Summary of evidence: Soils

1. General introduction

This summary sets out Natural England's assessment of the key evidence relating to soils and their conservation and management. It provides a statement of the current evidence base, presenting:

- what we know (with supporting data and key references);
- areas that are subject to active research and debate;
- what we do not yet know from the evidence base.

It also lists Natural England research projects and key external research programmes to show how we are seeking to fill gaps.

This summary forms part of a suite of summaries covering all of Natural England's remit. The summaries are not systematic reviews, but enable us to identify areas where the evidence is absent, or complex, conflicting or contested. The summaries are for both internal and external use, and will be regularly updated as new evidence emerges and more detailed reviews are completed.

2. Introduction to soils

The evidence is drawn together under the following headings:

- the soil itself;
- soils and society;
- soils and landscape;
- soil carbon and greenhouse gas flux;
- soil biodiversity;
- soils and land management;
- sustainable land use in relation to development;
- soils in climate change adaptation.

3. The soil itself

What we know:

3.1 Soil is made up of four components, mineral matter, organic matter, water and air. Over time, these components are formed into soil by the interaction of climate, organisms, parent material and topography (Jenny 1980). As these components become soil they develop structure, and carry out complex interactive processes, mediated by soil organisms.

3.2 Soil processes are an essential part of the global processes that cycle the elements required for life between living organisms, atmosphere, soil and water. Terrestrial life could not survive without these functions, which have been occurring since terrestrial life began, around 460 million years ago (Johnson 1990). These include cycling of carbon, fixation of nitrogen, and mediating the flow and quality of water.

3.3 Soils develop over hundreds of years. Some features, such as soil profiles, take centuries to millennia to develop, while other soil functions can develop rapidly as new soils form, mirroring the succession of vegetation (Chandler 1942). However, soil can be quickly lost or degraded and is ultimately constrained by our finite land resource.

3.4 Understanding soils and their function is central to understanding ecosystem services (UK NEA 2011). Most of the services provided by terrestrial ecosystems are dependent on soil function. The adoption of an ecosystems approach to the natural environment is developing the thinking in relation to soils and encouraging a more holistic approach (HM Government 2011; UK NEA 2011).

3.5 Soils are diverse in their structure and function and have been categorized by the properties of soil layers (known as horizons) and by the nature of the parent material from which they are derived. This diversity reflects differences in soil-forming conditions, but also reflects more recent vegetation and land management that influence both structure and ecosystem functions (Jenny 1980). Soil diversity is reflected in the variety of habitats, land use and landscape that create the unique character of England. A total of 698 soil types (series) have been described for England and Wales (Avery 1980; Clayden & Hollis 1984).

3.6 The current broad system of soil classification is a good predictor of some soil physical and chemical properties, but can be a poor predictor of nutrient and carbon mineralisation (Hall et al. 1977; Defra 2011a) when compared to vegetation cover.

Areas that are subject to active research and debate:

3.7 The value (economic and social) of ecosystem services provided by soils particularly with regard to food production, water management and purification, and the role of soil biodiversity in many soil functions (UNEP-WCMC 2011; Natural England 2009).

3.8 The nature of soil "health". This term is often used to described the desired target state of soils, but can be difficult to define, due to different expectations of soil by different people. A useful definition is therefore that soil health is how well the soil does what you want it to do. Some researchers have tried to define it by listing a range of services and functions a soil ought to provide (Doran & Safley, 1997), although these are generally geared towards maintaining agricultural productivity. However, non-agricultural soils in semi-natural or natural ecosystems may function perfectly well in supporting these ecosystems, with little agricultural productivity (Sparling, 1997). Elliott (1997) defines soil health as "normality of function", although "normal" functions in a soil will depend on its history, management, and other changing circumstances, and may reflect ongoing degradation. Elliott (1997) also relates soil health to soil diseases, but these remain natural parts of soil ecosystems, and are only a problem if the disease affects, for example, crop plants or humans.

3.9 How best to research soils in a way that acknowledges the very long timescales over which soils may respond, and the broad spatial variability in soils. Longer term studies and large numbers of sites would be required to understand some soil processes.

What we don't know:

3.10 Detailed distribution of soils in many areas. Our soils have been broadly mapped at the national scale, but detailed local maps are available for only about a quarter of England, and distribution of soils elsewhere must be inferred from detailed maps in other similar areas. Peatland distribution is likely to have changed in agricultural areas (Holman 2009). The use of different definitions confounds an overall UK assessment of soil resources (JNCC 2011a).

3.11 The rate of degradation and resulting change in many soil functions (Defra 2010d, e). Techniques to monitor degradation and evaluate the loss of function need to be developed. These should be appropriate to a range of land uses through initiatives like the UK Soil Indicators Consortium (Moffatt 2003; Ritz et al. 2009) and Defra's project SP1303.

4 Soils and society

We know that:

4.1 In the past soil protection received less attention than the protection of air and water (House of Commons Select Committee 1990). Some functions of soil are addressed through policies on planning, pollution, contamination, cross-compliance or Environmental Stewardship.

4.2 The importance of soils is now recognised as pivotal in valuing and protecting the natural environment and the services it provides (HM Government 2011; UK NEA 2011). The Natural Environment White Paper (HM Government 2011) builds on and develops some of the aims of the former soil strategy (Defra 2009c). The Scottish Government has published a report on the State of Scotland's soil (Dobbie and others, 2011) identifying key soil issues, but there is currently no equivalent report for England.

4.3 Information on soil is widely available, but often difficult to interpret (Defra 2005a). The classification system used can be difficult to understand, and local detailed soil maps may not be available.

4.4 Soils are not well represented among geodiversity sites, with no national site designations solely for soil science interest. In Wales, a network of soil profile exposures has been recognised as Local Geological Sites (Conway 2009) which are suitable for designation of areas with soil interest, but many geoconservationists lack the expertise to describe, interpret and manage soil sites, and select those suitable for designation. Many soil scientists lack the expertise of geoconservationists in site designation and conservation. Collaboration between soil scientists and geoconservationists would be likely to help develop geodiversity sites for soils.

4.5 Greater coordination and investment in soils expertise and advice is required to deliver better environmental and agricultural management of soils in the future (Kibblewhite et al. 2010). The Natural Environment Research Council has recently recruited a Soil Security Coordinator to coordinate soil research investment.

4.6 The British Society of Soil Science supports regional soils groups, which seek to promote discussion of soils and dissemination of new soil science to land managers, advisers and scientists.

4.7 A range of key parameters have been identified for monitoring soil characteristics. These include physico-chemical parameters which are well suited to understanding soil's interactions with other elements of the environment (Environment Agency 2006), and a suite of biological parameters (including microbial genetic and phenotypic profiling, mesofauna, and substrate responses) to indicate changes in soil ecology and biological function (Defra 2011i). Opportunities for using remote sensing to monitor soils are mainly restricted to arable or other bare soils (Defra,2014a). A recent project (SNIFFER, 2014) highlighted opportunities for citizen science to provide some types of data for soil erosion monitoring and validation of erosion modelling.

