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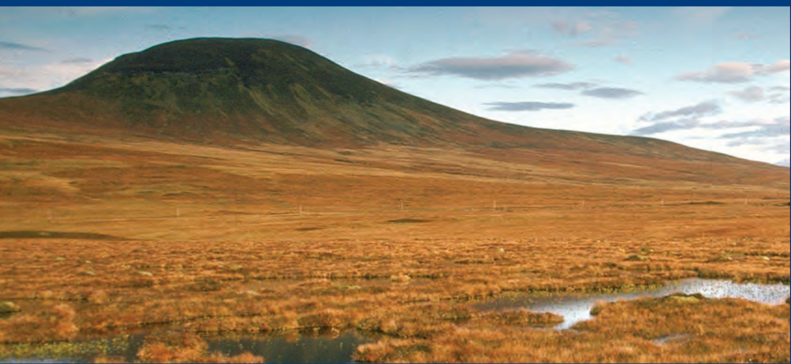
SCOTTISH GOVERNMENT

The State of Scotland's Soil



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Ministerial foreword

Our soils are a vital part of our economy, environment and heritage.

This new State of Scotland's Soil report follows on from the Scottish Soil Framework (2009), a wide-ranging review of the pressures on, and the opportunities for, our soils. This report responds to the Framework's vision that soils are a finite, non-renewable resource that should be managed for sustainable development.

The soil is fundamental to Scotland's agriculture with its £2.5bn a year turnover and, thus, to our food and drink industry. But all businesses and communities, urban and rural, depend on the land and the continuing health of our environment, of which the soil is an essential part. Since the first State of Soil Report was published in 2001, our understanding of the value of soils in the environment and for society, and of the pressures on them, has changed and grown.

Soils are important for climate change mitigation and adaptation. There is now wide recognition of the carbon in our soil (some 3,000 million tonnes), much of it in peatlands, and the need to retain it and prevent large scale losses. Soils in good condition contribute to many different ecosystem services, including protection of the water environment and biodiversity. The Report provides insights on the functions of soil, as well as on the nature and relative importance of the threats to soil quality.

This document is an important means of highlighting to a wide range of stakeholders some key issues for our soil environment. In future, State of Environment reports will be published on Scotland's Environment Website, which will be launched later this year. This will allow reports to be updated as new data becomes available and to be easily accessible to interested parties.

The State of Scotland's Soil Report, like the Scottish Soil Framework, has been developed with information and advice from the major Scottish research institutes, especially the Macaulay Land Use Research Institute, and from other public bodies, in particular the Scottish Environment Protection Agency and Scottish Natural Heritage, in consultation with the wider stakeholder community. The Report reflects the expertise and the interest in soil science we have in Scotland.

More than ever, Scotland's soils remain one of our nation's greatest natural assets.

Roseanna Cunningham MSP
Minister for Environment and Climate Change

Executive summary

The publication of this report is an action arising from the 2009 Scottish Soil Framework. It aims to contribute to the wider understanding that soils are a vital part of our economy, environment and heritage, to be safeguarded for existing and future generations.

This report will be revised in a web format before the end of 2011, taking into account any new information available and the feedback we receive on this publication. It will then be published on Scotland's Environment Website, which will allow it to be regularly updated in future as new information becomes available.

Soils are an important natural asset on which life depends. They perform a wide range of essential environmental, social and economic functions, such as growing food, controlling the quality and quantity of water flow, and storing carbon. Soil quality is defined as the ability of soils to carry out these functions. Ensuring that soils are in a good state to deliver these essential functions is vital for the sustainability of our environment. This is particularly important as soil is essentially a non-renewable resource whose role in supporting sustainable development needs to be better understood and protected.

Scotland's soils are highly variable because of the diverse geology and climate in Scotland. As a result, their nature and use differs markedly from soils in the rest of the UK and, indeed, most of Europe. Scottish soils are generally rich in organic matter and contain more than half of the UK's soil carbon. They support the important agriculture and forestry industries as well as a number of internationally important habitats.

The State of Scotland's Soil Report collates the most recent information available from a variety of sources and builds on previous reports by SEPA (2001) and Towers et al. (2006) and is part of wider environmental reporting activities. It adds to our understanding of soil by using a conceptual model to help describe the drivers and pressures that affect the state of the soil, how these pressures result in a number of threats to soil functions, and their consequences for the wider environment, the economy and society. Finally we describe potential management responses.

The most important pressures affecting soil are ***climate change*** and ***changes in land use and land management practices***. Climate change can have a range of impacts on soil processes, mainly due to changes in soil wetness, soil temperature and also rainfall patterns, which result in soil degradation, including loss of organic matter, erosion and compaction. Changes in land use and land management practices can also result in a range of soil degradation processes, including loss of organic matter, erosion and contamination as well as a direct loss of soil through sealing and development.

The report considers seven threats to soil functions:

- **loss of organic matter** – soil organic matter underpins many soil functions. It is particularly important as a carbon store and thus has implications for climate change. The most recent evidence suggests relatively low rates of change in topsoil soil organic matter concentration; however, there is still uncertainty about the status and change in the soil organic matter stock;
- **sealing** – there is no systematic data collection to capture the extent and the quality of land being sealed. It is essential that the value of soil functions is taken into account during development planning;
- **contamination** – data on the extent and nature of soil contamination is limited. There is some evidence that some contaminant inputs and their impacts are reducing, for example from atmospheric acid deposition. However, many other potential soil contaminants such as organic chemicals are not routinely measured;

- **change in soil biodiversity** – soil biodiversity is essential to most ecosystem services. However, relatively little is known about the state and trend of Scotland's soil biodiversity except for a few protected soil-dwelling species; this is a major gap in our understanding of the contribution of soils to ecosystem services;
- **erosion and landslides** – soil erosion is one of the more visible of the threats to soil. Impacts include loss of soil carbon, loss of fertility and off-site effects such as impacts on the water environment. Landslides, although potentially life threatening, remain rare in Scotland;
- **compaction** – the processes associated with soil compaction are broadly understood, but there is no systematic assessment of the extent and wider implications of soil compaction in Scotland;
- **emerging issues** – it is difficult to evaluate the potential impacts of emerging issues as there is little evidence currently available.

Thus, although there have been many steps forward since the first State of Soil Report, there is still a lack of data from which evidence of change in, and damage to, soils can be determined.

An evaluation of the relative importance of the threats to soil functions was carried out on the basis of assessment criteria and a scoring system developed for this report. This provides new evidence to enable future prioritisation of resources and focus activities on the most important issues for Scotland's soils. This assessment was primarily based on the collective expert judgement of the report authors. In addition, a socio-economic assessment of the impacts of the threats was derived from information published in Glenk et al. (2010). The two scoring systems were then brought together to provide a wider understanding of Scottish soils. The inclusion of the socio-economic analysis presents an important step forward from previous State of Soil reports and has highlighted the lack of Scotland-specific socio-economic data available from which assessments can be made.

This evaluation suggests that the principal threats to soil functions are ***loss of soil organic matter, changes in soil biodiversity***, and ***erosion and landslides***. ***Soil sealing*** was also ranked as an important threat.

This reflects the importance of soil organic matter, and the associated role soil biodiversity plays, in storing carbon as well as underpinning the majority of soil functions and wider ecosystem services.

In the future, the challenges facing Scotland's soil will be to understand and deal with a number of issues including:

- **the need for policy integration:** understanding the role of soil in existing policy and developing recommendations for future soil policy to ensure soil is sufficiently protected;
- **tackling the lack of systematic Scottish soil data:** understanding what information is already available, identifying gaps and making recommendations for future soil monitoring;
- **understanding soil management** and providing recommendations for targeting practical management options to minimise soil degradation and its consequences.

Addressing these issues will increase both our understanding of soils and our ability to improve soil protection and soil quality. Sustainable soil management should be recognised as part of the solution to a number of the key issues that the world faces; combining these three areas of policy, data and the implementation of practical solutions will help us make progress with this approach.

Gullies in peat, north-west Scotland

Contents

1 Introduction

1.1 Background

Soils are an important natural asset on which life depends. They perform a wide range of essential environmental, social and economic functions, such as growing food, controlling the quality and quantity of water flow and storing carbon. Soil quality is defined as the ability of soils to carry out these functions. Soils also underpin many other ecosystem services (Chapter 2). Ensuring that soils are in a good state to deliver these essential goods and services is therefore vital for the sustainability of the environment.

There is no Scotland-wide soil monitoring programme currently in place to assess the state of Scotland's soils and how they are changing through time. However, a number of organisations sample and analyse soils for a variety of purposes and report their results in a range of publications. This report collates the most recent data available from a variety of sources to provide a picture of the current state of soil in Scotland and to comment on whether there is any improving or worsening trend as far as current knowledge allows.

SEPA first reported on the State of Scotland's Soil in 2001 in the 'State of the Environment – Soil Quality Report' (SEPA, 2001). This was followed by a report to the then Scottish Executive on 'Scotland's Soil Resource: Current State and Threats' (Towers et al., 2006) which was used as evidence to support the development of the Scottish Soil Framework (Scottish Government, 2009). The State of Scotland's Soil (2011) report builds on these earlier reports; it aims to raise awareness of the importance of soils, to inform people of the key environmental issues relating to soil and to encourage greater debate on how to protect and enhance soil for a more sustainable Scotland.

1.2 Policy context

There is growing recognition amongst policy makers and land practitioners alike of the wide range of essential services provided by soils. It is also acknowledged that soils are essentially a non-renewable resource whose role in supporting sustainable use and management of the environment needs to be better understood and protected.

In 2006, the European Commission adopted a 'Thematic Strategy for Soil Protection' (European Commission, 2006a) that identified a number of threats to soil quality and submitted a proposal for a Soil Framework Directive (European Commission, 2006b) to put in place a statutory mechanism to address soil degradation. However, at the time of publication of this report, an agreement has not yet been reached between Member States on how to take this forward and the draft Soil Framework Directive has yet to be ratified.

The Scottish Government vision, set out in the Scottish Soil Framework (Scottish Government, 2009), is that "soils are recognised as a vital part of the economy, environment and heritage and should be safeguarded for existing and future generations". The Framework recognises that to achieve the Scottish Government's purpose of increasing sustainable economic growth it is essential to protect soils. For example, soils in Scotland underpin the important agriculture and forestry industries, and our ability to produce high quality, uncontaminated food relies on sustaining the fertility and health of our soil. [1]

[1] Agriculture contributed £654 million [Gross Value Added (GVA)] to the Scottish economy in 2009 (Scottish Government, 2010a), while the total GVA (direct, indirect and induced) associated with Scottish timber was estimated to be around £460 million at 2007/08 prices (Edwards et al., 2008).

There are a number of individual pieces of legislation spread across a range of policy areas that give some level of protection to some aspects of soil quality (Scottish Government, 2009); however, there is no single piece of legislation that sets out the appropriate protection that encompasses all soil types and soil functions. The Scottish Soil Framework (Scottish Government, 2009) recognises that there is a need for policy integration to ensure soils are adequately protected and highlights climate change, national food policy, flooding and water quality as particular areas where policy integration would be beneficial.

More recently, the Climate Change (Scotland) Act (2009) made a commitment that greenhouse gas emissions in Scotland will be cut by 80% of 1990 levels by 2050. Understanding the contribution of soil and land management practices to greenhouse gas emissions and how these can be mitigated will be a major factor in achieving these reduction targets. One of the requirements of the Act is that Scottish Ministers must lay a Land Use Strategy before the Scottish Parliament by 31 March 2011 (currently in draft form; Scottish Government, 2010b). This explicitly identifies the need to protect and manage soils given their potential to contribute to greenhouse gas emissions. Soils store carbon and exchange greenhouse gases with the atmosphere and the way in which they are managed can determine whether they become a net source or sink of greenhouse gases. Soils' wider role in land use is also acknowledged in the (Draft) Land Use Strategy for Scotland (Scottish Government, 2010b).

There is a need for robust evidence to allow effective decisions to be made on how to progress towards a more sustainable use of Scotland's soil resource. In particular, to allow a balance to be struck between, the often competing, social, economic and environmental issues. This report collates current knowledge and understanding of Scottish soils and presents the evidence base for policy review and development.

1.3 Factors influencing the state of soil

Evidence gathered to support the development of European and National soil strategies (e.g. European Commission 2006a; Towers et al., 2006; Defra, 2009) have shown that there are many factors that influence the state of soil, both natural and man-made. These range from climate change to land use, land use management and industry. The 2001 SEPA Soil Quality Report (SEPA, 2001) also assessed the pressures and impacts on soil from human activities, concluding that agricultural practices, acid deposition and the input of contaminants from waste application to land were the greatest threats. Towers et al. (2006) carried out a comprehensive review of the state of, and threats on, Scotland's soil resource. They concluded that climate change and loss of organic matter were the most significant threats to soil in Scotland on a national scale. SEPA's 2006 State of Environment Report (SEPA, 2006) emphasised that soil was poorly understood and that the nature, extent and diversity of soil types present in Scotland posed a considerable challenge in terms of reporting on the overall state of soil. All three reports highlighted that there was still only limited data available from which to draw conclusions on the State of Scotland's soil. In particular, Towers et al. (2006) concluded that there was a lack of trend data from which evidence of change in, and damage to, soils might be determined.

The 2011 State of Scotland's Soil report addresses these issues by collating updated evidence from the available literature. In addition, it presents, for the first time, a review of the collection and development of socio-economic data on Scottish soils specifically commissioned for this report (Glenk et al., 2010).

1.4 The State of Scotland's Soil Report

This report highlights the importance of soil in an environmental, social and economic context. It outlines the key properties of Scotland's soils, the pressures on them, what drives these pressures, and the consequences that any changes have for soil and the wider environment. The report describes the state of Scotland's soil to the extent that current knowledge allows, and identifies how and where improvements can be made to both the state of soil and our understanding of it.

A Management Group consisting of Scottish Environment Protection Agency (SEPA), Scottish Government (SG) and Macaulay Land Use Research Institute (MLURI) oversaw the production of the report. It was supported by a Working Group consisting of representatives from British Geological Survey (BGS), Centre for Ecology and Hydrology (CEH), Forestry Commission Scotland (FCS), Historic Scotland (HS), MLURI, Scottish Agricultural College (SAC), Scottish Crop Research Institute (SCRI), SEPA, SG and Scottish Natural Heritage (SNH).

Collation and publication of the report was managed by an Editorial Group (SEPA, MLURI and SNH). Specific contributions were written by small groups of specialists from a range of organisations including BGS, CEH, FCS, Institute of Occupational Medicine (IOM), MLURI, SAC, SCRI, SEPA, SNH, UK Biochar Research Centre (UKBRC) and University of Glasgow.

All member organisations of the Soil Report Working group as well as a wide range of stakeholders, including the Soil Focus Group (Scottish Government, 2009), were consulted on a draft of the report before publication. The report was independently reviewed by Brian Chambers (ADAS). Ian Rugg and James Skates from the Welsh Assembly Government also provided helpful comments. A wide range of comments was received, the draft report amended accordingly and the final report published.

It is intended that any relevant comments remaining will be addressed and the report amended where necessary before it is published on Scotland's Environment Website when it becomes available in the autumn of 2011. The web format will allow the report to be regularly updated when new information and data become available in the future.

