focussed solely on the restoration of grassland on agricultural land).

# 10 Useful websites and organisations

| | |
|---|---|
| British Geological Survey (BGS) | www.bgs.ac.uk |
| British Society of Soil Science (BSSS) | www.soils.org.uk |
| Changing Places Project (Groundwork) | www.changingplaces.org.uk |
| Countryside Council for Wales | www.ccw.gov.uk |
| Cresswell Associates | www.cresswell-associates.com |
| Defra (RDS) | www.defra.gov.uk<br>www.defra.gov.uk/rds/publications/default.htm |
| English Nature | www.english-nature.org.uk |
| Environment Agency | www.environment-agency.gov.uk |
| EU Habitats Directive | europa.eu.int/comm/environment/nature/nature_conservation/eu_nature_legislation/habitats_directive/index_en.htm |
| Forest Research | www.forestresearch.gov.uk |
| Groundwork | www.groundwork.org.uk |
| Institute of Professional Soil Scientists (IPSS) | www.soilscientist.org |
| Joint Nature Conservation Council | www.jncc.gov.uk |
| Local Councils | www.direct.gov.uk/Dl1/Directories/LocalCouncils/fs/en |
| MAGIC | www.magic.gov.uk |
| Met Office | www.metoffice.com |
| National Biodiversity Network (NBN) | www.nbn.org.uk |
| National Soil Resources Institute (NSRI) | www.silsoe.cranfield.ac.uk/nsri |
| Ordnance Survey | www.ordnancesurvey.gov.uk |
| Scottish Natural Heritage | www.snh.gov.uk |
| Soil and Groundwater Technology (SAGTA) | www.sagta.org.uk |
| The Macaulay Institute | www.macaulay.ac.uk |
| UK Biodiversity Action Plan (UKBAP) | www.ukbap.org.uk |
| Wildlife Trust | www.wildlifetrusts.org |
| Applying NVC to site restoration | www.ecoregen.org.uk |
| Landlife | www.landlife.org.uk |
| Landscape Character Network | www.landscapecharacter.org.uk |
| Common Ground | www.commonground.org.uk |
| Climate change | www.ukcip.org.uk<br>www.english-nature.org.uk/science/climatechange |

# Research Information Note

*English Nature Research Reports*, No. 712

## Guidance on understanding and managing soils for habitat restoration projects

Report Authors: Report Authors: Ian Bradley, Michelle Clarke, Helen Cooke, Jim Harris, Peter Leeds Harrison, Thomas Mayr, Willie Towers, John Rodwell and David Gowing.
Edited by: Anna Wetherell Date: October 2006
Keywords: Soil, Habitat Restoration, Guidance

## Introduction

This report fulfils English Nature's requirements under Action 43 of the First Soil Action Plan for England: 2004 – 2006 (Defra, 2004). It provides guidance on the use of soil information in the restoration of wildlife and wildlife habitats. As there is already a lot of published guidance in this area in different guises and formats, this report summarises the key advice and recommendations available and provides extensive references and commentary for existing guidance. The aim is to enable practitioners to obtain an overview of the key considerations from the report, and then to be able to follow up more detailed guidance and case examples from the references and further reading available, as appropriate to their habitat restoration project.

## What was done

The main work for this report was carried out by and co-ordinated by the National Soil Resources Institute (NSRI). Additional input was provided by Bruce Lascelles of Cresswell Associates, members of the Soil Lead Co-ordination Network (JNCC, SNH, CCW, English Nature) and colleagues in English Nature, Countryside Agency and Rural Development Service.

NSRI collated the guidance and provided the initial text. This was then commented on by staff in the various agencies and departments to ensure that the advice given correlated with key existing guidance and government recommendations, with final editing carried out by Anna Wetherell (English Nature).

The report provides an overview of what soil is, how varied it is and how it is classified. It outlines what its key properties are and the factors which affect and indeed control the habitats it supports. It looks at the key factors that should be considered in habitat restoration and outlines potential soil management options, should these be considered necessary. Most importantly, it provides an extensive bibliography for further research and information.

**Continued……**

# Results and conclusions

The key messages to come from this review and collation of existing guidance are as follows:

- Adequate soil analysis and gathering of soil data should be an essential component of habitat restoration projects. It enables appropriate objectives to be devised and helps to ensure the success of the project - soil is one of the essential foundations for habitats.
- While there are a range of soil 'restoration' or modification techniques available, it is better to work with the soil already present on a site and to devise project objectives accordingly. This can reduce the costs involved and can ensure the long term success of the project. Extensive soil modification is more costly, requires more long term input and management and may not achieve the outcomes hoped for.

# English Nature's viewpoint

This report should provide an essential guide for those undertaking habitat restoration projects. It summarises and outlines the key advice available and provides an overview of why soil should be a key consideration within these projects. While emphasising the importance of working with the soil already present on a site, information is given on soil modification and 'restoration' techniques should they be needed. Of particular use will be the extensive bibliography and list of websites which will enable practitioners to follow up in more detail the recommendations given and case examples appropriate to their site.

# Selected references

DEFRA. 2004. *The First Soil Action Plan for England: 2004-2006*. Product code PB9411.

BARDGETT, R. 2005. *The biology of soil: a community and ecosystem approach*. (Biology of Habitats Series). Oxford: Oxford University Press

DRYDEN, R. 1997. Habitat Restoration Project: fact sheets and bibliographies. *English Nature Research Reports*, No 260.

NSRI. 2006. *Soilscapes Viewer*. Available from: www5.landis.org.uk/soilscapes/

RODWELL, J.S. 1991 *et seq*. *British Plant Communities*. Cambridge: Cambridge University Press.

RODWEL, J.S. 2006. *National Vegetation Survey Handbook*. Peterborough: JNCC.

## Further information

*English Nature Research Reports* and their *Research Information Notes* are available to download from our website: www.english-nature.org.uk

For a printed copy of the full report, or for information on other publications on this subject, please contact the Enquiry Service on 01733 455100/101/102 or e-mail enquiries@english-nature.org.uk

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Front cover photographs:
Top left: Using a home-made moth trap.
Peter Wakely/English Nature 17,396
Middle left: $Co_2$ experiment at Roudsea Wood and Mosses NNR, Lancashire.
Peter Wakely/English Nature 21,792
Bottom left: Radio tracking a hare on Pawlett Hams, Somerset.
Paul Glendell/English Nature 23,020
Main: Identifying moths caught in a moth trap at Ham Wall NNR, Somerset.
Paul Glendell/English Nature 24,888