4.8 Organic farms typically implement a range of practices that tend to result in higher soil organic matter content compared to conventional farms. They are more likely to apply manures, compost, use grass-clover leys as break crops to build fertility, plant cover crops, use straw-based livestock systems instead of slurry and also to plant deep-rooting crops, adding root exudates and root biomass to the soil (Gattinger and others, 2012)

Areas that are subject to active research and debate:

4.9 How to address lack of public awareness and understanding. Novel approaches to engage with farmers have included "field labs" such as those organised by the Soil Association, where farmers facing soils or other issues can invite research scientists to help investigate the issues. The Institute of Professional Soil Scientists (IPSS) runs courses in soil science vocational skills in a range of topics, and new BASIS training modules are being developed to train advisors and farmers on integrated soil management issues.

4.10 How to make soil data more accessible. The development of the UK Soils Observatory (**http://www.ukso.org/**) by NERC has provided a portal for a wide range of freely available soils data, and is still being developed to include more data sets. The initiative has also developed apps and tools to make soils easier to interpret. Natural England is also working to make its soils data more accessible (see Research Project RP0229 below). However, much soils data remains only available under licence.

4.11 How best to extend geo-conservation and biological conservation principles to include soils (Conway 2009). Natural England, Geoconservation UK, British Society of Soil Science and The Geology Trusts are working together to develop guidance on local soil site designation and to link soil scientists and geoconservationists. Designated sites could recognise the value of undisturbed soils in ecosystems (SNH 2008) or for soil science education and communication.

4.12 How best to monitor soil properties and functions. There have been two national monitoring programmes covering soils in England (National Soils Inventory and Countryside Survey), measuring different parameters, with different approaches. There is interest in using citizen science or "crowd-sourced" data for soil monitoring.

What we don't know:

4.13 The impact of low soils awareness on decisions made by policy makers, land managers, developers, planners and public.

4.14 Whether any sites are of sufficient scientific interest, or of sufficient conservation concern, to justify national, or international protective designation status (SSSI, SAC). The development of data to support regional soil sites may enable this to be evaluated in the future.

5 Soils and landscape

We know that:

5.1 The diversity of soils reflects the diversity of the underlying geology. The mineralogy of the soils and the processes affected by climate and topography are driven by the underlying geology and landforms they create, linking the bedrock geology, or quaternary deposits, and the current landscape (Jenny, 1980).

5.2 Soils have informed landscape character assessments. An analysis of landscape character is required by the European Landscape Convention.

5.3 The National Character Area (NCA) framework is being informed by soil mapping. The 159 NCAs have been identified by a blend of geographical, ecological and historical variation in landscape features, all of which influence, and are influenced by, soil (Stace & Larwood 2006).

5.4 Our soil preserves a diverse range of archaeological remains from pollen records of past land uses and environmental conditions to buried artefacts. Some soil sequences, particularly peats, are of national significance for the Historic Environment because of the record of human history, environmental history and climate and environmental change that they preserve (Gearey and others 2010).

5.5 Some agricultural soil management such as cultivation and drainage can damage the buried archaeological resource. Damage to buried artefacts and earthworks can be minimised with shallower, or no, cultivation, lower ground pressure machinery and reduced traffic (Defra 2010a).

What we don't know:

5.6 The extent to which degraded (poorly functioning) soils contribute to degraded landscapes, causing reductions in aesthetic appeal, amenity value or health benefits from green spaces. A major sociological study of attitudes and use of the natural environment (Natural England 2013a) does not relate people's experiences to the extent of degradation of the landscape (eg. soil erosion) or other indicators of environmental quality.

5.7 How to quantify and value the landscape, amenity and cultural benefits provided by soil, to help prioritise and balance cultural benefits against other ecosystem services.

6 Soil carbon and greenhouse gas flux

We know that:

6.1 Soil carbon is predominantly derived from carbon fixed by plants. This enters the soil as litter or dung, root tissue turnover, root exudates and carbon allocated to mutualistic fungi. Carbon is mixed into the soil and transformed by biological processes, but some is also carried down the profile by downward movement of rain water. Where these biological processes are retarded, and mixing does not occur, soils can develop organic layers on their surface, and in waterlogged conditions these become deep peat deposits. Soils on limestone and chalk may also contain inorganic carbon as carbonate compounds. Some ammonia oxidising bacteria also fix carbon.

6.2 In all habitats most carbon is stored in soils in the form of soil organic matter (SOM), and peaty soils in particular, are major stores of carbon (Natural England 2012b). Globally soils contain more organic carbon than the vegetation and atmosphere combined (Swift 2001). Ten billion tonnes of organic carbon are estimated to be stored in UK soils, with over half stored in peat. Soils in England and Wales store 2.4 billion tonnes of carbon of which 58% is in the top 30 cm of soil (Defra 2011e). Soil carbon is stored in fresh and decomposing litter and as longer-lasting material stored in soil particles, in a complex with clays or in anaerobic waterlogged conditions. England's deep and shallow peaty soils are estimated to contain over 580 million tonnes of carbon (Natural England 2010), but in surface layers, denser mineral soils contain more carbon than peaty soils (Emmett et al. 2010). In peat, anaerobic conditions caused by waterlogging prevent the breakdown of phenols, which build up and inhibit other decomposition enzymes, while plants producing tannins also inhibit enzyme activity (Defra 2010g). In lowland fens where waterlogging is due to groundwater, peat can be formed from a wide range of plants that are found in waterlogged conditions. In bogs, where water supply is derived from precipitation only, peat is predominantly formed from Sphagnum mosses and Cotton-grass (*Eriophorum* spp.), with minor components of other plants reflecting past drier conditions or periods (Natural England, 2013).

6.3 Soils emit and process three major greenhouse gases: Carbon dioxide (CO_2) is emitted by decomposition of soil organic matter, but is recaptured by plants and enters the soil as plant litter or exudates. Methane (CH_4) is emitted from anaerobic soils, but processed into less harmful CO_2 in aerobic soils. While nitrogen is fixed as ammonia in the soil by free-living and symbiotic microbes, this ammonia may be turned into nitrate by microbial nitrification. This, along with the larger amounts of nitrate applied as fertiliser, may be broken down in the soil by microbial denitrification processes which can lead to emission as nitrous oxide (N_2O). Where human activity has affected these emissions this is reported in the Land Use, Land Use Change and Forestry (LULUCF) sector of the UK's Greenhouse Gas Inventory (Miles and others, 2014)

6.4 Cultivation of soils promotes the release of stored soil carbon by mineralisation of soil organic matter to CO_2 (Lal 2004). The conversion of grassland to arable cropland was the largest contributor to soil carbon losses from land use change in the UK between 1990 and 2000 (Ostle *et al* 2009). Carbon in the subsoil (below 15 cm for grassland or 30 cm plough layer for arable) is more stable and less influenced by surface processes (Defra 2011e).

6.5 **Draining a peatland results in loss of stored carbon** through erosion (Holden, 2006) or into dissolved carbon, but gaseous CO_2 emissions may change little, and drained peatlands tend to emit more N_2O but less methane (Bussell 2010). Cultivation of peatlands is associated with high ongoing loss of stored carbon through oxidation (Natural England 2010). An overview of peat drainage, rewetting and other management impacts is provided by Lindsay (2010) and Natural England (2013).