2 The Scottish soil resource: its role and importance

The importance of the soil resource is becoming increasingly recognised in today's society as the wider social, economic and environmental benefits that soil provides become more apparent. There are a number of topical issues, from a local to a global scale, that require the sustainable use of soil, including food supply and security, energy supply and security, loss of biodiversity and environmental change.

Soil not only provides the backbone of Scotland's rural economy but also underpins much of its natural heritage. It also forms the platform for vital greenspace in towns and cities. Agriculture contributes about £700 million to the Scottish economy annually (Scottish Government, 2010a) and, like the forestry industry, relies on healthy soils for its very existence. The impact of these industries extends well beyond rural Scotland, reaching to, for example, the food and drink industry, retail, tourism and construction industries. Soil also underpins nationally and internationally valued and rare habitats; these are important in their own right, as well as playing an important role in the tourism industry. Most drinking water has passed through or run-off over soils into lochs and reservoirs. Soils can also play a key role in flood management. The rural sector is a major and increasingly important contributor to Scotland's climate change response, through seeking to maximise soil's carbon storage capacity (Scottish Government, 2010b). Soils clearly make a very important contribution to the delivery of ecosystem services and this aspect will be explored in more detail in section 2.3.

Scotland's soils are relatively young compared to others worldwide and have slowly been developing over the past 10,000 years since the last Ice Age. However, human activities have left a significant imprint on Scotland's landscape and soils that appear to be 'natural' have been radically altered by man over centuries and even millennia. For example, the accumulation of waste products on the fringes of some early settlements has given rise to valuable soils enriched in organic matter and nutrients (plaggen soil). In addition, the extent of natural woodland in Scotland is a fraction of what it was previously as a result of clearance for fuel and agricultural improvement resulting in significant changes in soil properties.

The study of soils has gone through a number of phases over the past 100 years, from initially being focussed on the agricultural production role and benefit, to now encompassing the wider issues of delivering ecosystem services. Now is an apt time to bring the expertise developed during these different phases together as Scotland seeks to make its contribution to the current global challenges outlined above. The context has changed since the publication of the SEPA State of Soils Report of 2001 (SEPA, 2001) and the Scotland's Soil Resource report of 2006 (Towers et al., 2006) and this report provides an update to both of these.

2.1 The soils of Scotland

2.1.1 The soil resource

Scotland's soils are highly variable in type and because of Scotland's diverse (and unique) geology and climate differ markedly from those in the rest of the UK and, indeed, most of Europe. The complex pattern of soil types seen in Scotland today is the result of the combination of long-term processes such as weathering of geological material, accumulation of organic matter, redistribution and movement of elements between the different soil layers and short-term changes, usually as a result of human activities, such as ploughing, development or pollution. In general, soils change slowly over relatively long periods and reach a natural equilibrium with their environment. There are numerous examples from throughout

Scotland where distinctive patterns of soils occur in response to external conditions, in particular to climate changes with altitude. This natural sequence profoundly influences the functionality of these soils and the uses to which they can be put.

Climate is one of the key soil-forming factors and clearly soil will respond to any change in climate, depending on the size of that change. There is much debate on how much and how quickly soils may respond to a changing climate, for example in relation to carbon turnover rates and carbon storage particularly in peat soils. A changing climate will also impact soil hydrology and biodiversity (these aspects are discussed in more detail in later chapters). A change in climate is also likely to affect the ability of soil to deliver certain functions, for example, food production. These topics are the subject of ongoing research (e.g. Brown et al., 2008).

Key facts about Scottish soils are:

- only 25% of Scottish soils are cultivated for agriculture (including improved grassland); this is much lower than in most European countries. An additional 45% is also used for agriculture for rough grazing;
- 17% of soils are forested with a target to increase this to 25% by 2050;
- the majority of Scottish soils have highly organic surface horizons, often over 30% organic carbon in organo-mineral soils (soils with an organic surface layer less than 50 cm), but often over 50% in peats (organic surface layer more than 50 cm thick);
- these highly organic soils are acidic and have low inherent fertility;
- Scottish soils store over 50% of the UK's soil carbon and are expected to play a significant role in mitigating greenhouse gas emissions;
- many Scottish soils are naturally very poorly drained;
- some Scottish soils support a number of internationally important habitats, for example blanket bog, heather moorland and machair;
- some Scottish soils have a strong regional identity and are part of the culture and history of that area, for example, the machair of the Western Isles, the red soils of the Howe of the Mearns (southern Aberdeenshire) and stone consumption dykes on the land around Aberdeen.

For more information, see Towers el al. (2006) and the numerous publications listed in the Appendices. Figure 2.1 illustrates the distribution of the broad range of soil types in Scotland, as well as some of their distinctiveness, properties and the range of uses to which they are put.

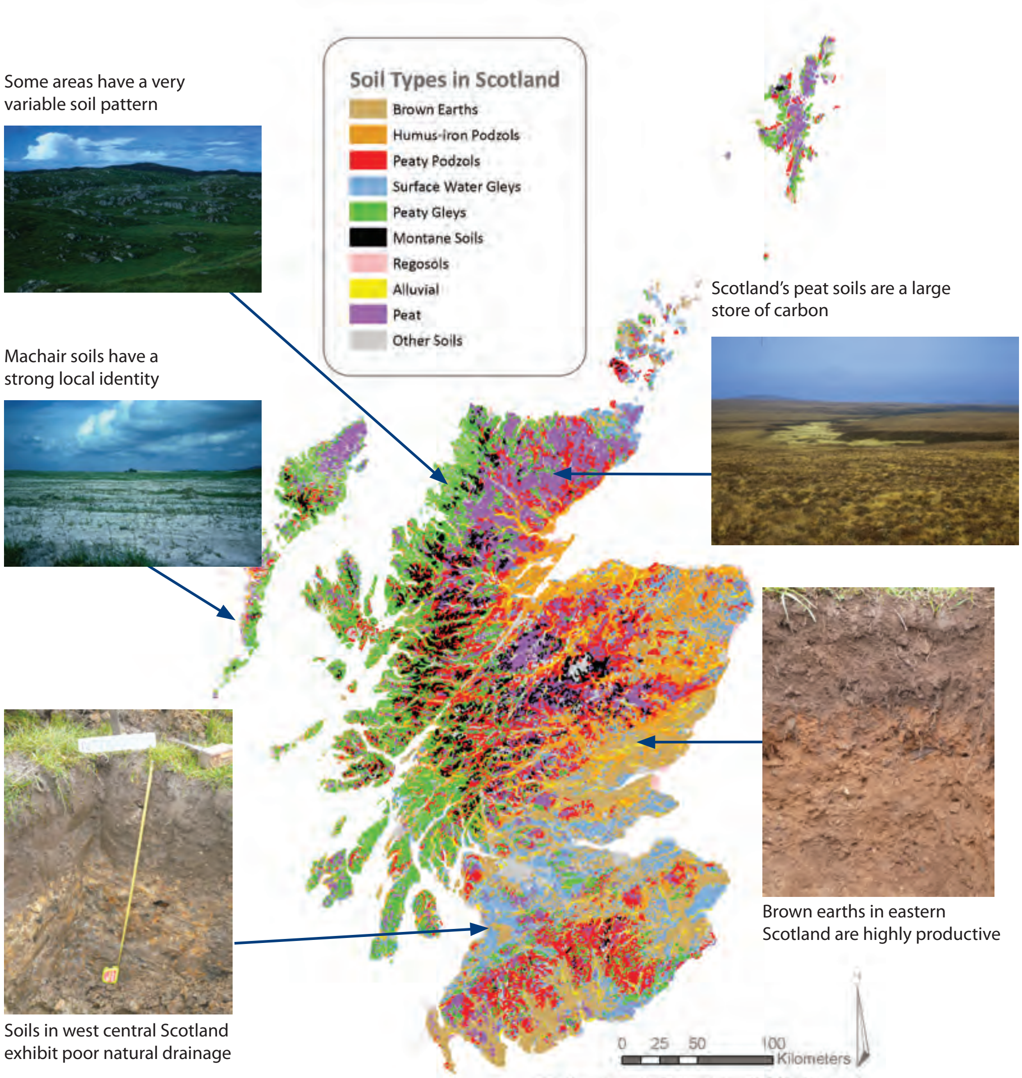
2.1.2 Existing sources of information on Scotland's soils

Data describing Scotland's soils have been comprehensively covered by Towers et al. (2006) and monitoring schemes have been described in the SNIFFER Project 'National Soil Monitoring Network: Review and Assessment Study' (SNIFFER, 2006). Existing data and monitoring schemes are briefly described in Annex 1. Annex 1 also defines the various acronyms commonly used for the data/monitoring schemes.

Soil data have been collected for a range of different purposes, for example, specific regulatory (e.g. SEPA), advisory (e.g. SAC), monitoring and survey (e.g. MLURI, CEH, BGS) or research purposes (e.g. Scottish universities). Key datasets describing Scottish soils are described in Annex 1 under 5 different categories (Scottish soil database, Regulatory database, Advisory database, Monitoring database and Research, and site specific database). Representative Soil Profiles of Scotland (RSPS) and the National Soil Inventory of Scotland (NSIS_1) provide the most comprehensive overview of Scottish soils, whereas many of the others are much more specific, for example pollutant levels [UK Soil and Herbage Study (UKSHS); Geochemical Survey of Urban Environments (G-BASE urban)], biodiversity [Natural Environment

Research Council Soil Biodiversity Programme (NERC SoilBio)] or fertility [Scottish Soil Fertility Information System pre- and post-1996 (SSFIS 1996; 1996+)], for monitoring change [Countryside Survey (CS)] or for more detailed characterisation and research [Soil Map Unit Transect Study (SSMUTS)]. The Scottish Soils Knowledge and Information Base (SSKIB) provides summarised information on Scottish soils and is underpinned by the Scottish Soils database, primarily RSPS and NSIS_1.

Figure 2.1: A generalised soil map of Scotland



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A range of mapped information on soils also exists. Again, these are comprehensively described in Towers et al. (2006). The key soil maps are the 1:250,000 national map series and the 1:63,360 series that covers most of the better quality agricultural land and the adjacent uplands. The 1:250,000 scale soil map is now available digitally and much of the 1:63,360 series has also been digitised.

The Scottish soil database and associated maps underpin a number of interpreted or derived products that have been used in a diverse range of applications. The best known and probably most widely used is the Land Capability for Agriculture (LCA) classification and the map series that has resulted from its application. It is now being revised to include assessments of the impact of potential future climate change and variation in Scotland. Most of these interpreted datasets use soil data along with other data, for example, climate, topography and geological information. The full list of available soil and derived maps can be found at http://www.macaulay.ac.uk/mscl/products_maps_list.php.

The SSKIB provides summarised soil properties from around 44,000 soil samples collected during the soil survey of Scotland. This dataset is available as a web interface, 'Soil Indicators for Scottish Soils' (SIFSS), which allows the comparison between the properties of individual soil samples with national averages. It summarises the characteristics of around 600 different Scottish soils (http://sifss.macaulay.ac.uk/).

Although Scottish soils have been well characterised compared to many other countries, and despite the number of different data sources in place (Annex 1), there is a distinct lack of trend data for key attributes where sites have been visited more than twice. This lack of trend data restricts the ability to assess how soils have responded to change over time. The main exception to date is the Countryside Survey (CS). Whilst this survey only deals with the upper 15 cm of soil, it nevertheless provides a useful overview of trends within this upper part of Scottish soils between 1978 and 2007 based on four different sampling dates (1978, 1990, 1998 and 2007).

The National Soil Inventory of Scotland (NSIS_1) was partially resampled between 2007–2009 (NSIS_2) to provide information on change since it was initially undertaken in 1978–1987 and also to provide new information on physical and biological soil properties in particular. MLURI will report the results of NSIS_2 to the Scottish Government in 2011.

2.2 Soil functions

Soil is an important environmental asset. It sits at the interface between water and air and, therefore, plays a key role in the exchange of a range of elements, compounds and gases between all three compartments. With the recognition of the role of soils in the climate change debate, arguably one of the most important functions of soil is that of storing carbon and exchanging greenhouse gases between soil and air. However, soil carries out many other important functions, for example growing food and filtering drinking water. The multi-functional dimension of soils is one that is becoming increasingly recognised and soils are being required, certainly implicitly if not explicitly, to provide multiple benefits.

Traditionally soil science was concerned with 'what soils are' (characterisation and single function) but there is increasing emphasis on understanding 'what soils do'. The concept of soils providing functions has become recognised both in scientific and policy thinking and has been described in the Scottish Soil Framework (Scottish Government, 2009) under seven main classes (Figure 2.2):

- providing the basis for food and biomass production;
- controlling and regulating environmental interactions: regulating water flow and quality;
- storing carbon and maintaining the balance of gases in the air;
- providing valued habitats and sustaining biodiversity;
- preserving cultural and archaeological heritage;
- providing raw materials;
- providing a platform for buildings and roads.

Soil quality is defined as the ability of soil to carry out these functions.

Figure 2.2: Soil functions - 'what soils do for us'

© Whitlaw Mosses © L Gill/SNH

2.3 Soils and ecosystem services

Ecosystem Services is a concept that has been around for several decades but is now a widely used mechanism for identifying and quantifying the benefits that individuals and society can obtain from ecosystems. The Millennium Ecosystem Assessment (MA, 2005) provides a coherent summary of the concept and includes both tangible and intangible benefits which, although sometimes separated into 'goods' and 'services' (Daily, 1997), the MA refers to collectively as Ecosystem Services.

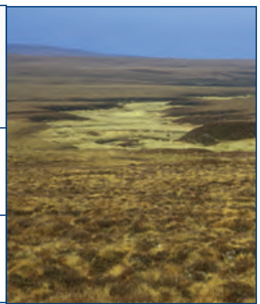
The MA classifies these ecosystem services along functional lines using the following categories:

- provisioning – the products obtained from ecosystems;
- regulating – the benefits obtained from the regulation of ecosystem processes;
- cultural – the nonmaterial benefits, such as spiritual enrichment, reflection and recreation that people obtain from ecosystems;
- supporting – the services that are necessary for the production of all other ecosystem services.

Soils contribute to all of these service types, for example, provision of food, fibre and raw material (a provisioning service), provision of clean water (a regulating service), protects, and is part of, our cultural heritage (a cultural service) and soil formation itself (a supporting service). Although similar to the soil function concept, the ecosystem approach has a stronger human dimension and actually identifies the services that are used by people. Both concepts (soil function and ecosystem services) provide useful ways of exploring the multifunctional role of soils and the benefits they provide to society. Tables 2.1 and 2.2, although they grossly simplify the complexity of soils, demonstrate how different soils perform some functions more effectively than others and as a result provide different benefits to society.