6.6 **Most dissolved and particulate matter lost to watercourses from peatlands is rapidly converted to CO_2.** Between 80-100% of dissolved organic carbon lost to watercourses from peatlands, and approximately 70% of particulate organic carbon is likely to be converted into CO_2 during their journey through the river system, primarily due to photo-degradation (Defra, 2013 x).

6.7 **Rewetting peatlands will reduce CO_2 losses**; however it usually increases methane emissions (Bussell 2010; JNCC 2011b), which may reduce or counteract the benefits of lower CO_2 emissions.

6.8 **Blanket bog restoration by ditch blocking reduces particulate carbon loss and can reduce dissolved carbon and flashy flows**, although this effect is likely to be dependent on the properties of the catchment affected (Natural England 2013a).

6.9 **Economic models suggest re-wetting of some cultivated fen peatlands could deliver more benefits to society than agriculture**, through biodiversity and GHG emissions reduction, and could regenerate and protect peat and the carbon and historic environment features it supports. The long-term impact on the potential reduction in agricultural productivity could be mitigated by retaining the ability to re-drain peatlands for agricultural use if required in the future (Morris and others 2011).

6.10 **The current climatic conditions in areas where upland peat is found will probably be rarer in the UK under climate change**, and more restricted to northern and western parts of the UK (QUEST 2009). However, these current climatic conditions may not represent those prevalent when most peat was formed, and future peat formation will also be influenced by local hydrological and other conditions.

6.11 **On mineral soils, Environmental Stewardship is estimated to have reduced England's agricultural GHG emissions by around 11% a year** (Defra 2007), mainly through increases in soil organic carbon delivered by options such as buffer strips that take land out of cultivation.

6.12 **The greatest benefits in terms of increase in soil carbon can be realised through land use change from intensive arable to grasslands (Conant and other, 2001), woodlands or some biofuels** (Defra 2003). Avoiding disturbance of undisturbed soils, and changing land use to grassland, heathland, woodland or wetland is likely to deliver carbon storage benefits (Natural England 2012b), including on organo-mineral soils (Defra 2011f). Conversion from arable to grassland may, however, be offset to some extent by methane emissions associated with livestock production.

6.13 **Without changing land use or agricultural systems there are some management options available to increase soil organic matter.** Management of manures and crop residues can increase soil organic matter and carbon, but most such sources are already eventually applied to soil and there is little scope to increase their availability, although there is potential for greater disposal of organic waste (eg composts, paper crumble etc) to land (Defra 2009d; Defra 2012a). Winter cover/catch crops can also provide new sources of soil carbon (Defra 2012a; Mutegi and others 2013). Other developing approaches to increasing agricultural carbon storage such as intercropping, agroforestry, perennial crops, and crops with deeper or leakier root systems could all potentially increase soil carbon (Defra 2010g) but the best opportunities to increase carbon storage come from planting perennial crops, returning crop residues to the soil and application of organic manures (Defra, SP1113).

6.14 **In the short to medium term (up to 10 years) zero tillage does not result in increased levels of soil carbon compared to conventional tillage (Defra 2014b), but global data suggests that zero tillage results in more total soil carbon storage when applied for 12 years or more** (Alvarez, 2006).

Arable land under zero tillage has more carbon in its upper layers than conventionally tilled soils (Lal, 2004), but less carbon lower in the plough layer, due to lack of mixing (Defra 2003; Defra 2009d; Defra, 2014b; HGCA 2013), . There are other likely benefits, in promoting soil biological function, and reducing fuel usage and associated emissions, but there is concern that the practice may increase N_2O emissions (Defra 2012a).

6.15 Application of agricultural lime to soils releases inorganic carbon that has been stored in limestone for millions of years, but could be replaced with silicate minerals which release no CO_2 (Defra 2010g).

6.16 High nitrous oxide emissions are predominantly related to the application of nitrogen fertilisers, but soils with higher temperatures, compaction, more water in soil pores, and high organic matter are more likely to have higher emissions of nitrous oxide. (Ball and others 1999; Cosentino and others 2013).

6.17 Elevated atmospheric CO_2 is likely to increase the rate of sequestration of carbon into agricultural soils, but this can be almost completely counteracted by increased N_2O emissions from fertiliser (Dijkstra and Morgan 2012).

Areas that are subject to active research and debate:

6.18 The carbon dynamics associated with restored peatlands, especially whether the method of restoration affects GHG emissions (see Defra project SP1202) and the duration of any greenhouse gas fluxes associated with conditions immediately following restoration (see RP0322). Greenhouse Gas Abatement estimates have been published (Artz and others, 2013), but there is little data on emissions from peatlands immediately following restoration.

6.19 The impacts on carbon dynamics of peatlands dominated by heather and how best to restore these. Over-dominant heather is a cause of unfavourable condition in blanket peatlands. These areas develop more peat pipes and may lose more dissolved carbon (Natural England 2013a). Defra project BD5104 is examining how to reduce heather dominance and restore blanket bog vegetation and functions.

6.20 Whether soil organic matter (SOM) is increasing, stable, or decreasing nationally. Recent surveys disagree on the direction of change (Emmett and others 2010; Bellamy and others, 2005). Integration of soil data has been used to model soil carbon change nationally (Defra 2011b).

6.21 How grasslands can be managed to increase carbon storage. Defra Project BD5003 is finding that older, and particularly semi-improved grasslands are important carbon stores compared to intensively managed, improved grasslands. Defra (2014b) found insufficient evidence on the impact of grassland intensification on soil organic carbon to make recommendations for LULUCF reporting, but effects may depend on soil type. There is a lack of data on the effects of drainage, liming and fertilisation of rough grassland on organo-mineral soils and their soil organic carbon stocks.

6.22 Whether impacts of soil warming will counteract any carbon storage benefits associated with higher CO_2 levels in agro-ecosystems (DIjkstra and Morgan 2012). Models suggest that climate warming would increase microbial decomposition and loss of soil organic matter, if plant inputs remain the same (Bradley 2005). However, there are uncertainties about other climate change impacts on plant productivity and decomposition and there is no current consensus on the impacts of global warming on soil carbon (Davidson and Janssens 2006).

6.23 Whether we are measuring peatland GHG flux adequately to generate emissions factors for peatland management and restoration to inform GHG reporting, management and approaches to carbon trading. A research programme was planned (JNCC, 2011b, c), and elements are being delivered by Defra project SP1210, SP1202 and BD5104, but a wider range of peatland sites and managements may be required.

6.24 The total carbon stored in our soils. Soil carbon to 1 m depth has been estimated using soil maps and databases (Bradley and others 2005), but we need to improve information on the depth and quality of deeper peat soils (see RP0437, and Defra 2011b) and on soil carbon changes below 15 cm depth.

6.25 How best to mitigate nitrous oxide emissions from agricultural soils. Options include reduced or more targeted application of fertilisers, different fertilisers, managing soil structure and/or chemistry, or use of nitrification inhibitors.

What we don't know:

6.26 Whether the soil carbon increases created by converting arable land to grassland would be counteracted by livestock methane emissions. This will depend on the use of the grassland and stocking levels.

6.27 Whether hydrological restoration will be enough to make upland peatlands resistant to the effects of climate change. Our lowland raised bogs and fens show that peat can form in warmer drier climates than those that characterise our blanket peatlands, provided hydrological conditions are right.

6.28 The depth of our peat soils, across most of their range. This has been mapped, and modelled in project RP0437, but additional work is needed to provide more representative data from more peatlands, especially around the edges of peat masses, and to integrate it with LIDAR or similar data to account for the impact of peat erosion on carbon storage.

7 Soil biodiversity

We know that:

7.1 Soils are habitats for millions of species, ranging from bacteria, fungi, protozoa, and microscopic invertebrates to mites, springtails, ants, worms and plants. It is estimated that more than 1 in 4 of all living species in earth is a strictly soil-dwelling organism (Decaens and others 2006).

7.2 A single gram of soil can contain a billion bacterial cells from up to 10,000 species (Torsvik and others 1990, 2002).

7.3 Soil organisms are involved in delivering all the main supporting and regulating ecosystem services (Turbé and others 2010), including food and fibre production, soil formation, flood risk management, water quality, climate control, waste and pollutant processing, and nutrient cycling. Earthworms are hugely beneficial for forming and structuring soils, cycling nutrients, improving drainage and remediating pollution, but tend to reduce carbon storage and can enhance N_2O emissions (Blouin and others 2013).

7.4 Soil biota are strongly influenced by land management. Modern farming has sought to replace many soil biota functions with less sustainable technological solutions, which lead to loss of soil biodiversity (Stockdale and others 2006; Defra 2010c). For example, changes in land management practice and land use can have large effects on soil biodiversity over relatively short-time scales. Reducing the intensity of management, introducing no-till management and converting arable land to pasture usually has substantial beneficial effects (Spurgeon and others, 2013).

7.5 Agricultural land management practices, which reduce disturbance and increase and diversify organic matter inputs are most likely to benefit soil biota and their function (Natural England 2012a). Such activities are likely to benefit crop yields, improve water retention, improve nutrient capture, reduce inputs, improve soil structure, reduce diffuse pollution, and enhance nutrient turnover. Management activities may involve zero-tillage, manure management, composting, making informed crop choices, mixed cropping, green manures, cover crops and diverse grassland swards.

7.6 Soil biodiversity reflects above-ground plant diversity (Wardle 2005), but can be highly variable over short distances and times. Microbial diversity in the UK reflects soil conditions, especially pH, but also vegetation, climatic and other environmental factors. Distinct specialist communities occur in more extreme soils with low diversity (Griffiths and others 2012).

7.7 Soil biological measurements are capable of indicating impacts of soil management and distinguishing between different types of habitats. The subtlety of differences that can be detected is enhanced by applying a range of phenotypic, genotypic and functional measurements. A combination of the following can readily distinguish different soil conditions and impacts, with each reflecting different conditions and pressures (Defra 2004a; Defra, 2014c):

- genetic profiling of archaea and fungi, characterising microbial cell wall constituents;
- the ability of soil microbes to decompose a suite of different substrates; and
- the balance between different groups of soil mites.

Natural England's Long Term Monitoring Programme is applying the majority of these soil biological analyses to assess long term change across 40 National Nature Reserves.

7.8 Soil organisms are arranged in food webs of varying complexity, with internal feedbacks (Bardgett and others 2005). Many soil organisms can remain inactive for long periods when conditions are unfavourable. Highly complex soil environments over space and time probably reduce the impact of competition, but we do not truly understand the true niche requirements of most soil organisms.

7.9 The vast unexplored biodiversity of soils will be economically important in areas such as medicine, industry, agriculture and environmental bioremediation. Most clinically relevant antibiotics today originate from soil-dwelling actinomycetes (Keiser 2000) and compounds from soil microorganisms have applications as antitumor, cholesterol-lowering, immunosuppressant, antiprotozoal, antihelminth, antiviral and anti-ageing drugs (Vaishnav & Demain 2011).

7.10 Soil biodiversity has been largely ignored by conservationists (Usher, 2005). Despite their huge diversity, only 1% of IUCN red list species are soil organisms (Turbé and others 2010) and the topic has often been seen as too complex to address. Recent advances in molecular techniques enable us to unravel the diversity of soils (eg. the soil metagenome), and many larger soil organisms such as worms are amenable to standard approaches to conservation (eg. Jones & Eggleton 2010).

Areas that are subject to active research and debate:

7.11 The extent to which soil diversity is important to soil function and resilience. The ability of perturbed soil systems to deliver some ecosystem functions despite losses of biodiversity suggests that many species carry out similar functions within soil communities, and that diversity itself is not necessary for soils to function - a phenomenon referred to as "functional redundancy" (Settälä and others 2005). However, there is also much evidence of highly specific trophic interactions among soil communities. For example, selective grazing on one fungal species, over another, by a springtail changed the balance of fungi and thereby the decomposition rates of coniferous leaf litter (Newell and others, 1984a, 1984b). Other important functions, such as mycorrhizal mutualisms or nitrogen fixation are specifically associated with particular suites of organisms. and assumptions of redundancy based on broad-scale functions such as nitrogen release are unlikely to reflect the complexity of the soil environment (Schimel and others, 2005). Biological diversity has been shown to be important for the resistance and resilience of biological functions against perturbations (Defra 2010i). There is also evidence that the diversity of soil communities, as well as the biomass and activity, is linked to the provision of a wide range of ecosystem services. A less diverse soil was observed to leach more phosphorus, sequester less carbon, turn over less nitrogen and support lower plant diversity (Wagg and others, 2014).

7.12 The extent to which plants drive soil biotic processes, or soil biotic processes control plants. If soil biotic processes provide positive feedback mechanisms to stabilise plant communities, how can these be influenced to promote succession to more diverse habitats? Defra project BD1451 has indicated that species-rich grasslands often have a high soil fungi:bacteria ratio, which was proposed as an indicator for grassland restorability. Further experiments, however, have shown that the development of these types of communities cannot reliably be accelerated by planting "facilitator" plant species.

7.13 The impact of climate change on soil communities and their function. Defra (2011h) reports that soil microbial community profiling (using Phospholipid Fatty Acids) can detect soil community resistance and resilience to drying or flooding, and suggests that UK soil communities may be particularly susceptible to drying.

7.14 How best to integrate soil biology into farm advice. Natural England (2012) reports that farmers would appreciate tools to assess the soil biological health, and more practical examples of soil biological management. The development of such tools remains an ongoing challenge for applied biologists.

7.15 The extent of variation in many soil organisms across soil types and their interdependences with vegetation and management. Defra (2011a) has begun to explore this. The Countryside Survey (CS) has measured abundance and composition of microbial and invertebrate groups in the major habitats and vegetation classes across GB (Emmett and others, 2010; Griffiths and others, 2011), and has found that soil pH is a major determinant of soil community composition. The EcoFINDERS project (EU FP7) is exploring how soil communities across Europe relate to soil conditions, soil function and land use intensity.