Table 2.1: Qualitative assessment of the capability of contrasting soils to perform soil functions (+++ high capability for that function; --- low capability for that function)

Brown earth under arable management	Soil functions	Blanket peat semi-natural habitats
+++	Providing the basis for food and biomass production	---
+++	Controlling and regulating environmental interactions	++
--	Storing carbon and maintaining the balance of gases in the air	+++
+/-	Providing valued habitats and sustaining biodiversity	+++
---(i)	Preserving cultural and archaeological heritage	+++
-	Providing raw materials	+++
+++	Providing a platform for buildings and roads	---



(i) May have a high value at local level

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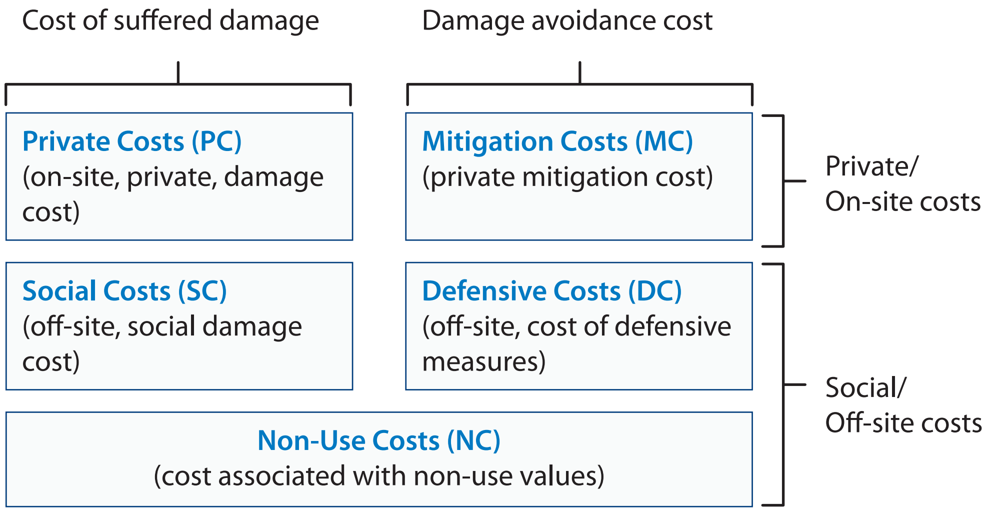
Table 2.2: Examples of Ecosystem Services derived from contrasting soils

Ecosystem service	Brown earth under arable management	Blanket peat semi-natural habitats
Provisioning	Food and drink	Fuel
Regulating	Flood mitigation, water regulation	Climate regulation
Cultural	Imprint of past land use	Sense of place, educational
Supporting	Nutrient cycling	Soil formation

2.4 Socio-economic importance of Scotland's soils

There is increasing awareness that socio-economic information is required to support and understand the development and implementation of effective strategies to protect and manage soil resources into the future. Economic data for Scotland are sparse, but a standard methodology has been used to identify the different types of costs associated with the various types of degradation of soils (Glenk et al., 2010). Five cost types are identified and briefly described in Figure 2.3 (also see Glossary), along with who or what has been affected. In subsequent chapters, these costs are presented for each of the main threats to soil quality (see section 2.5, below) in the form of a table where each impact is classified under a specific cost type. In these tables, the soil functions affected are identified and a qualitative indication of the scale of the economic impact has been made. Lastly, an indication of the robustness of the data that underpins these judgements is made; in most cases the data are not Scottish, so care must be taken in their interpretation.

Figure 2.3: Overview of different economic impact categories (adapted from Görlach et al., 2004) (see Glossary for details)



These assessments are the first to have been made of the economic impact of threats to Scottish soils and represent a further development of the soil function and ecosystem approaches. These approaches are, in essence, frameworks intended to express societal perspectives on, and requirements from, our soils. Thus the inclusion of cost assessments associated with damage to them is a logical extension of that thinking.

2.5 Threats to soil

Soil quality is at risk from a number of threats. The State of Scotland's Soil report considers the principal threats to soil quality as described in the proposed Soil Framework Directive (European Commission, 2006b) and the Scottish Soil Framework (Scottish Government, 2009), and are also outlined below:

- **loss of organic matter** - refers to a reduction of organic matter in soils. Organic matter is important in its own right as a direct loss no matter how small, but also because the scale of loss may lead to a reduction in the capacity of different soils to deliver their functions;

- **soil sealing** - the permanent covering of the soil surface with an impermeable material;
- **contamination** – an effect caused by the addition of a substance or substances to soil that causes a deterioration in the ability of a soil to perform key functions and often has a negative impact on soil, water or air;
- **change in soil biodiversity** – either a change in the diversity itself or on the ability of soil biodiversity to perform its functions;
- **erosion and landslides** - soil erosion, i.e. the movement of soil particles, becomes of concern when the rate exceeds "natural" or "background" rates that can be considered as broadly equal to the rate of formation of new soil material by weathering processes. Landslides are mass movements of rock, earth or debris down a slope;
- **soil compaction** - generally refers to the loss of porosity through mechanical damage to soil and can affect both topsoil and subsoil. Compaction occurs when an external stress exceeds the mechanical stability of soil;
- **emerging issues** - such as genetically modified organisms, asbestos, nanoparticles and biochar.

These threats are driven by a range of pressures, for example climate change, land use change and land management practices, and have a number of consequences for soil, the wider environment and also for the economy and society.

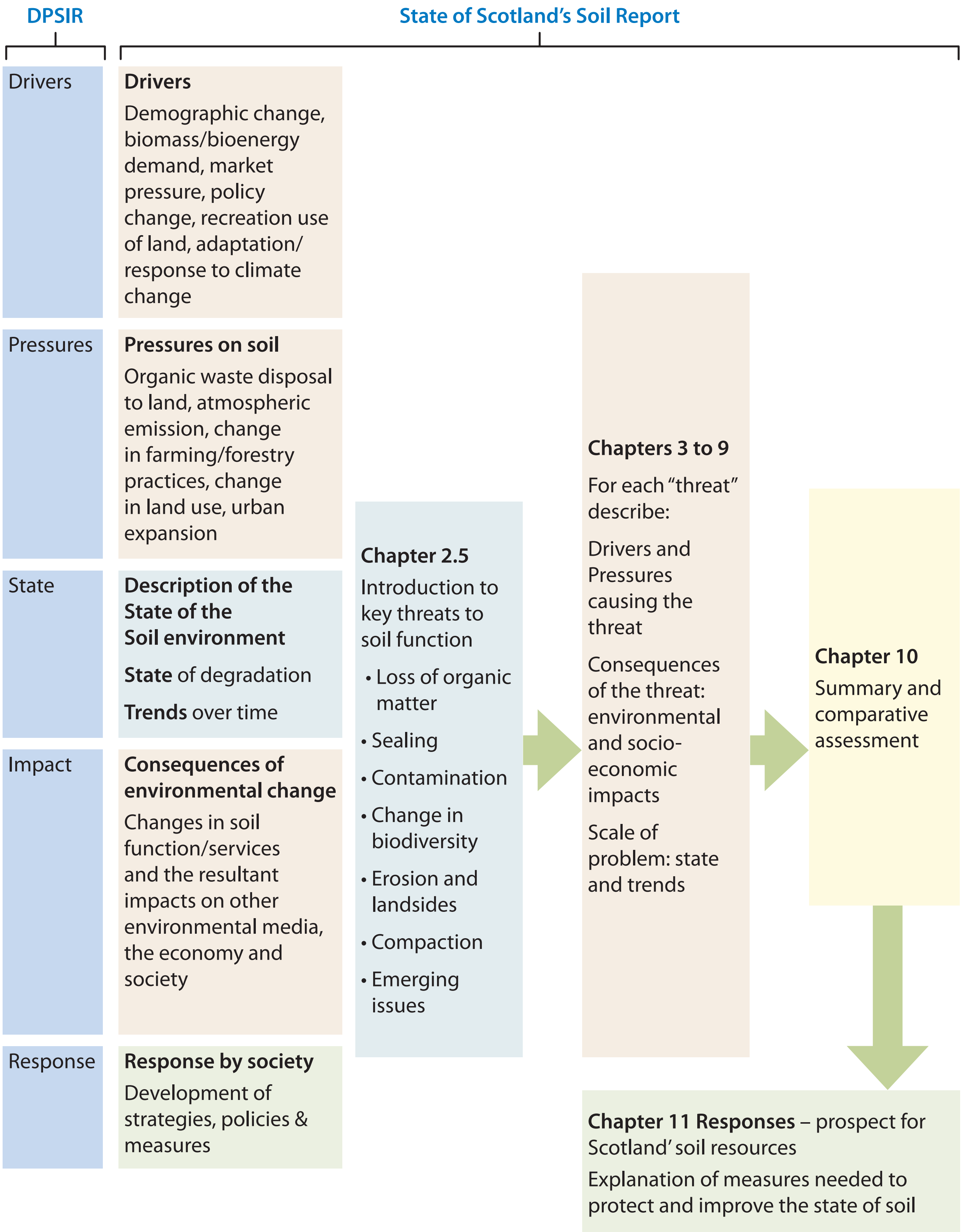
It should be noted that SEPA's Soil Quality Report (SEPA, 2001) predated the proposed EU Soil Framework Directive (European Commission, 2006b) and therefore does not explicitly refer to the threats outlined above. It identified that the principal threats to soil quality at that time were soil erosion, loss of fertility, contamination as a result of organic waste application to land, and acid deposition.

2.6 Reporting and assessing the threats to soils

There are many ways of reporting and assessing threats to soil. This report has developed a conceptual model (Figure 2.4) to explain the wider context and implications of the threats to soil. The model is adapted from the Driver – Pressure – State – Impact – Response (DPSIR) and Environmental Pressures, Impacts, Consequences and Solutions (EPICS) frameworks and also recognises the ecosystem services provided as developed for the Millennium Ecosystem Assessment (MA, 2003).

DPSIR is an analytical tool used to understand the causes of environmental change, the subsequent environmental and socio-economic impacts of these changes and how measures may be developed to address these. It has been used for the development of the EU soil thematic strategy (European Commission, 2006a). However, work by Loveland and Thompson (2002) identified difficulties with this approach in relation to soil – it can rapidly become unmanageable as more and more layers of information are added in detailed analysis (resolution issues). The EPICS framework was developed by the Environment Research Funders Forum and used by the Earth Observation Framework to describe a range of environmental problems. This report uses the conceptual model as a standard framework to help describe the drivers and pressures causing environmental change, the resulting threats to soil quality, and their consequences for the state of soil, the wider environment, the economy and society.

Figure 2.4: Conceptual model describing the key threats to soils and their wider environmental and socio-economic context



The following chapters (Chapters 3–9) describe the key threats to soil in turn. For each threat, the main drivers and pressures that lead to the threat, the consequences of the threat and resulting state of environment are explained.

Common assessment criteria and a scoring system were developed and used by the authors of the relevant chapters to assess the relative importance of the different pressures on each soil threat and the impact of each threat on soil function. The resulting assessments are presented in tables in each chapter. The authors individually provide different perspectives in their area of expertise and therefore represent the best available grouping to make the judgements represented in the tables. The methodology is explained in more detail in Annex 2. This expert-based assessment may be refined in future.

Each chapter also includes a summary table presenting an overview of the economic impacts for Scotland associated with each threat based on work published by Glenk et al. (2010).

The information provided in the tables in Chapters 3–9 is subsequently used as the basis for the analysis in Chapter 10 where a comparative assessment of the threats is made. Chapter 10 further develops the expert judgement approach used by Towers et al. (2006) and combines this with the socio-economic evaluation of Glenk et al. (2010) to provide a risk-based evaluation of the relative importance of the threats to soil and their impact on the wider environment and society. The methodology used is described in detail in Annex 2. This represents the first attempt to include socio-economic impacts in an analysis of the consequences of soil degradation. While this is an important step forward, it is recognised that there are flaws in the analysis. However, it will be subject to periodic scrutiny and update as new data and understanding are developed.

Chapter 11 concludes the report by discussing potential responses to the issues raised.

3 Loss of soil organic matter

3.1 Definition and scope

Soil organic matter is a universal constituent of soils and plays a vital role in contributing to a range of soil functions. Soil organic matter is formed from the breakdown and incorporation of plant and animal matter in soil. Organic carbon is the dominant component of soil organic matter (around 50%), so management of soil has important wider consequences in the context of greenhouse gas emissions and climate change. Soil organic matter also contains a wide range of nutrients (e.g. nitrogen, phosphorus) and trace elements that are essential for plant growth and health. The presence of soil organic matter is a critical indicator of soil quality and is required to deliver many of the vital functions of soil including its ability to provide nutrients, ameliorate the inputs of wastes and pollutants, contribute to the formation of good physical conditions, improve water storage and provide a habitat for microbial populations.

Scottish soils are particularly rich in soil organic matter because the cool, moist climate encourages the retention of decomposed organic materials, with Scottish peatlands containing the largest quantities of soil organic matter. These soils are important global reserves of soil carbon. The distribution of peat soils is influenced very strongly by east-west gradients in rainfall that results in these soil types occurring predominantly in the west. Scotland's peatlands are discussed in more detail in Box 3.1.

Box 3.1: Peatlands

Peatlands, are very important in Scotland and form an important and distinctive part of the natural and historical landscape. The term 'peatlands' conjures up recognisable images of peat soil deposits, and internationally valued habitats and biodiversity.

Scotland's landscape is covered by extensive areas of internationally protected habitats such as Atlantic Blanket bog (e.g. Flow Country of Caithness and Sutherland). Bog- and fen-type peatlands occupy around 1.5 million hectares in Scotland (19% of land area) and adding other vegetation- type peatlands increases this to 23% (Joint Nature Conservation Committee, 2011).

Peatlands provide many ecosystem services and are particularly important for mitigating climate change as they store carbon in peat deposits and continually sequester new carbon via peat-forming vegetation.

Flow country of Caithness and Sutherland

© S Moore/SNH

Sphagnum moss

© L Gill/SNH

Cotton grass

© T Dawson/SNH

Box 3.1: Peatlands (continued)

The current estimate of the amount of carbon held in Scotland's organic soils (associated with bog- and fen-type peatlands) is 1,600 million tonnes, which represents over 100 times Scotland's net annual greenhouse gas emissions. Active peatlands tend to act as a carbon sink but following changes in land use or land management practices, or changes in ongoing active processes as a result of climate change, peatlands may turn into net sources of greenhouse gases and increase inputs of carbon to fluvial systems. (Worrall et al., in press)

Peat cutting Western Isles

Peatlands are not just important for their biodiversity and carbon balance, but also bring wider ecosystem benefits such as purifying and retaining water, providing social and economic benefits through tourism and recreational uses, and as a valued repository of archaeological deposits and paleo-environmental records.

To ensure that peatlands continue to provide such benefits, we need better understanding on the extent of peatlands and also their condition and rate of active processes in transitional degradation/restoration stages (see Scottish Government management of carbon rich soil: http://www.scotland.gov.uk/Resource/Doc/921/0109512.pdf). This will help ensure adequate protection and restoration for an extremely important type of soil and habitats.

3.2 Drivers and pressures

The organic matter content of Scottish soils is at risk from a range of pressures (Table 3.1), with land use change and climate change being of particular importance. The threat and severity of these pressures reflect their extent across Scotland and their influence on the processes that form and break down organic matter. The pressures affect the incorporation, cycling and breakdown of organic matter in the soil through alteration of soil conditions (e.g. temperature or moisture content).

The major pathway of loss of organic matter from soils is by carbon dioxide (CO_2) emission to the atmosphere via soil respiration, but other greenhouse gases can also be emitted as a result of soil organic matter decomposition, for example methane (CH_4) and nitrous oxide (N_2O) (Scottish Executive, 2007). In addition, carbon compounds can be released from soil into water, for example dissolved organic carbon and particulate organic carbon (Buckingham et al., 2008; Dinsmore et al., 2010). Other processes can also influence the amount of organic matter loss, such as soil erosion (Bilotta et al., 2007). Although most CO_2 is returned to soils as a consequence of the photosynthetic activity of plants, the net exchange (the difference between gains and losses) of carbon from land surfaces may still be large. For example, recent measurements from Scottish grasslands have shown net carbon gains of three tonnes per hectare per year (Soussana et al., 2007).

3.2.1 Climate

Climate is important in determining the equilibrium soil organic matter content. Temperature and rainfall influence both the input of organic matter via photosynthesis (e.g. litter and root inputs), and its subsequent decomposition through microbial activity, with resultant release of greenhouse gases and dissolved organic carbon, along with nutrients and trace elements. It is usually in locations where organic matter decomposition is reduced (by, for example, low temperature and/or waterlogging) that organic matter accumulations are the greatest. Thus any change in climate, for example increased rainfall and/or increased temperature, is likely to change the rate at which organic matter is lost or accumulated in Scottish soils.

There is a particular concern regarding the sensitivity of soil organic matter to changes in climate. Projected climate change in Scotland, with warmer and drier summers and wetter winters, threatens to increase losses of soil organic matter. Indeed, modelling of the climate impacts over the next 50 years suggests that there will be significant loss of soil carbon across much of the UK (Smith et al., 2005). However, this modelling has also indicated that some soil management practices, for example use of minimum tillage, crop residues, fertilisers and manures, can reverse these losses in arable and farmed systems and so contribute to the net removal of carbon from the atmosphere. Another concern is that extreme weather events such as heavy rainfall could contribute to significant losses of organic matter through soil erosion (Chapter 7).

3.2.2 Land use and land management practices

Land use and land use change are important in determining the amount of soil organic matter present at a given site (Foley et al., 2005). Under certain land use types (e.g. forests and grasslands) soil organic matter will tend to accumulate, but a significant proportion of this organic matter can be lost quickly if the soil is subsequently cultivated. Thus, a land use change from grassland to arable land will generally result in a loss of soil organic matter. Woodland planting on arable soil is likely to increase the soil organic matter content over time, but this will depend on soil type as soils that are already highly organic may not accumulate additional large quantities of soil organic matter. Although the loss of soil organic matter can be quite rapid after land use changes, the organic matter contents may take a long time (decades to centuries) to stabilise at a given site. Therefore, planned uses of soil to achieve carbon targets should be seen in this context, for example the benefits of increasing land covered by forestry to 25% by 2050 could result in an increase in the soil carbon stock long after the trees have been planted, depending on the soil type.

In general terms, land management practices that cause soil disturbance are likely to result in a loss of soil organic matter, whereas other practices, such as reducing tillage and applying organic materials to land, may increase the soil organic matter content of land in the long term.

Agricultural practices

This covers a wide range of activities. Grasslands are commonly used for agricultural production and cover large areas of the Scottish landscape. They are associated with high rates of organic matter accumulation; however, periodic ploughing can reverse this process. Thus, permanent grasslands, particularly at more fertile sites, have greater potential of accumulating organic matter than rotational grassland. Arable agriculture focused in the south and east of Scotland tends to take place on soils with lower organic matter content. There is currently much interest in developing management systems that would increase the organic matter content of these soils. This could include the application of organic materials, such as composts and manures, to provide agricultural and ecological benefit. Such materials are also used in land reclamation projects to improve soil quality, for example to restore opencast coal sites. Applying organic materials to soils over an extended period can result in significant changes to the soil organic matter content (King et al., 2004) but the contribution of different organic matter additions to the build up of soil organic matter will vary according to intrinsic properties of the material added and subsequent management of the soil (Jones et al., 2006). In organically farmed systems, increases in soil organic matter are actively promoted in order to improve soil quality and fertility.

Forestry practices

Forests and woodlands generally accumulate soil organic matter throughout their lifespan; however, plantation forestry is also characterised by soil disturbance, not only at the time of first planting, but also as part of subsequent replanting operations. This can lead to losses in soil organic matter over the life-cycle of forest crops. However, the new forestry standard and related guidance documents (Forestry Commission, 2004) include practices to keep such losses to a minimum. In many instances, planting trees will lead to increases in soil organic matter content, although the end result is a little uncertain for soils with relatively high initial levels of organic matter. The quantity, quality and turnover of this organic matter will depend on the tree species used and associated management practices.

Recreation/game management

Recreational pursuits in Scotland will have a limited localised impact on soil organic matter and this will be mainly through exacerbation of erosion (Chapter 7). Damage by walkers will be restricted to a few high impact areas. Game management will potentially have a greater impact. Deer can cause compaction and erosion (Chapters 7 and 8) and it is necessary to maintain the deer population at a sustainable level. Grouse shooting requires management of the moorland habitat such that a good balance of young heather is available for forage. This is normally done by burning (muirburn), typically in patches which are burnt every 10–20 years. Carefully managed heather moorland should aim to retain soil organic matter and the soil carbon balance over time but poorly managed burning can result in losses. There is evidence of soil organic matter loss following burning though the evidence base is scant.

Peat exploitation and utilisation

Peat removal clearly results in a direct loss of organic matter from the soil. Peat is cut for fuel on a small scale and is generally restricted to the Highlands and Islands. Industrial use of peat is still practised locally in Scotland, for example for whisky production and horticulture use.

Development

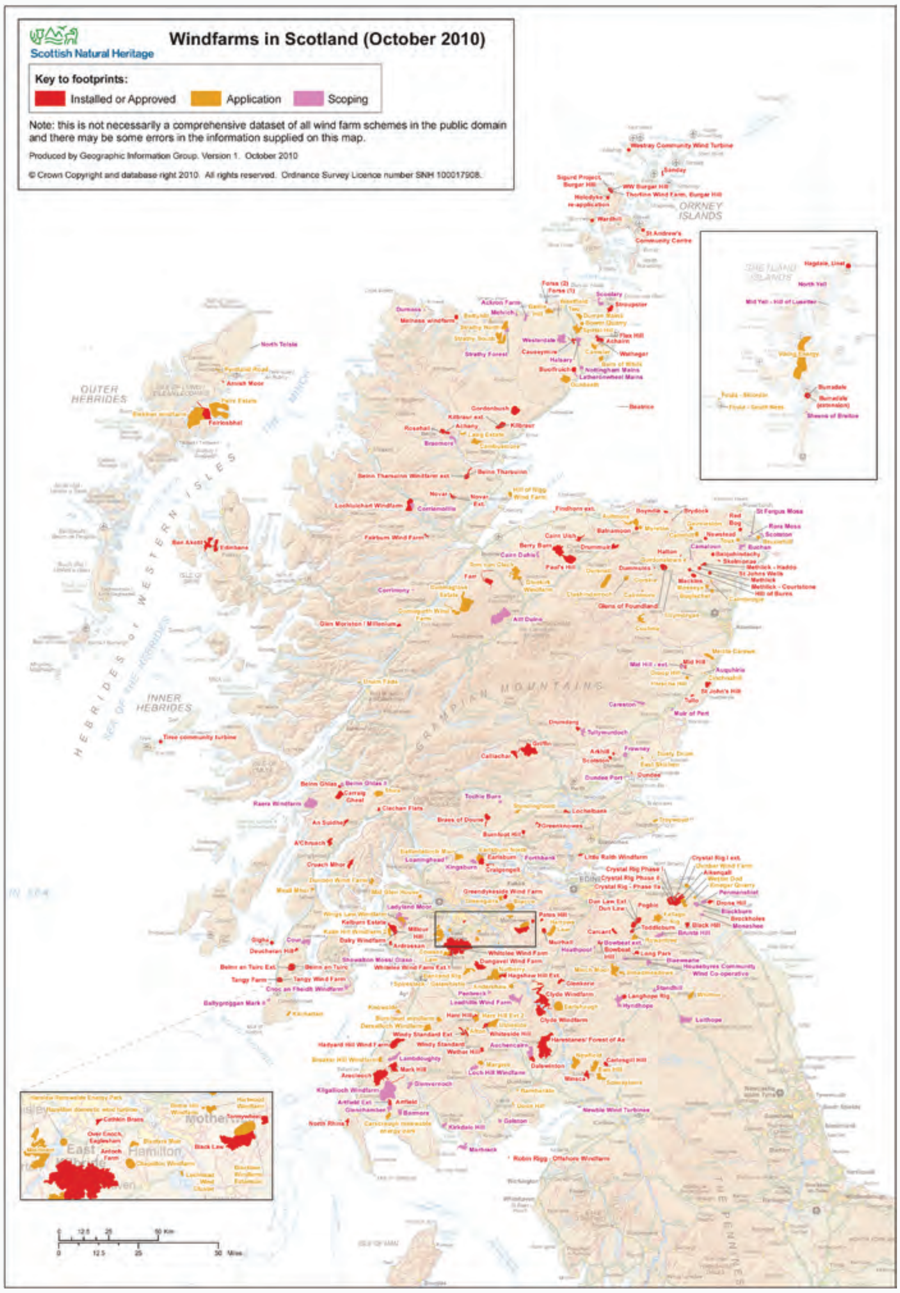
Urban development can lead to changes of soil organic matter in a number of ways. Soil disturbance and removal of vegetation lead to organic matter loss and reduced organic matter incorporation. Sealing soil (Chapter 4) inevitably results in a net loss of organic matter by removal of organic rich topsoil and preventing further new organic matter being added to the soil. Some urban areas, such as parks, gardens and other vegetated areas, can, however, contribute to soil organic matter accumulation. Peat removal is often associated with major planning developments such as windfarms. The siting of windfarms on peatland sites represents a specific challenge in terms of effects on soil organic matter and greenhouse gas emissions (Box 3.2 and Chapter 4).

Box 3.2: Windfarm development and potential impacts on soil

Scotland is committed to generating 80% of electricity from renewable sources by 2020. At present, 59% of UK onshore windfarm provision and almost 70% of the generation capacity of projects under construction and consented in the UK are located in Scotland because of its excellent wind energy potential. However, some of the best sites for commercial wind generation in Scotland are also significant soil carbon storage sites.

Deploying on-shore windfarms on these sites necessitates disturbance of carbon-rich soils during construction, which may lead to exposure and de-watering of peat. Windfarms are known to cause an increase in loss of soil organic matter into drainage water (e.g. Grieve & Gilvear, 2008) which can lead to degradation of aquatic habitats. The greatest uncertainty is to what extent changes in water retention and movement will alter the formation and retention of soil organic matter, and the effectiveness of site restoration to re-establish soil carbon sequestration (Nayak et al., 2008).

Figure B3.2: Windfarm footprint map



There is a need for information on the extent to which windfarm infrastructure influences the capacity of carbon-rich landscapes to sequester carbon. Changes in the microclimate caused by turbines may affect processes occurring in the soil profile. This may lead to changes in evapotranspiration and water table height which may, in turn, affect the capacity of the system to accumulate carbon.

Research is currently being carried out to investigate these potential effects.

Table 3.1: Relative importance of pressures leading to loss of organic matter (scored on a 25-year timescale using expert judgement)

Pressure	Magnitude of pressure(i)	Reversibility of pressure(ii)	Spatial extent of pressure(iii)	Trend in pressure(iv)	Uncertainty of pressure(v)
Climate change	3	3	3	+1	3
Land Management practices					
• arable - cultivation	2	2	2	0	2
• grassland - cultivation	2	2	2	0	2
• forestry - cultivation	2	1	2	+1	2
Land use change					
• expansion of agriculture	2	1	2	+1	2
• expansion of forestry	1	1	2	+1	
Development/transport	3	3	2	+1	1
Peat exploitation	3	3	1	-1	1
Recreation	1	3	1	0	1

(i) Magnitude of pressure: 1, not significant; 2, significant; 3, very significant.
(ii) Reversibility of pressure: 1, short-term and reversible; 2, medium-term and reversible; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in pressure: -1, predicted to decrease in intensity; 0, predicted to be stable; +1, pressure predicted to increase in intensity.
(v) Uncertainty of pressure: 1, pressure well characterised and quantified; 2, pressure moderately well characterised but data primarily qualitative; 3, pressure poorly characterised.

For more details on scoring and methodology see Annex 2.

3.3 Consequences of loss of soil organic matter: environmental impacts

Losses of soil organic matter will lead to deterioration in soil quality. There is general recognition that lowering soil organic matter content can contribute to a loss of structural stability, reductions in soil fertility, lower water-holding capacity and reduced capacity to buffer and break down contaminants. Soil organic matter loss, therefore, has a wide range of effects on soil functions, many of which are interlinked as discussed below. The relative importance of the impacts are summarised in Table 3.2.

3.3.1 Providing the basis for food and biomass production

Soil organic matter can improve conditions for plant growth and biomass production through the development of good soil structure, improved water-holding capacity and higher nutrient levels. Although Loveland and Webb (2003) found no evidence of a critical level affecting crop yields, there is some evidence to support the concept of a desirable range in soil organic matter content and for the replacement of inorganic fertilisers by organic fertilisers to maintain soil fertility levels.

3.3.2 Controlling and regulating environmental interactions

Losses of soil organic matter to water can have important environmental impacts. These include discolouration and contamination of drinking water and, in some cases, nutrient enrichment (e.g. eutrophication), where organic matter carries with it organically bound nitrogen and phosphorus. The ratio of total organic carbon to dissolved organic carbon can also be considered to have an impact on freshwater systems, with higher ratios resulting in more significant biological damage. The loss of soil organic matter also reduces the capacity of soils to filter out pollutants (such as heavy metals and organic pollutants) and to regulate water flow within catchments. Organic matter improves the infiltration of water into soil and the water-holding capacity of a soil and, therefore, reduces the prevalence of flooding in response to storm events.

3.3.3 Storing carbon and maintaining the balance of gases in the air

The concern about loss of soil organic matter is linked not only to its intrinsic role in contributing to soil quality but also to the potential environmental risks that are associated with large scale loss of carbon from ecosystem degradation and land use change to the atmosphere. This is of particular significance in terms of increasing CO_2 (and other greenhouse gas) emissions from soils and their role in contributing to climate change. The presence of organic matter in soils can also influence the release of methane and nitrous oxide. On farmland where nitrogen fertiliser is applied to grassland soils with relatively high organic matter levels, emissions of these other greenhouse gases tend to be higher than those from agricultural soils with lower organic matter contents.

3.3.4 Providing valued habitats and sustaining biodiversity

Many of Scotland's most valued natural habitats are located on soils that contain large amounts of organic matter. These include native Caledonian pine forests in areas such as the Cairngorms, and peatlands in the Flow Country as well as elsewhere within the Scottish landscape. These habitats have sometimes been associated with earlier land use change (such as deforestation) but for their survival they continue to be dependant on the maintenance of high organic matter soils, so any factors contributing to organic matter loss could threaten their sustainability. It should also be noted that the soil itself and, in particular the organic component, provides an important habitat for soil microorganisms that support the many wider functions of soil (Chapter 6).

3.3.5 Preserving cultural and archaeological heritage

Soil provides an important medium for the preservation of archaeological material and climate records, with soils of high organic matter content, in particular peat soils, providing the ideal cool, oxygen-poor, acidic environments in which to slow the degradation of organic artefacts to very low rates thus preserving these records. The loss of soil organic matter, or its quality, could have a direct impact on the archaeological record at some sites.

3.3.6 Providing raw materials

As discussed earlier, peats form a significant resource for use in the horticultural industry, to a lesser extent as a fuel source for local use in some rural areas (e.g. in the north-west of Scotland and the Outer Hebrides) and in industry (e.g. whisky production). The extensive use of this resource in some areas in the past has already placed limits on further exploitation of these soils in these areas.