7.16 The distribution and abundance of our rarest earthworms. Recent Natural England research has collated more records of our 5-6 rarest earthworms, but surveys found no evidence of our rarest earthworm *Dendrobaena pygmaea* at its former recorded sites.

7.17 Whether it is possible to deliver measurable improvements in agricultural or environmental functions as a result of managements to enhance soil biota in UK farms. Some of the techniques and systems identified in Natural England (2012) (such as increased organic matter inputs and conservation tillage) are being explored through the HGCA's soils programme using field trials to demonstrate their effectiveness and explore their processes, but these would benefit from more, coordinated, application of soil biological measurements and studies of other techniques such as mixed, or cropping or impact of crop varieties.

7.18 Whether DNA barcoding can be linked to analysis of the soil's metagenome to identify and characterise soil communities. A current Natural England project (RP1439) is exploring this approach, which should enable reliable, low-cost and rapid assessment of soil communities for research and monitoring purposes. The project has identified that multiple gene markers can be used for community assessment, but more complete databases of taxon-specific marker sequences will be needed to support characterisation of communities in terms of species composition.

What we don't know:

7.19 Basic knowledge of most soil organisms: Out of ~11 million species of soil organisms, an estimated 1.5% have been named and classified (Turbé and others 2010) and most ecological roles are understood only at a general level.

7.20 The range of soil species occurring in the UK. While some groups such as earthworms and springtails are relatively well known, genetic analysis is likely to find that some recognised "species" are in fact several similar species. Species lists for other groups, such as soil mites and nematodes, are likely to be incomplete, out of date and confounded by taxonomic changes, and for some groups such as soil rotifers we have no idea how many soil dwelling species we have in the UK. Increasing genetic barcoding of species will not only help to clarify the state of our soil diversity, but will facilitate characterisation of communities by metagenetic approaches.

7.21 The distributions, abundance and population trends for almost all of our soil-dwelling organisms, due to lower survey and monitoring effort than for most above-ground species. The Countryside Survey (CS) has provided a national-scale assessment of microbial biodiversity and of invertebrate groups in the UK (Black and others, 2003; Emmett and others., 2010; Griffiths and others. 2011), providing the first ever national scale understanding of microbial biodiversity. Soil invertebrate data enabled exploration of some patterns among soil communities, but the data are insufficiently numerous or detailed to provide a basis for monitoring or conservation of species or communities. The National Biodiversity Network, Biodiversity Fellows and other initiatives may help, but greater effort, more recorders, more recording schemes, better methods for identification and more accessible identification resources are needed.

7.22 The habitat management requirements for conservation of most soil organisms, including their requirements for undisturbed sites, ongoing management, ephemeral or anthropogenic habitats or for mosaics of different soil and above-ground conditions at different scales. We also do not know the extent to which soil organisms currently benefit from protected status or conservation actions, or whether it is possible to develop and implement conservation management strategies.

7.23 Specific circumstances where soil inoculation is worthwhile to encourage the beneficial function of mycorrhizae, rhizobia, or other beneficial organisms in agriculture. Inoculation success will vary with soil conditions, strains of organisms, crops used, and mode of application.

7.24 How to interpret soil biological measures to link them to desired soil functions, conditions and services. Defra (2014c) has shown that soil life and its functions are sensitive indicators of change, but we don't know whether they can be benchmarked to provide subtle information on soil functions, to inform soil management or set targets.

8 Soils and land management

We know that:

8.1 We have managed our soils since ~4500 B.C. to produce food, fibre and fuel (Pryor, 2010). The intensity of soil management has increased over the last 70 years (eg. Hooftman and Bullock 2013) reflecting increasing population and advances in agricultural and forestry technology. There are very few areas of the UK which have not been strongly influenced by land management, making undisturbed soils such as those under ancient woodlands, a scarce and valuable national resource (Ball and Stevens, 1981).

8.2 Soil structure and function are directly and indirectly affected by land management. Direct effects act through vegetation, organic matter inputs, soil disturbance, hydrology, soil chemistry and nutrient regimes, while indirect effects include ammonia deposition, climate change or competition for water supplies. Modern agricultural use of soils can cause losses of soil organic matter, compaction, erosion, changes in soil biodiversity, and soil contamination (Sakrabani and others 2012).

8.3 Soil degradation is estimated to cost society £1.2 bn per year. Approximately 20% of these costs relate to impacts on agricultural productivity, 20% to flooding, 10% to water quality and the remaining 50% to greenhouse gas flux. However, the costs of losses of soil biodiversity associated with soil degradation, the costs of soil sealing and the cultural impacts of soil degradation are largely unknown (Defra, 2011d).

8.4 Nutrient and sediment losses from agricultural soil are a major source of water pollution. Run-off associated with poor soil structure or capping, releases phosphates and sediment; nitrate is lost by subsurface leaching (Natural England 2009). The water treatment cost of soil erosion could be £21 million per year (Environment Agency 2007) while the annual total cost of soil erosion due to agriculture is estimated at £45 million (Defra 2009c).

8.5 Pesticides, particularly insecticides and fungicides, applied to agricultural land impact on soil communities (Bünemann, 2006) and their function, and are transferred from soils into watercourses, where they cause damage to freshwater ecosystems (Cooper, 1993). Soils also immobilise many pesticides. The microbial communities in soils are important in breaking down pesticides. (Pal and others, 2006).

8.6 Most practices that improve soil function for agriculture are also broadly beneficial for other soil environmental functions and vice versa (Defra 2010j). However, the Defra study did not focus on conflicts between food production and biodiversity.

8.7 Soil organic matter is a key indicator of many desirable soil functions. It helps to maintain soil structure, provides and stores nutrients, supports biological activity, increases water retention and stores carbon (Gobin and others, 2011). Early results from project BD5001 indicate that grassland soils in good structural condition tend to have more organic matter than soils in moderate or poor condition. Soils with more organic matter tend to be more resistant and resilient to damage, with this effect interacting with soil texture and biological properties (Defra 2010i).

8.8 Soils with more organic matter tend to have lower run-off, more infiltration and stronger soil particles (Guerra 1994; Wischmeier & Mannering 1969). Enhancing organic matter should help reduce diffuse pollution, but this can be difficult to achieve within existing farm systems because of limited availability of organic materials (Defra 2009d).

8.9 Loss of organic matter from soils is recognised as a key threat both for its impact on global warming and on soil structure (European Commission 2006). It has been estimated that the annual cost, in terms of treatment, prevention, administration and monitoring, of the carbon lost due to soil cultivation in the UK amounts to £82 million (Environment Agency 2007).

8.10 Mechanical alleviation of soils is unlikely to deliver agricultural yield benefits unless there are clear signs of compaction. Yield increases are most likely in some spring-sown arable crops on light textured soils. Although yield effects are inconsistent, mechanical alleviation of compacted soils can increase infiltration rates. Avoidance of compaction is always likely to be more cost effective than mitigation (Defra 2012b, project RP0359 early results).

8.11 Acidification and nutrient enrichment continue to impact on soil and associated vegetation. Despite recent improvements, 54% of sensitive habitat area still receives damaging levels of acid deposition. Though NOx deposition has reduced, total nitrogen deposition has changed little over 20 years (RoTAP 2011) and 71% of all sensitive habitats receive damaging levels of nutrient nitrogen.

8.12 Agricultural land management options can be employed which should reduce diffuse pollution from soils. A range of practices relating to cultivation, cover crops, controlled traffic, nutrient/manure management and targeted vegetation change are already encouraged through schemes and advice programmes.

8.13 Understanding the limitations and opportunities presented by soil is key to determining habitat restoration success. (Bradley and others 2006). The National Soil Resources Institute Soilscapes map provides broad information on the type of potential natural and semi-natural habitats associated with different broad soil types (NSRI 2011). This will be important in delivering ecological networks to improve habitat connectivity and climate change adaptation.

8.14 Contamination of soils by industrial pollutants can reduce their ability to provide many ecosystem functions and may threaten human health. However, some abandoned contaminated soils support rare and potentially valuable plant species and strains (Whiting and others 2004) capable of tolerating extreme conditions that other species cannot and many such areas do not pose any direct threat to health. Organic contaminants can be broken down in-situ or ex-situ by soil organisms, which can be aided by additives or management to promote activity (Defra 2011c.)

8.15 Deep rooting hybrid grasses (Festulolium) can help reduce runoff, by increasing infiltration (Macleod and others 2013). Although this has only been demonstrated in pot experiments or at the small plot scale.

8.16 Soil hydrology is a key determinant of habitats and animal and plant communities. Subtle differences in water table regimes are associated with distinct plant communities in floodplain meadows (Gowing and others, 2002).

8.17 The Catchment Sensitive Farming programme is having measurable impacts to improve water quality. An assessment of the impact of the first 4 years of the catchment-based farm advice and grant programme indicates that it has had measurable improvements in water quality across the majority of catchments and across the majority of pollutants (Environment Agency 2011).

Areas that are subject to active research and debate:

8.18 The nature of soil compaction, its impacts on soil function, including biodiversity, how it can be characterised or measured in the field, and whether it can be remediated by mechanical loosening or deep rooting plants. Defra project BD5001 is exploring this through survey approaches and experiments measuring compaction indicators, soil properties and function.

8.19 Techniques, technology or systems which could result in more sustainable management of agricultural soils for the future. These could include perennial crop breeds (Glover 2010), improved rotations (eg. Schönhart 2011), agro-forestry (Bullock and others 1994), permaculture (see **http://www.permaculture.org.uk/whats-going-on/association-work/farming**), biodynamic farming (eg. Fließbach and others 2007).

8.20 How effective regulation and cross compliance are at preventing damaging soil practices.

8.21 How to improve coordination and delivery of soil guidance and regulation engage land managers, developers etc,(see Defra FF0204).

8.22 Whether plant extractable P (Phosphorus) is a suitable indicator for restoration success for species-rich grasslands. This has been used to target grassland restoration options in agri-environment schemes (Defra 2001) but other options, such as nitrogen supply, total soil P, or ratios of cell membrane lipids from fungal and bacterial cells (see project RP0194), have been suggested as better indicators.

8.23 The impacts of atmospheric deposition on soil functions and habitat restorability. Peatland function is being examined through the PeatBog programme (see **http://www.sste.mmu.ac.uk/peatbog/**).

8.24 The relationship between reduced or no-till agriculture and soil structure and function including the impacts of greenhouse gas emissions of adopting the practice, both from soils and management. Some aspects of this are being examined by the HGCA Soil Research Programme (HGCA 2013)

8.25 True rates of soil erosion. Defra (2011g) proposes a range of techniques for monitoring soil erosion and these are now being put into practices in a current pilot project (SP1311).

What we don't know:

8.26 Whether field and catchment-scale manipulation of soil organic matter can impact on runoff, erosion, sedimentation and phosporus pollution.

8.27 Practical management to improve soil resilience to degradation. Increasing organic matter content would be likely to confer resilience in soil structure and function, but the impact of this has yet to be demonstrated in the field.

8.28 How to quantify economic and environmental benefits and manage risks of improved soil management techniques so farmers are persuaded to implement these techniques.

8.29 How soil properties will influence habitats and communities under future climate or management scenarios. Data has been gathered relating some soil characteristics to plant species' requirements, to inform air pollution impact assessment (RoTAP 2011), but this approach could be developed for a wider range of soil properties and plant species using Countryside Survey and other data. This also has good potential applications for informing habitat creation and conservation management.

8.30 Impacts of grazing on many soil properties, including carbon storage and GHG flux (Natural England 2012b) and compaction (Defra 2012b).

8.31 The combinations of crop or forage species that would deliver the best interactive effects on soil carbon structure, function (eg infiltration) and biological activity, and the impacts of longer term crop rotations (eg over 6 years).

8.32 Whether background levels of toxic pollutants in intensively managed or urban soils impact on the soil communities and functions. Risk modelling on pollutants has identified possible risks for UK soils, such as critical loads for metals, but their actual impact on UK soils has not yet been assessed..

8.33 The economic impacts of soil biodiversity losses associated with soil degradation (Defra, 2011d).

9 Sustainable land use in relation to development

We know that:

9.1 The importance of protecting the soil and the many ecosystem functions it provides in spatial planning and in the urban environment has generally been under-recognised and undervalued (Defra 2009b). Urban ecosystems can play a key role in improving towns and cities (Royal Commission on Environmental Pollution 2007).

9.2 Development has a major impact on soil, reducing its capacity to fulfil many important functions (EEA 2011; European Commission 2006). Soil loss and degradation by sealing (eg covering by concrete or tarmac) is nearly irreversible (European Communities 2005), reducing the soils' ability to deliver important ecosystem services. This is recognised in national planning guidance which requires that the benefits of high quality agricultural land are taken account of in planning decisions and that soils are protected and enhanced. (DCLG 2012).

9.3 Sealing issues can be mitigated in some cases by use of alternative surfacing materials and by building green roofs (European Commission 2011). Development can double run-off, increasing the risks of urban flooding (RHS 2005), but Sustainable Drainage Systems (SUDS) such as permeable paving or gravel can enable soil to perform its role in groundwater recharge (Woods-Ballard and others 2007; Hou and others 2008; European Commission, 2011).

9.4 Some developments are less harmful to soil functions or are more amenable to soil restoration. With care, former mineral extraction sites can be restored to high standards for agriculture (MAFF 2000a) and provide important areas for new habitat creation. The Nature After Minerals project is helping to deliver biodiversity outcomes (Davies 2006).

9.5 During construction soils may be subject to loss, compaction and contamination causing loss of and damage to the soils. Careful planning and soil management can reduce soil degradation as well as the overall costs of development (Defra 2009b).

9.6 The use of soil as a raw material is depleting the available in-situ resource and in many cases is not considered sustainable. For example, extraction of peat for horticultural use (Defra 2010b; HM Government 2011) and sand for brick-earth (European Commission 2005).