3.3.7 Other soil functions

As topsoil is usually removed during construction, the soil function 'providing a platform for buildings and roads' is not affected by loss of soil organic matter. Highly organic soils, such as peatlands, are generally poor environments for construction as deep levels of wet organic matter provide little mechanical support and may become prone to erosion. In these instances, the organic matter often has to be removed, to the detriment of overall soil quality.

Table 3.2: Consequence (i.e. impact) of soil organic matter loss on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of imapact(ii)	Spatial extent of imapact(iii)	Trend in imapact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	3	3	3	+1	1
Controlling and regulating environmental interactions	3	3	3	+1	2
Storing carbon and maintaining the balance of gases in the air	3	3	3	+1	2
Providing valued habitats and sustaining biodiversity	3	3	3	+1	2
Preserving cultural and archaeological heritage	2	3	1	+1	2
Providing raw materials	1	3	1	+1	2
Providing a platform for buildings and roads	1	3	1	0	2

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

3.4 Consequences of loss of soil organic matter: socio-economic impacts

Recent work (Glenk et al., 2010) has sought to identify the socio-economic impacts of soil degradation and Table 3.3 summarises their findings for loss of soil organic matter. Figure 2.3 explains the different cost types.

Table 3.3 shows that the socio-economic impacts associated with a decline in soil organic matter affect five soil functions. Eight different socio-economic impacts were identified by Glenk et al. (2010), three of which had cost estimates available in the literature considered. The impact status varies from low to high across the impact categories. The social cost of loss of soil organic matter on the storing of carbon and maintaining the balance of gases in the air function is the socio-economic impact with the highest status and data are available to allow costs to be estimated for this. In addition, the other two categories where data are available have medium impact status. Thus, in the future, it may be possible to assess relatively accurately the socio-economic impacts of loss of soil organic matter.

It is notable that, while different types of costs and the soil functions affected can be identified, actual data for Scotland are scarce and insufficient to support quantitative assessments.

Table 3.3: Overview of economic impacts for Scotland associated with a decline in soil organic matter

Soil function	Cost type	Off site /on site	Description	Impact status[(i)]	Data status[(ii)]
Providing the basis for food and biomass production	Private cost	On	Soil organic matter is a key factor for soil fertility; soil organic matter decline may result in losses of agricultural productivity	Medium	Y
	Mitigation cost	On	Restoration of higher soil organic matter levels or costs associated with higher input requirements	Medium	Y
Controlling and regulating environmental interactions	Social cost	Off	Reduced capacity for pollution retention from soil organic matter decline can directly affect ground and surface water quality and availability.	Variable	N
Storing carbon and maintaining the balance of gases in the air	Social cost	Off	Soil organic matter loss equals a loss in carbon; microbial decomposition of soil organic matter produces CO_2 or CH_4 potentially increasing atmospheric greenhouse gas concentrations	High	Y
	Defensive cost	Off	Costs of defensive measures against climate change impacts	Variable	N
Providing valued habitats and sustaining biodiversity	Non-use value cost/ private cost/ social cost	Off	Soil organic matter decline can be associated with losses in soil biodiversity and, hence, a deprivation of the genetic resource limiting its potential for future commercial/ societal use	Variable	N
	Non-use value cost	Off	If soil organic matter levels drop beyond thresholds, a shift in land cover can impact on landscape/ amenity values	Low-to-medium	N
Preserving cultural and archaeological heritage	Non-use value cost	Off	If soil organic matter levels drop beyond thresholds, a shift in land cover can impact on landscape/ amenity values	Low-to-medium	N

(i) Impact status: based on 20–25-year timescale assessment of severity of biophysical change, geographical extent, contribution of single economic impact

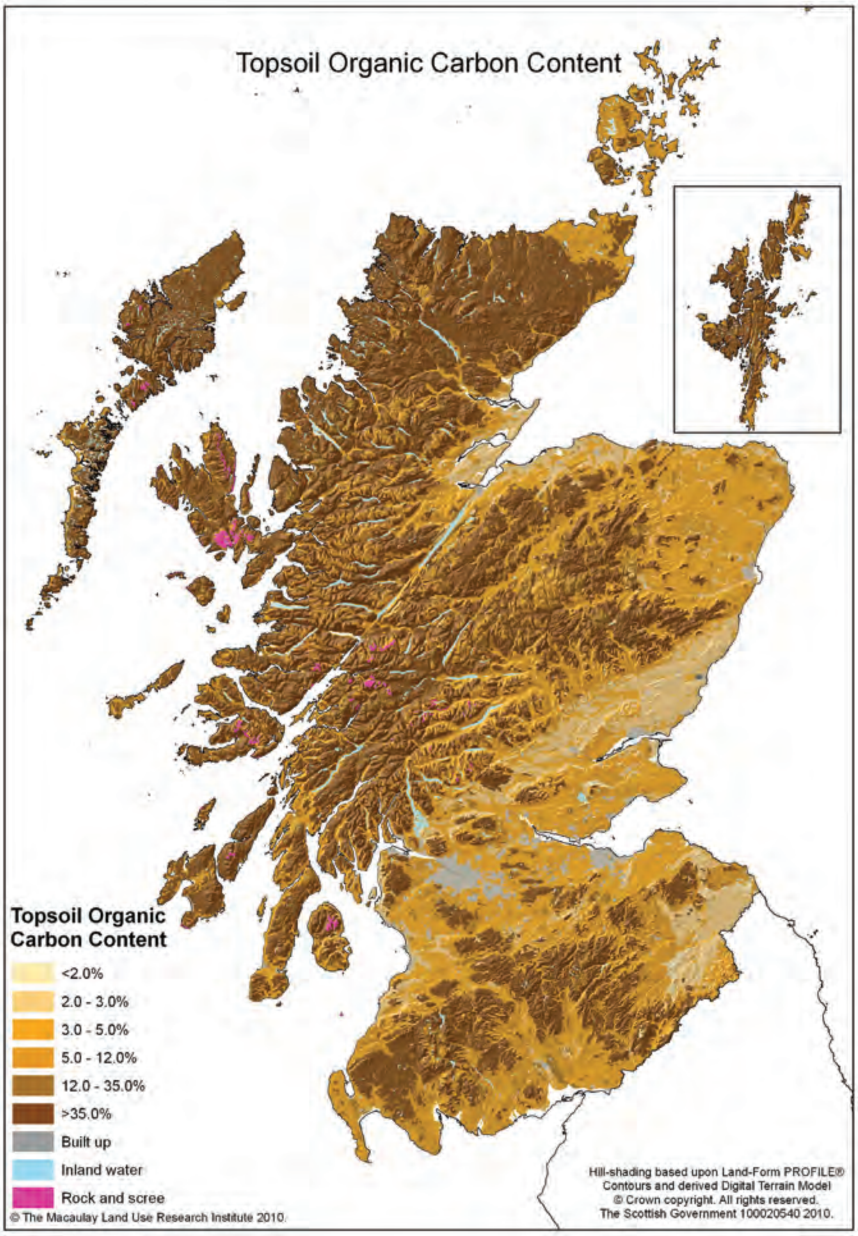
(ii) Y = economic estimates are available in Görlach et al. (2004), ADAS (2006) and Defra (2009).
N = no data available

For more details on scoring and methodology see Annex 2.

3.5 Description of the environment: state of soil organic matter

Scotland's soils contain more than half of the soil carbon in the UK, and these highly organic soils are distinctive in a European context. It is estimated that Scotland's soils contain approximately 2700 million tonnes (Mt) of carbon to a depth of 1 m (Lilly et al., in press) and an additional 516 Mt carbon below 1 m in organic soils (Chapman et al., 2009). This compares with a total of 110 Mt carbon in UK surface vegetation (Milne & Brown, 1997; Chapman et al., 2009). The importance of this carbon pool can be seen by comparing it with Scotland's total greenhouse gas emissions expressed as carbon equivalents. In 2007, the total emission of greenhouse gases from Scotland was 14.9 Mt carbon, equivalent to just 0.5% of the carbon stored in its soils. In other words, if just 1% of the carbon contained in soil was lost in a year it would be enough to triple Scotland's annual greenhouse gas emissions. The contribution of Scotland's peatlands to soil carbon storage is discussed in more detail in Box 3.1.

Figure 3.1: Topsoil organic carbon content in Scotland (based on the uppermost soil horizon)



The distribution of organic matter within Scotland's soils is highly variable and climate has played a particularly important role in this distribution (Chapman et al., 2001). There is a good knowledge of the spatial distribution of organic soils in Scotland (Figure 3.1). However, some estimates of soil carbon stocks lack measures of statistical uncertainty, as data were, in some cases, derived from soil surveys carried out several decades ago, at a time when soil organic matter measurements would not have been a primary objective and soil bulk density was not measured routinely. A recent study of carbon sequestration and emissions from Scottish and Welsh soils (Scottish Executive, 2007) provides a valuable summary of the most recent estimates of soil organic matter stocks and their rate of change. There is a range of additional studies that provide indirect or proxy information on the status of soil organic matter; for example work on peatland habitats (Joint Nature Conservation Committee, 2011) and soil erosion (Chapter 7).

3.6 Description of the environment: trend in soil organic matter

Scottish soils play an important role in accumulating and storing carbon. Recent estimates suggest that in 2000, soils in the UK were slowly accumulating carbon at a rate of 0.22 Mt per year (as reported to the United Nations Framework Convention on Climate Change). However, there is an absence of reliable, quantitative trend data, which limits the ability to forecast likely future changes in soil organic matter in Scotland, such as long-term experimental sites or constituent records from field monitoring. Much of the information relating to changes in soil organic matter is derived from small-scale research projects, inference from studies in other countries, and modelling. For example, a study in England and Wales (Bellamy et al., 2005) highlighted potentially large losses of soil organic matter from organic-rich soils in recent years.

The studies that exist do not provide evidence of such a large or widespread loss of soil organic matter in Scottish soils. A variety of data for Scottish topsoils indicate no obvious change in the latter part of the last century. For example, data from the Countryside Survey (CS) (Emmett et al., 2010) indicate that there was no change in either the density or concentration of soil organic matter in the top 15 cm of Scottish soils between 1978 and 2007. Soil samples sent by farmers (so, primarily agricultural topsoils) to the Scottish Agricultural College (SAC) analytical laboratory between 1996 and 2006 show no discernable change in soil organic matter concentrations (12,700 routine samples; SAC, unpublished data, SSFIS 1996+) as do data from the long-term rotational experiment at Craibstone (Aberdeen), which has occasional measurements of soil organic matter dating back to 1922.

Overall, these studies point to relatively low rates of change in soil organic matter concentrations, particularly in the cultivated soils of Scotland. However, it should be emphasised that these studies do not discount the possibility that the total amount of soil organic matter present is changing because they do not consider the whole soil profile. This highlights a potentially crucial gap in knowledge. Forthcoming research in Scotland and elsewhere (e.g. BIOSOIL) will provide valuable information on the status and change in total soil organic matter stock.

The Macaulay Land Use Research Institute undertook a partial re-sampling of the National Soils Inventory between 2007 and 2009 (NSIS_2). Only the results from the first year of sampling are available at the time of going to press; however, it is expected that this will provide important information on any changes of soil organic matter content since the first sampling period.

The recent findings of the CarboEurope project are part of a growing body of evidence that suggests losses of organic carbon from many cultivated and grassland soils are small (http://www.carboeurope.org; Ciais et al., 2010). In some cases, this may be because measurements have taken place on sites where, historically, deforestation has occurred. They may not be losing much carbon now (having lost most of it in the past) but they could hold much more if their management was to change to 'natural' woodland. However, the reality is that most of the prime agricultural land in Scotland will remain in agriculture given the need to maintain food production.

There are knowledge gaps in terms of effects of land use change on soil organic matter storage. It is generally the case, for example, that grasslands or woodlands converted to use for arable agriculture will lose soil organic matter. Conversely, the conversion of arable land to long-term grassland or woodland is associated with an increase in soil organic matter. However, there are relatively few experimental studies that have quantified these changes within Scotland. There is also much poorer knowledge of the changes taking place in Scotland's organic and organo-mineral soils, particularly with respect to climate change. Emerging evidence and ongoing research will be crucial in determining changes that may be occurring in these environments.

Future changes in soil organic matter are difficult to predict and are based largely on biogeochemical models linked to the understanding of the main socio-economic drivers that are likely to influence patterns of land use in the coming decades. The ECOSSE model (Scottish Executive, 2007) has been specifically developed to understand the behaviour of carbon in the organic soils of Scotland and Wales.

It is becoming apparent that the export of carbon from peatlands into streamwater is an important part of the carbon budget for Scottish peats (Billett et al., 2004; Dinsmore et al., 2010). There is some evidence for increasing trends in dissolved organic carbon concentrations in streamwater over the last 30 years (e.g. Evans et al., 2005; SEPA, 2009). However, this trend is not consistent across all land uses/soil types and has been related to a range, and possible combination, of factors including increasing temperature, changing hydrology, land management, changing acidity and reduced sulphate deposition (Worrall & Burt, 2009).

4 Soil sealing

4.1 Definition and scope

Soil sealing refers to the permanent covering of the soil surface with an impermeable material. In most circumstances, this includes new residential, retail or industrial developments, but new transport links are also included. Consideration is also given to renewable energy developments (e.g. windfarms) and, although only a small part of these sites is permanently sealed, in the same way as other developments, their impact can extend beyond the land occupied by the turbines and infrastructure. It should be recognised that sealing differs from the other pressures in that it is a planned and deliberate activity taken for specific economic and social reasons.

4.2 Drivers and pressures

The key driver underpinning soil sealing is the demand for land for new development (Table 4.1). The primary objective of the Scottish Government is sustainable economic growth and this is likely to accelerate the increase in built infrastructure, as well as development by the private sector. There are also a number of demographic issues that underpin development. Chief among these is the increase in the number of households, as household size reduces (i.e. the number of people in each household reduces).

It is well recognised that the rate of loss of and impact on soils as a result of development varies with the state of the economy. Impacts are greatest during periods of economic growth, when the new building rate is at its greatest. During periods of lower economic growth, or recession, the impact on soils from infrastructure projects where longer-term public funding is in place increases proportionately.