Areas that are subject to active research and debate:

9.7 How soil resources can be managed to optimise land use including through the planning system, for example by encouraging multi-functionality, but recognising that not all soils are inherently suitable for all purposes (Haygarth & Ritz 2009

9.8 How best to get the ecosystem services delivered by soil better recognised and protected within the planning system, for example by providing better guidance to planners on the potential services provided by different soils (Defra 2009c).

9.9 Extent and significance of loss of soil and 'best and most versatile' (BMV) agricultural land through development or other irreversible land use change. Planning studies have shown that the presence of BMV agricultural land is given consideration, but to varying levels of detail (Defra 2010k).

What we don't know:

9.10 How best to measure the long term economic and other impacts of development on our national stock of soils (Natural Capital Committee 2013) including our best and most versatile farmland (Foresight Land Use Futures Project 2010),so that these finite resources and their protection can be better quantified, monitored and addressed (Defra 2011d).

9.11 Relative value of soils for other potential and current ecosystem services besides agricultural production and how this could be translated into practical tools for land use planning to support national planning guidance.

9.12 How best to maintain, develop and deploy our existing tools such as the Agricultural Land Classification in a changing planning and environmental context, including making the archive of existing data more widely accessible.

9.13 The extent to which current published best practice guidance on soils and soil handling is taken into account in development projects, for example in mineral restoration and construction, and whether there are any gaps or modifications needed to improve outcomes for soils. Current guidance (MAFF 2000b; Defra 2004c; Defra 2009b) focuses strongly on physical characteristics of mineral soils with less emphasis on biological impacts and processes (Harris and others 2005) and with little recognition of the distinctive requirements for organic and peaty soils.

9.14 Environmental, economic and social value of urban green infrastructure soils. A recent report showed that quality of green space was important (CABE 2010), but did not consider the value of the underlying soils nor the potential links these have to the successful creation of priority habitats and other green infrastructure.

9.15 We know little about urban soils. There is a lack of data on the extent and fate of soil removal prior to development, and the carbon stocks of urban soils. Improved data on these topics would strengthen the LULUCF element of the UK Greenhouse Gas inventory (Webb and others, 2014)).

10 Soils in climate change adaptation

We know that:

10.1 Predicted hotter drier summers and warmer wetter winters, and more frequent extreme weather (Defra 2009a) will present both opportunities and challenges for soils (Defra 2010c, h).

10.2 Low lying and coastal soils will be affected by sea level rise. The 12-75 cm absolute sea level rise predicted by 2095 (Lowe and others 2009) will impact on areas which are important:

- as carbon stores;
- for biodiversity; and
- for food production.

10.3 Less rainfall in summer will increase the risk of wind erosion and increase soil droughtiness. Soil organic matter content is positively correlated with rainfall (Defra 2004b), so drier soils could lose the structural and water holding benefits that organic matter confers. Although short-term yields could increase, crops will be more likely to suffer summer moisture deficit (Defra 2005b).

10.4 Greater intensity rainfall events and more rainfall in winter will increase the risk of soil erosion by water, especially of bare upland soils, and increased losses of dissolved organic carbon (Dinsmore 2014, unpublished). In the lowlands there will be risks of structural damage of soils, increased run-off and erosion of soil into watercourses and loss of soil nutrients (Defra 2005b).

10.5 The ability of landscape-scale projects to link existing areas of wildlife habitat will be determined in part by the suitability of the soils to support those habitats (Bradley and others 2006).

10.6 Climate change is likely to impact on the function of urban soils, damaging buildings and landfill caps through increased shrink-swell of clays. More extreme weather will make management of flooding through control of soil sealing more important (Defra 2010h).

Areas that are subject to active research and debate:

10.7 The role of non-degraded soils and how to improve their resilience in climate change adaptation terms. The requirement for robust protection for least damaged soils (in biological terms) needs to be considered as part of the adaptation strategies, alongside consideration of how to define a non-degraded soil.

10.8 How climate change will influence agricultural land use and management, and the impacts of this on soils and the natural environment. A Defra study (Defra SP1104) is beginning to address this by considering the impact of climate change on the suitability of soils for agriculture as defined by the Agricultural Land Classification.

What we don’t know:

10.9 Impacts of climate change on soil biological function, pests and diseases, pollutant processing and interactive effects between changes in CO2, temperature, rainfall and atmospheric deposition (Defra 2005b, Defra 2010c).

10.10 What soil management could make soils and their functions more resilient in the face of climate change, including more frequent extreme weather events.

10.11 The impact of sea level rise and increased flood risk upon soils and whether these present opportunities to deliver different ecosystem services.

10.12 How soil biota will react to changes in climate, especially those with limited dispersal ability or occupying narrow ecological niches, or what effects soil biotic impacts will have on wider biodiversity. Focus to date has been on above ground ecology.

10.13 How the ability of above-ground plants and animals to adjust to climate change will be limited or facilitated by soil conditions (eg soil texture, chemistry, hydrology, microbiology). See Land Management section for opportunities for linking plant trait, soil and climate databases.

10.14 The likely impact of climate change on other characteristics of urban soils, including carbon storage, localised risk of heavy metal contaminant mobilisation, soil biological diversity, soil-borne pathogens and soil run-off.

11 Current Natural England evidence projects

11.1 RP1439: Genetic Barcoding and Metagenetic approaches for Grassland Soil Mesofauna Communities. Project to link species barcoding approaches for springtails and mites with soil metagenetic approaches in grassland, to develop techniques for monitoring and researching the ecology, distribution and trends in soil mesofauna.

11.2 RP0437: Mapping Peat Depth and Carbon Storage in England. Project with North Pennines AONB Partnership to develop peat depth and carbon storage survey techniques, gather data and produce maps and estimates of peat carbon storage in England.

11.3 RP0229 Soil Data Project Making soils data collected as part of the Agricultural Land Classification survey programme available digitally.

11.4 RP0322 Managing Peatlands as Carbon Stores. PhD CASE studentship under Natural England and University of Leeds, exploring GHG emissions from raised bog over a chronosequence following restoration.

11.5 RP0194 Diversification of grassland through the manipulation of plant-soil interactions and the identification of indicators of restorability. A Defra-funded project, (BD1451) managed by Natural England, aiming to explore and explain the links between soil fungal:bacterial ratios plant diversity and succession and evaluate potential indicators for targeting sites for grassland re-creation or enhancement.

11.6 Evidence Project Database. A list of current research and monitoring projects is available on Natural England's internal systems. We are currently working on making this available to everyone. In the meantime a list of Natural England's evidence projects that were current in 2014 can be seen on the National Archives at:
http://webarchive.nationalarchives.gov.uk/20140711133551/http://www.naturalengland.org.uk/ourwork/evidence/register/default.aspx

12 Key external research programmes

Defra has a large R&D budget in relation to soils with around 300 projects listed in its database. **http://randd.defra.gov.uk/** . The following current projects are of particular relevance to Natural England.