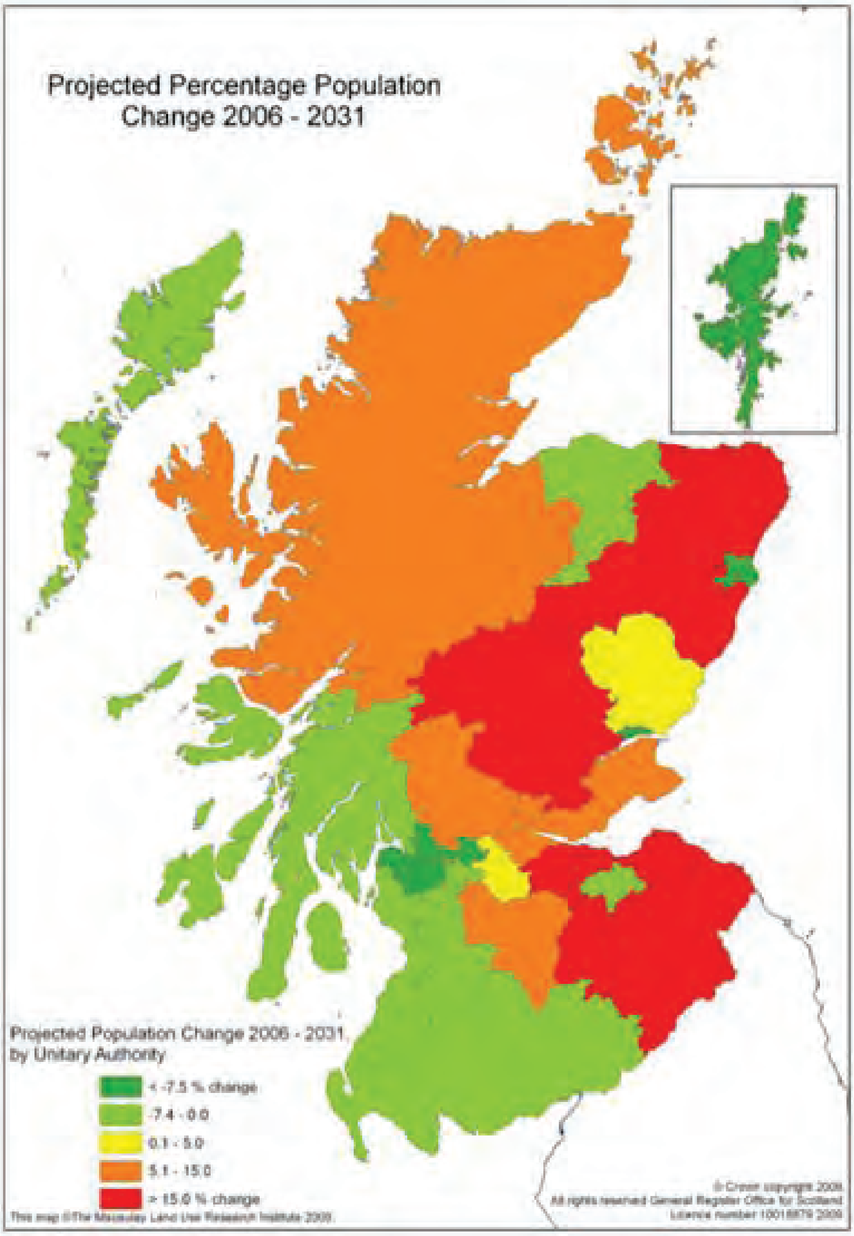
The intensification of existing development, for example sealing parts of gardens as parking areas, is perhaps a reflection of societal pressure and behaviour.

4.2.1 Population growth

Scotland's population was almost 5.2 million in 2009, representing just over a 1% increase between 1997 and 2009. However, there is doubt about longer term projections. The Scottish Executive (2007) estimated that it would fall to 5.07 million by 2031, whereas a recent Scottish Government land use study suggested that it would actually rise to 5.9 million by the same date (Miller et al., 2009) (Figure 4.1). As with any projection, there are large uncertainties. A more recent projection estimates a population of 5.54 million by 2033 (General Register Office for Scotland, 2010).

Irrespective of the scale of change, any increase or decrease in population will not be uniform across Scotland. A net migration out of all the major cities except Edinburgh is expected towards smaller and more rural settlements. Rural areas in the east, including Aberdeenshire, the Borders, and East and West Lothian, are expected to have the largest percentage population increases. These areas coincide with the highest quality agricultural soils and clearly these soils will be under threat from increased development.

Figure 4.1: Projected percentage population change: 2006–2031 (Miller et al., 2009)



4.2.2 Housing demand

Between 2004 and 2024, the number of households in Scotland is projected to increase by 13% to 2.5 million and by a further 8% to 2.7 million by 2031 – an average of 14,800 additional households per year. The average household size is expected to decrease from 2.22 people in 2004 to 1.97 people in 2024. Most of the estimated increase is the result of the ageing population and more people living alone or in smaller households, and is not strictly in line with population growth. Not all development, however, will take place on Greenfield sites; at present around 55% of development is on Brownfield sites.

Figure 4.2: Greenfield development in Aberdeenshire

4.2.3 Transport

Road length in Scotland increased from 52,346 km in 1994 to 55,089 km in 2007. A number of new or improved road transport links are at various stages of the planning process. These include the Aberdeen Western Peripheral Route (which will cover 500 hectares), dualling of the A9 from Perth to Inverness and a second Forth River Crossing, which would require extensive, additional road building in Fife and West Lothian. Not only do these developments cause sealing, they also result in land fragmentation. This can have an adverse effect on soil quality if the land is no longer utilised or managed to the extent that it once was. The engineering works associated with road building affect a larger area than just the final sealed area.

4.2.4 Renewable energy

Infrastructure for renewable energy projects, for example windfarms, utilise land and permanently seal part of it. These developments often occur on vulnerable soils, such as carbon-rich soils and, although the part of the development that is sealed is relatively small, much more of the site is affected and the functionality of the soil on it can be disturbed during, and after, construction. Given the exposed location of these sites, remediation can often be difficult and slow. The functionality of peat soils as a carbon sink, and the impact on peat over a much wider footprint than that of turbines and access roads (through fragmentation and consequent drainage, for instance) is an important consideration (Box 3.2). New power lines that can also cause soil disturbance during construction are a likely consequence of renewable energy development.

4.2.5 Landfill sites

No data appear to be available on the area of land occupied by landfill sites, although 190 were in operation in 2005. Although the area is likely to be relatively small, the impact on soil functionality, even after restoration, can be considerable.

4.2.6 Increased soil-sealing in already-developed areas and permitted development

Within existing developed areas, further loss of soil is experienced by continuous intensification of development. Much of this is a cumulative process of small-scale permitted development, i.e. changes that do not require planning permission. Examples include gardens being sealed for car parking, erection of garages, sheds, etc. and sealing of green areas within urban areas to save on vegetation management costs. Parks and green areas within cities also come under pressure to accommodate "infill" development. Soils provide the platform for greenspace within our towns and cities and there is growing recognition of their value to society (Box 4.1).

Outwith urban areas, agricultural buildings, and hard-standing areas and agricultural tracks (often benefiting from permitted development rights or a simple planning notification process) are becoming increasingly larger scale. Small-scale agricultural buildings are replaced, or supplemented by ones with a much greater footprint; with modern equipment, soil is stripped to form farm and hill tracks of considerable length.

Table 4.1 assesses the impact of each pressure on soil sealing.

Table 4.1: Relative importance of pressures leading to soil sealing (scored on a 25-year timescale using expert judgement)

Pressure	Magnitude of pressure(i)	Reversibility of pressure(ii)	Spatial extent of pressure(iii)	Trend in pressure(iv)	Uncertainty of pressure(v)
Development/transport	3	3	1	+1	1
Renewable energy	2	3	1	+1	1
Waste Management	1	2	1	-1	1

(i) Magnitude of pressure: 1, not significant; 2, significant; 3, very significant.
(ii) Reversibility of pressure: 1, short-term and reversible; 2, medium-term and reversible; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national,
(iv) Trend in pressure: -1, predicted to decrease in intensity; 0, predicted to be stable; +1, pressure predicted to increase in intensity.
(v) Uncertainty of pressure: 1, pressure well characterised and quantified; 2, pressure moderately well characterised but data primarily qualitative; 3, pressure poorly characterised.

For more details on scoring and methodology see Annex 2.

4.3 Consequences of soil sealing: environmental impacts

Built development such as urban expansion and new road building are planned activities that culminate in soil sealing and, in that context, sealing differs from the other pressures that occur because of inappropriate management (e.g. compaction or accelerated erosion) or are triggered by events that, although man-made, are of a scale beyond the control of individuals (e.g. atmospheric pollution) (Table 4.2). Additionally, soil sealing is, in most circumstances, a pressure that endures for a very long time, certainly decades, but in most circumstances, centuries. In effect, sealed soil completely loses all its other functions. Although areas of soil are retained within built developments, the scale of fragmentation of the resource means that its functionality has been radically altered and cannot be compared to its original state. Some of the main impacts on the soil functions are described below.

4.3.1 Providing the basis for food and biomass production

Loss to development prevents soil performing this function to any great extent. Although some land will be retained for gardens and allotments, the rural attributes and food production capacity of the land will be irreversibly changed. However, soils in allotments and gardens within urban areas are also being continually lost because of intensification of existing development and new "infill" development (section 4.2.6). Sealing has implications for food supply and security, for example between 1–2% of the land used for spring barley, winter wheat and potatoes was sealed between 1997 and 2004. While these percentages may be perceived as relatively low, they should be seen in the wider global context. There may be an increasing dependence on home grown produce in the future as more vulnerable areas of the world become susceptible to the impacts of climate change.

4.3.2 Controlling and regulating environmental interactions

This function is seriously diminished by sealing, but is retained to a small degree in gardens, amenity areas, roadside verges, etc. The major impact on soil function is the reduction in infiltration of water which leads to change in hydrological regimes in rivers, specifically greater run-off and peak flows. In addition, as water is no longer passing through soil, there is likely to be a greater risk of pollutants going straight into watercourses. There is also concern that construction may lead to increased sediment transport to watercourses. It has been recognised that there is a greater threat of flooding in the future in Scotland and one mechanism to reduce the impact of this is to minimise the area of new hard surfaces (soil sealing) that promotes rapid run-off.

4.3.3 Storing carbon and maintaining the balance of gases in the air

Soil in Scotland contains large amounts of carbon and, even if the soil is re-used after stripping for development, the disturbance involved in engineering works means that some of the soil and soil carbon will be lost. Soil sealing and activities subsequently associated with developed land result in a deterioration of both the ability of soil to store carbon and to regulate greenhouse gas exchanges with the atmosphere. There is also less land available that could be managed to enhance carbon sequestration potential. Air quality, in a more general sense, will be affected as a result of the likely increase in traffic volumes associated with many sealing projects.

4.3.4 Providing valued habitats and sustaining biodiversity

Overall, soil sealing has a highly negative impact on the ability of soil to sustain biodiversity. The current planning system and designation of sites of high conservation interest does, however, constrain development on land with valuable and/or rare habitats and sites of high biodiversity. It is also worth pointing out that most of the extensive areas of valued and/or rare habitats in Scotland are not found adjacent to potential development sites. Those that are near settlements could, therefore, be perceived as being under greater pressure and of higher value. However, there are likely to be specific areas where conflicts may arise, for example golf course developments (often including considerable built elements), land-based renewables, such as hydro schemes and windfarms, in areas of conservation value (often requiring significant road infrastructure) and where conservation and development objectives may clash, for example within National Parks.

4.3.5 Preserving cultural and archaeological heritage

Soil protects archaeological remains but also provides a record within it of previous cultivation and improvement and, therefore, of the historical development of landscapes and societies. It could be argued that urbanisation is another step in the process of change, but the disturbance and redistribution of soil associated with it destroys any historical record of change captured within the soil. There is a relationship between soils around settlements and the historical development of these settlements, so cultural heritage can be compromised further through urban sprawl.

4.3.6 Provision of raw materials

Depending on the specific site, resources such as sand, gravel and clay may be exploited during the initial development phase; indeed, this may be viewed as maximising the use of the resource. In addition, soil stripping is part of the land development process and, ideally, the soil removed should be re-used on site for landscaping and amenity areas. As a substantial proportion of the site is likely to be covered by buildings, roads etc., surpluses are likely to occur. These can be used in areas, particularly of redevelopment, where topsoil is in short supply, but this clearly requires a high degree of co-ordination and compliance with waste and contaminated land regulations and topsoil standards.

4.3.7 Providing a platform for buildings and roads

Essentially this function of soil is being exploited in the sealing process. This process appears to be largely "one-way." Once developed, there is little land that is returned to multi-functional soil use.

Figure 4.3: New road required for new development

Table 4.2 summarises the relative impact of sealing on the range of soil functions. Given the almost permanent nature of development, the impacts are assessed as serious.

Table 4.2: Consequence (i.e. impact) of soil sealing on soil functions (scored on a 25- year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	3	3	1	+1	1
Controlling and regulating environmental interactions	3	3	1	+1	1
Storing carbon and maintaining the balance of gases in the air	3	3	1	+1	1
Providing valued habitats and sustaining biodiversity	3	3	1	+1	1
Preserving cultural and archaeological heritage	3	3	1	+1	1
Providing raw materials	3	3	1	+1	1
Providing a platform for buildings and roads	Does not apply to this function				

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

4.4 Consequences of soil sealing: socio-economic impacts

Recent work (Glenk et al., 2010) has sought to identify the socio-economic impacts (or costs) of soil degradation and Table 4.3 summarises their findings for soil sealing.

Table 4.3: Overview of socio-economic impacts for Scotland associated with soil sealing

Soil function	Cost type	On site/ off site	Description	Impact status(i)	Data status (ii)
Biomass, food and fibre production	Private cost	On	Opportunity costs of alternative land use activities, potentially including a reduction of a country's capability to produce food	Variable	N
Regulating water flow and quality	Social cost	Off	Impacts on water quality due to unfiltered run-off and exposure to contaminants (housing, industry, traffic)	Medium	N
	Defensive cost	Off	Indirect costs of retaining and channelling water from sealed surfaces and cleaning/filtering it	Low	N
Storing carbon and maintaining the balance of gases in the air	Social cost	Off	Impacts on climate change related damage due to removal of topsoils and subsequent release of greenhouse gases	Medium	Y
Providing valued habitats and sustaining biodiversity	Social cost	Off	Compromises nature conservation; habitat fragmentation and interruption of migration corridors	Low	N
Protection of cultural and archaeological heritage	Non-use value cost	Off	Landscape/amenity values can be compromised	Medium	N
Providing a platform for buildings and roads	Private cost	On	Opportunity costs of alternative land use activities, potentially including a reduction of a country's capability to produce food	Variable	N
	Mitigation cost	On	Cost of de-sealing and restoration	Low-to-medium	N

(i) Impact status – based on 20–25-year timescale assessment of severity of biophysical change, geographical extent, contribution of single economic impact.
(ii) Y = economic estimates are available in Görlach et al. (2004), ADAS (2006) and Defra (2009).
N = no data available.

For more details on scoring and methodology see Annex 2.

Table 4.3 shows that the socio-economic impacts associated with soil sealing affect six soil functions. Eight different socio-economic impacts were identified by Glenk et al. (2010), only one of which had cost estimates available in the literature considered. Thus, actual data enabling quantitative assessments to be made are very scarce. The impact status varies from low to high across the impact categories, the majority being low or medium.

It is important to note that only considering the "cost" of soil sealing can be misleading as sealing can also provide benefits. For example, landscape values may be compromised by road building but roads open up access for more people to enjoy the landscape. Therefore, management strategies should not necessarily always aim to eliminate all threats to soil (which may be unrealistic anyway), but seek a social optimum of soil degradation instead (Kuhlmann et al., 2008). It is also important to note that the costs of soil sealing are highly dependent on both the spatial context (the initial extent of sealed soil) and the layout of a development project (e.g. how drainage is planned). As a consequence, the costs of soil sealing are best assessed as part of the planning process.

4.5 Description of the soil environment: state of soil sealing

There are a number of different sources of information on the extent (or state) of soil sealing in Scotland that give rise to a wide range of estimated values. Different sources define urban or sealed land in different ways and it is difficult to arrive at a definitive estimate.