BD5001 Characterisation of soil structural degradation under grassland and development of measures to ameliorate its impact on biodiversity and other soil functions. A Defra-funded project

(BD5001) managed by Natural England, characterising soil compaction on 300 grassland sites in England and Wales, and conducting experiments to explore remediation by loosening and use of diverse seed mixes, and the impacts of these on biodiversity, soil and infiltration
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16827

SP1202 Investigation of restoration peatland (grip blocking) techniques to achieve best outcomes for methane and greenhouse gas emissions / balance. Developing restoration methods for blanket peatlands which produce the lowest methane emissions and global warming potential.
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=16991

SP1205 Greenhouse gas emissions associated with non gaseous losses of carbon - fate of particulate and dissolved carbon. Exploring the fate of peat-derived fluvial carbon, including losses as greenhouse gases.
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=17326

SP1210 Lowland peatland systems in England and Wales – evaluating greenhouse gas fluxes and carbon balances
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=17584

SP1311 Piloting a cost-effective framework for monitoring soil erosion in England and Wales.
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18369

SP1104 The impact of climate change on the suitability of soils for agriculture as defined by the Agricultural Land Classification - URL:
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16929

BD5104 - Restoration of blanket bog vegetation for biodiversity, carbon storage and water regulation
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=17733

BD5003 - Managing Grassland Diversity For Multiple Ecosystem Services:
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=17251

AC0111 Air quality measurements on cracking clay soils. Exploring pollution swapping issues relating to manure and slurry additions on poorly drained soils.
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15541

DECC tender TRN860/07/2014 "Scoping the use of the methodology set out in Chapters 2 and 3 of the '2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories': Wetlands in the UK GHG Inventory: Land Use, Land Use Change and Forest". This project will explore GHG fluxes from peatland drainage and rewetting, review literature on emission factors and develop projections of greenhouse gas mitigation potential.

The STARS Centre for Doctoral Training is a consortium of 8 organizations, comprising 4 UK universities and 4 UK research institutes, who are collaborating to support PhD studentships in soil science. **http://www.starsoil.org.uk/portal/projects**

The Scottish Government funds a range of applied strategic soils research through its Environmental Change and Food, Land and People Programmes **http://www.scotland.gov.uk/Topics/Research/About/EBAR/StrategicResearch/future-research-strategy/**, which include work on how soil impacts on agri-food production, climate, biodiversity and society. Research includes developing methods for minimising the impact of agriculture on soils through improved crop varieties; investigating the effect of tillage, compaction, conventional versus organic management and land use change on soil structure and GHG emissions; estimating the amount of carbon that cultivated topsoils could potentially gain, store or lose; characterising soil biodiversity and its role in soil function (including microbial communities), and examining the role of soils in water quality and food quality.

In addition, the Scottish Government's ClimateXChange (CXC) Centre of Expertise **http://www.climatexchange.org.uk/** has investigated the climate change abatement potential of restored peatlands, whilst the Centre of Expertise for Waters **http://www.crew.ac.uk/** (CREW) has dealt with a number of areas relating to soil management, eg water quality and diffuse pollution mitigation.

Forest Research have a soils research programme (**http://www.forestry.gov.uk/fr/INFD-623H2G**) which includes projects examining effects of tree harvesting on soil, air pollution soil impacts, climate change impacts on forest soils, soil quality indicators, fine tree roots, wood ash application to forests and forest soil survey and monitoring (BioSoil project **http://www.forestry.gov.uk/fr/INFD-73UDF3**)

Scottish Natural Heritage published their research strategy to 2014 (**http://www.snh.gov.uk/docs/C265328.pdf**) which included work on the role of soil and soil biodiversity, mapping the conservation value of soils, developing mitigation strategies against climate change impacts on soils, managing organic soils as carbon sinks, and soil impacts of energy crops. Future research will be coordinated through the Scottish Soils Framework **http://www.scotland.gov.uk/Publications/2009/05/20145602/0**.

HGCA, with support from Defra are conducting a 4-year research programme on the impacts of tillage practices, potato management, organic matter management on soil conditions and function, along with studies to make better use of soil and crop yield data. **http://www.hgca.com/content.output/6321/6321/Research/Research/Soil%20research.mspx**

IUCN peatlands programme have conducted a "peatlands inquiry" - a series of 8 linked reviews, a public inquiry event and a final report due to be published in Autumn 2011. This programme is also attempting to establish a peatland research hub. **http://www.iucn-uk-peatlandprogramme.org/**

Living with Environmental Change Programme – a partnership programme of funding and delivery bodies aiming to coordinate interdisciplinary research to adapt to and mitigate against climate change and other environmental changes. **http://www.lwec.org.uk/**

Agricultural UK Greenhouse Gas Platform. A collaborative project to generate emissions factors for agriculture, based on existing data, specifically for livestock methane, and experimental work on nitrous oxide emissions associated with additions to cultivated and grassland soils. **http://www.ghgplatform.org.uk/**

Natural Environment Research Council (NERC) thematic programmes provide funding for research on specific themes. Among the current thematic programmes (**http://www.nerc.ac.uk/research/programmes/list.asp**) the following areas are relevant to soils: Biodiversity and Ecosystem Service Sustainability, Carbon Capture and Storage, Changing Water Cycle, Ecosystem Services for Poverty Alleviation, Flood Risk from Extreme Events, Land Based Renewables, Macronutrient Cycles, Methane Network, Post Genomics and Proteomics, Quantifying and Understanding the Earth System, Taxonomy and Systematics, Valuing Nature Network, Virtual Observatory.

The Centre for Ecology and Hydrology Delivers environmental research at the UK scale, including the Countryside Survey, which involves periodic assessments of the natural environment, including soil characteristics at 500 or more sites. CEH is also a partner in the EcoFINDERS project (EU FP7) which has undertaken i) a large-scale transect across EU of different soil types and land uses to ascertain normal operating ranges of soil microbial and invertebrate groups, and ii) Studies of effects of land use intensity on soil biological communities and soil functioning. These both included various sites in England. Findings are currently being prepared for publication.

Land Use, Land Use Change and Forestry (LULUCF) Inventory. DECC-funded work contracted to CEH and Forest Research to report annually on emissions from this sector. This includes emissions and removals of carbon dioxide from soils as a result of land use change and land management, and emissions of nitrous oxide and methane from soils as a result of land use change.

Biotechnology and Biological Sciences Research Council (BBSRC) also fund soil research. This includes studies of microbial effects on soil surface hydrophobicity. a suite of experimental work on nitrous oxide and soil structure. "Understanding soil quality and resilience: effects of perturbations and natural variations on nitrous oxide emission, water retention and structure." ERFF codes 375177. 375180, 375182, 375184, 375468. See **http://www.environmentalresearch.info/search/OrganisationDetail.aspx?id=372834#80d07485-6e52-4ab9-91fd-c8b61c391d14**

PeatBog programme. A European project examining impacts of atmospheric deposition and climate change on peat bog function. **http://www.sste.mmu.ac.uk/peatbog/**

Conservation Evidence provides an evidence synopsis service which synthesises research into a range of environmental topics to inform conservation management, including soils. Evidence on soil management impacts can be found at **http://conservationevidence.com/data/index?category_id=2**

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