Rural Scotland Key Facts (Scottish Government, 2010) states that urban land covers 6% of Scotland. This value is derived from boundaries between different land classes within an urban/rural classification rather than a measure of specific land use and, therefore, gives a broad measure that is likely to be an overestimate (I. Volante, Scottish Government Planning Statistics Unit, personal communication). The UK Yearbook (Office for National Statistics, 2005) gives a figure of 8% of Scotland; however, the category that includes urban land also includes non-agricultural semi-natural environments and inland waters, and is also thought to be an overestimate (I. Volante, Scottish Government Planning Statistics Unit, personal communication). Scottish Natural Heritage (SNH, 2009) found that approximately 2.7% of Scotland was urban in 1988, whilst the General Register Office for Scotland (2001) provides a figure of 2.2% coverage by settlements (population greater than 500). These latter estimates, plus that within the Land Cover of Scotland 1988 dataset (MLURI, 1993) of 2.4%, are likely to be closer to the true value than those quoted above.

4.6 Description of the soil environment: trend in soil sealing

Towers et al. (2006) described the range of data that can be used to capture the rate of soil sealing, the issue of definition of the activity and the opportunities and difficulties associated with different methods. The best estimate in the seven years up until 2004 was that an average of 1,200 hectares of land was sealed annually; much of this occurred at a time of relatively stable population. Little was known about the quality of the sealed land. Two recommendations from this report fed into the Scottish Soil Framework (Scottish Government, 2009); firstly, the need to systematically capture the area and quality of land being lost to development and; secondly, that consideration be given to reinstate a higher level of protection to prime agricultural land.

The most recent figures produced by SNH (2008), based largely on Ordnance Survey data with an assumed high degree of confidence, suggest that the rate of sealing between 2005 and 2008 was just over 2,000 hectares per year. Care must be taken when comparing this with earlier estimates and on further examination it would appear that the figure for sealing, itself, should be nearer 1,000 hectares per year as a result of reassessment of specific features (D. Blake, SNH, personal communication).

By August 2010, 1,162 wind turbines had been installed in Scotland, with more than twice that number at different phases of the planning process (Scottish Renewables, 2010). This could mean a tripling of the area already occupied by turbines in future, leading to a significant increase in the amount of soil sealing and related disturbance and impacts. Research is ongoing into determining what the impacts are both to the soil and to the wider environment (Box 3.1).

In Scotland, 7.4 million tonnes of waste were landfilled in 2007, approximately 20% of which was biodegradable municipal waste. Between 2000 and 2007 the total waste sent to landfill decreased by 34%, while the amount of biodegradable municipal waste sent to landfill decreased by 28%. Much of this decrease occurred in the first half of this period with a distinct levelling off in the later years. Increases in landfill tax coupled with the Zero Waste Strategy, mean that demand for new sites should decrease over time. It should, perhaps, be stated that a number of landfill sites were not excavated specifically for that purpose, for example, disused quarries, and therefore do not represent a loss to the soil resource.

Box 4.1: Soils within built-up areas

While new developments are, on balance, detrimental to soil quality and function, most of the Scottish population live in towns and cities and the greenspace within them is important for enhancing quality of life for their residents. Greenspace is defined as any vegetated land or water within, or adjoining, an urban area and includes:

- green corridors like paths, disused railway lines, rivers and canals;
- woods, grassed areas, parks, gardens, playing fields, children's play areas, cemeteries and allotments;
- countryside immediately adjoining a town that people can access from their homes;
- derelict, vacant and contaminated land that has the potential for a change of land use

In 2009 there was estimated to be 84,870 hectares of greenspace in Scotland, as defined above. Soils support greenspace functions such as contributing to improving people's physical and mental health by providing places for informal recreation: walking; cycling; sitting; socialising and children's play; 'breathing spaces' to take time out from the stresses of modern life; and growing their own food and other plants in their gardens and allotments. The contribution of soil to well-being and to social cohesion in urban areas is under-recognised and further research is required to achieve a better level of understanding.

5 Contamination

5.1 Definition and scope

Soil contamination occurs when substances are added to soil, resulting in increases in concentrations above background or reference levels. Pollution may follow from contamination when contaminants are present in amounts that are detrimental to soil quality and become harmful to the environment or human health. Contamination can occur via a range of pathways including direct application to land and indirect application from atmospheric deposition.

Contamination was identified by SEPA (2001) as a significant threat to soil quality in many parts of Scotland. Towers et al. (2006) identified four principal contamination threats to Scottish soils: acidification; eutrophication; metals; and pesticides. The Scottish Soil Framework (Scottish Government, 2009) set out the potential impact of these threats on the principal soil functions.

Severe contamination can lead to "contaminated land" [as defined under Part IIA of the Environmental Protection Act (1990)]. This report does not consider the state and impacts of contaminated land on the wider environment in detail. For further information on contaminated land, see 'Dealing with Land Contamination in Scotland' (SEPA, 2009).

This chapter considers the causes of soil contamination and their environmental and socio-economic impacts before going on to discuss the status of, and trends in, levels of contaminants in Scotland's soils.

5.2 Drivers and pressures

A range of human activities can lead to soil contamination, including fossil fuel combustion, industry, agriculture and forestry, and waste management. Contamination may also occur as a result of global atmospheric cycling when contaminants emitted into the atmosphere are transported large distances across national boundaries. The main contaminants found in soils are acids, nutrients, metals, organic chemicals [including persistent organic pollutants (POPs)], man-made radioactive substances and pathogens. The main causes of soil contamination are discussed below and summarised in Table 5.1. If the inputs of contaminants reach such a level that they may pose a risk to human health, ecosystems or water bodies, then the soil can be defined as "contaminated land".

5.2.1 Fossil fuel combustion and transport

Fossil fuel combustion can result in emissions of a range of contaminants, depending on the chemical composition of the fuel, the efficiency of the combustion process and the effectiveness of control measures designed to reduce emissions. Some of these contaminants may then be deposited on land in either an unaltered or altered state (e.g. by dissolution in rainwater), potentially resulting in soil contamination by acids, nutrients, metals and organic chemicals. For example, motor vehicle emissions are a significant source of metals such as lead and zinc in many soil environments, while spillage or leakage from fuel storage tanks are significant sources of contamination by organic chemicals in soils.

5.2.2 Industry

Both manufacturing and extractive industries (i.e. quarrying and mining) can result in contamination of soils directly, through discharge of contaminants to land on which the industrial process is situated, and indirectly through emissions to the atmosphere and subsequent deposition of contaminants on land. Potential pollutants from industry include acids, nutrients, metals, organic chemicals and radioactive substances.

5.2.3 Agriculture and forestry

Land management practices may result in soil contamination either through direct application of potential pollutants to land or indirectly through gaseous emission and subsequent deposition of contaminants on land. Again, the principal potential pollutants are acids, nutrients, metals and organic chemicals, as well as pathogens.

Many substances are applied to soil for the benefit of agriculture or forestry, including fertilisers, which provide nutrients that promote crop and tree growth, and pesticides to protect crops, trees and livestock from disease. If applied correctly there is little risk to soil or the wider environment. However, if applied in excessive amounts, or at the wrong time of year, these substances can cause damage to the environment or become toxic to plants, livestock and, ultimately, to humans.

In addition, 95% of atmospheric ammonia emissions in Scotland in 2007 (National Atmospheric Emissions Inventory, 2009) came from agricultural sources, such as cattle, pig and poultry farms, the majority of which is deposited close to the source of emission (SEPA, 2001) and can be detrimental to soil quality.

5.2.4 Waste management

There is an increasing drive to seek alternatives to the disposal of organic waste in landfill sites. Two potential alternatives are recycling organic wastes to land for agricultural or ecological benefit and incineration, both of which can affect soil quality.

In addition to livestock manures and slurries, various organic wastes are routinely applied to land in Scotland as fertilisers, including sewage sludge, distillery waste and compost. As well as nutrients, these wastes can contain potentially toxic constituents such as metals, organic chemicals and pathogens, and so have the potential to cause soil contamination. However, waste application to land is regulated to minimise risk to the environment and human health.

Incinerators may be significant point-sources of atmospheric emissions of metals and organic chemicals, such as furans and dioxins.

5.2.5 Global atmospheric cycling

Scotland's soil quality may be affected by continued production of atmospheric pollution throughout the world. Some contaminants (e.g. mercury; Farmer et al., 2009) may be entering Scottish soils following deposition of emissions originating from rapidly-industrialising parts of the world, such as South-East Asia.

Table 5.1: Relative importance of pressures leading to soil contamination (scored on a 25-year timescale using expert judgement)

Pressure	Magnitude of pressure(i)	Reversibility of pressure(ii)	Spatial extent of pressure(iii)	Trend in pressure(iv)	Uncertainty of pressure(v)
Fossil fuel combustion and transport	2	3	3	0	3
Agriculture - application of chemicals	3	3	3	+1	2
Forestry - application of chemicals	1	1	2	+1	2
Waste management	2	3	1	+1	1
Industrial emissions	2	3	1	-1	1
Global cycling	1	2	3	+1	3

(i) Magnitude of pressure: 1, not significant; 2, significant; 3, very significant.
(ii) Reversibility of pressure: 1, short-term and reversible; 2, medium-term and reversible; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in pressure: -1, predicted to decrease in intensity; 0, predicted to be stable; +1, pressure predicted to increase in intensity.
(v) Uncertainty of pressure: 1, pressure well characterised and quantified; 2, pressure moderately well characterised but data primarily qualitative; 3, pressure poorly characterised.

For more details on scoring and methodology see Annex 2.

5.3 Consequences of soil contamination: environmental impacts

The addition of contaminants to soils has a number of potential impacts on soil function. These impacts are often associated with the "critical load" concept, i.e. the idea that soil has a limit beyond which function is impaired. If the rate of addition of a potential pollutant is maintained below its critical load, the soil will be resilient to changes caused by the addition of that contaminant and will continue carrying out its function. If, however, the addition rate exceeds the critical load then the soil will not be able to absorb the excess contaminant, potentially leading to wider environmental harm. Critical loads give an indication of which areas are most vulnerable to particular potential pollutants and which areas may already be suffering from the effects of that pollution (Holden et al., 2007).

5.3.1 Acids and nutrients

Gaseous emissions of sulphur dioxide and oxides of nitrogen can be dissolved in rainwater to form sulphuric and nitric acids which can subsequently be deposited on soil, causing soil acidification. Excess nitrogen deposition can also lead to soil eutrophication.

Table 5.2 illustrates the impacts of acidification and eutrophication on soil functions. Acidification and eutrophication impacts are often greatest in upland areas as a result of high rainfall and are exacerbated by predominantly poorly-buffered and nutrient-poor soils and the greater sensitivity of locally adapted biodiversity to a change in soil conditions. However, lowland soils, especially those associated with ecosystems of high conservation value, may also be affected by acidification and eutrophication. In addition, fertiliser application in excess of crop nutrient requirements can result in acidification and eutrophication of agricultural and forestry soils.

Providing the basis for food and biomass production

In intensively managed food and biomass production systems, including most agricultural systems, the direct impacts of soil acidification and eutrophication caused by atmospheric deposition are likely to be mitigated by land management practices. Reductions in tree growth resulting from soil acidification, while evident in North America, mainland Europe and eastern Asia (e.g. Nisbet, 1974; Elias et al., 2009; Yang Jae et al., 2009), have not been recorded in Scotland (e.g. Sheppard et al., 2008), probably because of lower deposition rates (Fischer et al., 2007).

Controlling and regulating environmental interactions

During the 1990s, researchers identified that acidification impacts on soil nutrient cycling, resulting from critical load exceedance, could reduce the ability of soils to filter contaminants. Acidification of watercourses in Scotland has been linked with soil acidification (e.g. Helliwell et al., 2001).

Further nitrogen additions are also less readily retained in ecosystems where the critical load for nitrogen is exceeded. This leads to 'nitrogen saturation', where the excess nitrogen may leach into watercourses (Agren & Bosatta 1988; Aber et al., 1989). In addition, application of nitrogen and phosphorus fertilisers in excess of crop nutrient requirements can lead to a build up of nutrients in soil. Excess nutrients can then be lost through leaching into watercourses or transportation to watercourses via erosion and run-off. Excess nitrogen may also be transformed by microbes in the soil and emitted to the atmosphere as the greenhouse gas nitrous oxide (N_2O). Diffuse pollution resulting from transport of nutrients from soil to water is a major cause of poor water quality in Scotland, while the majority of Scotland's N_2O emissions come from fertilised agricultural soils (Box 5.1).

Storing carbon and maintaining the balance of gases in the air

The impact of acidification on the carbon storage function of soil is currently the subject of considerable debate. It has been suggested that the recovery of soils from acidification is encouraging the production of dissolved organic carbon in soils, leading to a loss of soil carbon as dissolved organic carbon is flushed out of soil into watercourses (Evans et al., 2008).

Providing valued habitats and sustaining biodiversity

At deposition rates above the critical load, both acidification and eutrophication of soils will alter available nutrient distribution, potentially leading to changes in plant communities and soil formation processes. For example, in peat soils, increased acidity can reduce plant litter decomposition rates, encouraging peat formation (Sanger et al., 1994), but nitrogen enrichment can harm plant species such as sphagnum mosses, potentially reducing peat formation as available plant litter is reduced (Gunnarsson & Rydin, 2000).

Other functions

There is some evidence that the application of fertiliser alters the preservation of buried artefacts. As yet, however, not enough is known about the effects of specific compounds on different archaeological materials to allow conclusions to be drawn (Davidson & Wilson, 2006). Fertiliser application also has implications for cultural landscape preservation as the current patchwork of soils that has evolved from past land management practices can be lost through modern improvement schemes.

The addition of acids and nutrients to soils has no significant effect on providing raw materials and providing a platform for buildings and roads.

Table 5.2: Consequence (i.e. impact) of acidification and eutrophication on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	2	1	2	-1	2
Controlling and regulating environmental interactions	3	2	3	-1	2
Storing carbon and maintaining the balance of gases in the air	3	3	2	-1	3
Providing valued habitats and sustaining biodiversity	3	3	2	-1	2
Preserving cultural and archaeological heritage	1	3	1	-1	2
Providing raw materials	0	0	0	-1	1
Providing a platform for buildings and roads	0	0	0	-1	1

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

Box 5.1: Soil nitrogen

Nitrogen is an essential plant nutrient and is routinely applied to agricultural soil in both inorganic and organic forms (e.g. mineral fertilisers, livestock manures) to promote crop growth. However, if more nitrogen is applied than required by the crop, the remaining nitrogen in the soil will be available for chemical or biological transformation, which may have environmental consequences.

Fertiliser application to emerging crop

Available nitrogen in soil can be dissolved by rainwater and leached into rivers or ground water, with the potential to cause eutrophication of water. Certain areas where nitrogen in water is a recognised problem are designated as Nitrate Vulnerable Zones and there are restrictions in place regarding the timing and amount of nitrogen fertiliser that can be applied to crops to avoid excess nitrogen building up in the soil and leaching to water.

Available nitrogen may also be transformed by microbes in the soil and emitted to the atmosphere as nitrous oxide (N_2O) – a greenhouse gas 300 times more powerful than carbon dioxide (CO_2). Soil management is increasingly seen as making an important contribution to reducing Scotland's greenhouse gas emissions. Nitrous oxide is mostly produced by agricultural soils. In fact, more than half of agriculture's contribution to greenhouse gas emissions results from N_2O emissions. Whilst it is not possible to avoid such emissions completely (given the need to produce food), there are opportunities to achieve significant reductions in emissions through better soil and crop management. Such measures would include improved fertiliser management (timing and amounts), improved soil management (particularly improved structure and drainage), the use of new crop varieties and mixtures, precision farming, and nitrification inhibitors. Many of these measures would contribute to increased efficiency within farming systems and, therefore, both reduced costs and greenhouse gas emissions. It is likely that the management of soils to reduce N_2O emissions will be one of many objectives required to deliver improvements in soil quality and environmental protection in the years ahead.

5.3.2 Metals

Metal concentrations in soil are fundamentally related to those in the soil parent material that are often linked to the underlying geology. Human activities can lead to increases in these concentrations above natural background levels, with potential impacts on soil quality (Towers et al., 2006). Table 5.3 illustrates the impact of metal contamination on soil functions.

The toxicity of metals in soil is not only dependent on the total metal concentration in the soil but also on the mobility and bioavailability of the metal (e.g. Sauve et al. 1998) which in turn is dependent on other properties such as soil pH (Towers & Paterson, 1997).

Providing the basis for food and biomass production

Although some metals are important trace nutrients for plants and animals, they can inhibit plant growth at higher concentrations. In addition, they can accumulate in the plant and become toxic to animals and humans via the food chain. The quality of food crops may be affected by soil metal concentrations. For example, grain cadmium concentrations have been found to be higher than acceptable food standard values when grown in soils with elevated cadmium concentrations (e.g. Baize et al., 2009).

Controlling and regulating environmental interactions

Contamination of soils with metals can impact directly on water quality if metals become mobilised and are leached into watercourses. For example, Farmer et al. (2002) and Whalley et al. (1999) found high concentrations of chromium in both surface and groundwater around sites in the Glasgow area where soils and sub-surface materials contain waste from historic chromite ore processing. Whilst limited in spatial extent, these impacts can be locally significant.

Providing valued habitats and sustaining biodiversity

Metal contaminants in soils may impair the growth of certain types of vegetation, particularly on highly contaminated sites, for example coal bings (Paterson et al., 2003), and can lead to losses of soil biodiversity on a local scale. On the contrary, contaminated soils may, through the nature of their contamination, support plant communities of high conservation value (SEPA, 2009). Further detail on the impact of metal contamination on soil biodiversity is discussed in Chapter 6.

Other functions

The addition of metals to soils has no significant effect on storing carbon, preserving cultural and archaeological heritage, providing raw materials or providing a platform for buildings and roads (unless the land has been classified as contaminated land – see section 5.3.6).

Table 5.3: Consequence (i.e. impact) of metal contamination on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	2	2	1	+1	2
Controlling and regulating environmental interactions	2	3	1	+1	3
Storing carbon and maintaining the balance of gases in the air	1	3	2	-1	3
Providing valued habitats and sustaining biodiversity	2	3	2	-1	3
Preserving cultural and archaeological heritage	0	0	0	-1	3
Providing raw materials	0	0	0	-1	3
Providing a platform for buildings and roads	0	0	0	0	2

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

5.3.3 Organic chemicals

Organic chemicals are introduced to soil from a variety of sources. Persistent organic pollutants (POPs) are of most concern as they break down slowly and are retained in the soil for long periods of time. Generally, however, the organic chemicals used in the environment in recent times are no longer "persistent" as a result of legislation banning the use of POPs (European Commission, 2010) (Box 5.2). The magnitude of impact on soil functions is shown in Table 5.4.

Providing the basis for food and biomass production

Pesticides, herbicides and other organic chemicals are routinely applied to land to protect crops from pests, diseases and weed encroachment and hence increase production. Although some organic chemicals can have toxic effects on plants and animals, the environmental response to those used in modern agriculture has been extensively tested, and most will break down rapidly in the soil environment. Persistent organic pollutants such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) that enter soil through atmospheric deposition or application of organic waste are of more concern due to their slow breakdown rates and toxicity to humans and animals.

Controlling and regulating environmental interactions

Impacts of organic contaminants in soil on water quality are important at a local level in Scotland. For example, D'Arcy et al. (2006) found that pesticide pollution in Loch Leven was a result of large inputs of pesticides to agricultural soils in the catchment. It is also possible that potential organic pollutants in soil may indirectly impact on water quality through impairing the action of soil biota in breaking down other pollutants, which are subsequently leached to watercourses.

Providing valued habitats and sustaining biodiversity

Persistent organic pollutants in soils can affect biodiversity and ecosystems either through direct toxicity to soil organisms and vegetation or through their potential for uptake by plants and accumulation in organisms at higher levels in the food chain.

Other functions

There is no evidence available for the effects of organic contaminants on storing carbon, preserving cultural heritage, providing a platform for building (unless the land has been designated as contaminated – see section 5.3.6) or providing raw materials. However, there are increasing numbers of man-made organic chemicals in the environment, and the activity and fate of some of these have not been extensively studied. Therefore, there is considerable uncertainty about the effect of organic chemicals upon soil functions.

Box 5.2: Pesticide use and soil contamination with pesticides in Scotland

Formerly, many pesticides in widespread use were persistent in the environment [e.g. organochlorines, such as dichlorodiphenyltrichloroethane (DDT)]. However, most pesticides currently in use break down rapidly in soil (Towers et al., 2006).

Applications of pesticides in Scotland have remained stable over the last 10 years at around 1,500 tonnes per year [Science and Advice for Scottish Agriculture (SASA), personal communication]. This is further illustrated in Figure B5.2 for arable crops in Scotland normalised over the area applied.

Fungicides are the most commonly applied pesticide (ca. 50% of the total), followed by herbicides (35%). The rapid breakdown of most pesticides in soils suggests that they will not impair soil quality or affect soil functions, although this is an area that has not been extensively studied. The activity, as well as the amount of pesticide applied to land, influences its environmental impact, and activity has increased significantly in recent years (SAC, personal communication).

Figure B5.2: Trends in rate of pesticide applications to Scottish soils 1998–2008. Data supplied by Pesticides Usage and Wildlife Management Department, SASA

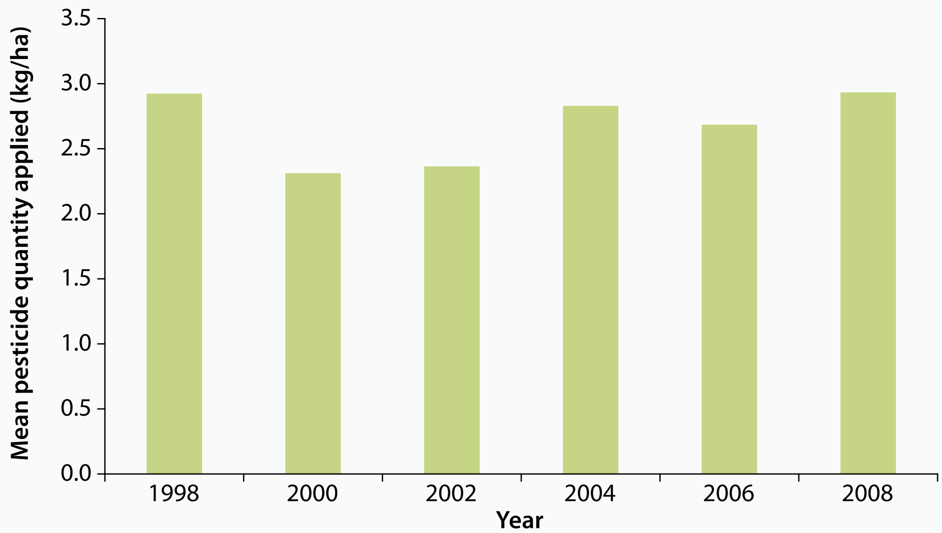


Table 5.4: Consequence (i.e. impact) of organic chemicals on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	1	2	1	+1	3
Controlling and regulating environmental interactions	1	3	1	+1	3
Storing carbon and maintaining the balance of gases in the air	0	0	0	-1	3
Providing valued habitats and sustaining biodiversity	1	3	1	-1	3
Preserving cultural and archaeological heritage	0	0	0	-1	3
Providing raw materials	0	0	0	-1	3
Providing a platform for buildings and roads	0	0	0	0	3

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3 national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

5.3.4 Man-made radioactive substances

Man-made radioactive substances can be introduced to soil through atmospheric deposition following nuclear incidents or through waste disposal. The legislation surrounding activities involving man-made radioactive substances is very stringent and thus limits the risk to the environment. Table 5.5 illustrates the relative importance of the impacts of soil contamination with man-made radioactive substances on soil functions.

Providing the basis for food and biomass production

Man-made radioactive substances in soil can be taken up into crops or livestock and subsequently enter the human food chain. However, if this is likely to occur, restrictions are put in place to avoid the consumption of affected food. For example, restrictions were placed on the consumption of meat from some farms in Scotland following the Chernobyl incident in 1986.

Other functions

There is no evidence available for the effects of man-made radioactive substances on environmental interactions, storing carbon, providing a habitat, preserving cultural heritage, providing raw materials or providing a platform for buildings or roads (unless the land has been designated as contaminated – see section 5.3.6). However, there is potential for man-made radioactive substances to impact upon most soil functions in the event of a major incident resulting in large-scale release of radioactive contamination into the environment.

Table 5.5: Consequence (i.e. impact) of man-made radioactive substances on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	2	2	2	0	2
Controlling and regulating environmental interactions	1	2	1	0	3
Storing carbon and maintaining the balance of gases in the air	0	0	0	0	3
Providing valued habitats and sustaining biodiversity	1	2	1	0	3
Preserving cultural and archaeological heritage	0	0	0	0	3
Providing raw materials	0	0	0	0	3
Providing a platform for buildings and roads	0	0	0	0	2

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

5.3.5 Pathogens

Pathogens may enter soil through the application of certain organic materials and wastes to land, for example livestock manures, compost and abattoir waste, and also through airborne hosts. Many pathogens are also naturally resident in soil with populations and activity changing in response to changing soil conditions. There is legislation in place to regulate pathogen concentrations in waste, and most wastes that may contain pathogens are treated in some way to reduce this threat. If pathogens enter soil, they may have impacts on human and animal health, but their impact on soil functions is limited. Table 5.6 illustrates the impact of pathogens on soil functions.

Providing the basis for food and biomass production

The presence of pathogens in soil may reduce the potential for a soil to safely grow certain food crops. This is particularly applicable to crops that are eaten raw, such as salad vegetables. There is also the potential for plant pathogens introduced into soil to reduce yields from both agriculture and forestry.

Controlling and regulating environmental interactions

The introduction of pathogens to soil may damage the natural soil biota. This may reduce the effectiveness of contaminant break down in soil, potentially leading to negative impacts on water and air quality.

Providing valued habitats and sustaining biodiversity

Soil-dwelling pathogens that attack particular plant or animal species may cause disruption to ecosystems, particularly if the target species performs a vital function within that ecosystem.

Other functions

There is no evidence available for the effects of pathogens on storing carbon, preserving cultural heritage, providing a platform for building or providing raw materials.

Table 5.6: Consequence (i.e. impact) of pathogens on soil functions (scored on a 25- year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	2	1	1	+1	2
Controlling and regulating environmental interactions	2	1	1	0	2
Storing carbon and maintaining the balance of gases in the air	0	0	0	0	3
Providing valued habitats and sustaining biodiversity	1	2	2	+1	2
Preserving cultural and archaeological heritage	0	0	0	0	2
Providing raw materials	0	0	0	0	2
Providing a platform for buildings and roads	0	0	0	0	2

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3 national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

5.3.6 Contaminated land

Severe soil contamination can lead to "contaminated land" [as defined under Part IIA of the Environmental Protection Act (1990)]. This is often caused by point source pollution originating from a previous occupant of the land. Contamination may result from deliberate discharge or disposal of waste to land, accidental spillages or leakages from storage facilities and localised fallout of airborne emissions, for example dust. Contaminated land may be caused by a range of substances, including metals, organic substances and man-made radioactive contaminants, depending on the activity or activities that formerly took place on the site.

Contaminated land can have a number of impacts on soil functions depending on the type of contaminant, soil properties and location. The impacts are likely to be of greater magnitude than those outlined above for the different contaminants and, thus, they may be more difficult, or costly, to reverse. In addition, contaminated land legislation means that once land has been designated as "contaminated" under Part IIA of the Environmental Protection Act (1990), there are restrictions on its redevelopment depending on a number of criteria, including the type of contaminant, the intended land use and the soil properties. A number of soil guideline values have been designed for the protection of human health (Environment Agency, 2010). If land exceeds soil guideline values for a specific use, then further investigation is required to ascertain whether remediation is necessary before the land can be developed. There are also specific constraints in place to ensure that redevelopment of land that may be contaminated with radioactive substances does not pose a significant risk to human health. This has major implications, therefore, for the function providing a platform for building and roads.

Table 5.7 indicates how contaminated land may impact different soil functions.

Table 5.7: Consequence (i.e. impact) of contaminated land on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	3	2	1	-1	2
Controlling and regulating environmental interactions	3	2	1	-1	2
Storing carbon and maintaining the balance of gases in the air	0	0	0	-1	2
Providing valued habitats and sustaining biodiversity	3	2	1	-1	2
Preserving cultural and archaeological heritage	0	0	0	-1	2
Providing raw materials	0	0	0	-1	2
Providing a platform for buildings and roads	3	2	1	-1	2

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional, 3 national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

5.4 Consequences of soil contamination: socio-economic impacts

Recent work (Glenk et al., 2010) has sought to identify the socio-economic impacts associated with soil contamination. Figure 2.3 explains in more detail the different cost categories considered in this interpretation.

In order to investigate the socio-economic impacts of soil contamination, it is helpful to distinguish between point sources and diffuse sources of contamination, as indicated in Table 5.8. Point sources of contamination are more likely than diffuse sources to give rise to "contaminated land" as defined under Part IIA of the Environmental Protection Act (1990).

Table 5.8: Examples of point and diffuse sources of soil contamination

Point sources	Diffuse sources
Municipal and industrial waste disposal sites	Waste disposal or use of chemicals on land
Industrial and commercial sites	Fertiliser application
Mining/quarry sites	Contaminants originating from atmospheric deposition
Former military sites	Run-off from urban surfaces such as roofs and roads
Oil extraction	

Table 5.9 and Table 5.10 are derived from Glenk et al. (2010). Table 5.9 gives an overview of possible socio-economic impact categories that are mainly, but not exclusively, associated with point sources. Table 5.10 summarises socio-economic impact categories associated specifically with atmospheric deposition, as this is a significant source of soil contamination in Scotland.

Table 5.9: Overview of economic impact categories for Scotland associated with contamination

Soil function	Cost type	On site/ off site	Description	Impact status(i)	Data status(ii)
Providing the basis for food and biomass production	Social cost	Off	Contamination of agricultural land constrains usage resulting in loss of farm income and property value of land	Low	N
Controlling and regulating environmental interactions	Private cost/social cost	On	Costs of monitoring and risk/impact assessments	Low	Y
		On	Costs of protection of workers and/or the public from exposure to harmful substances	Low	N
		Off	Legal restrictions to using land for certain purposes can have negative impacts on land/property values	Low	N
	Private cost	On	Costs of land/property depreciation (estimated with damage function)	Low	N

Table 5.9: Overview of economic impact categories for Scotland associated with contamination (continued)

Soil function	Cost type	On site/ off site	Description	Impact status[(i)]	Data status[(ii)]
Controlling and regulating environmental interactions (continued)	Mitigation cost	On	Costs of decontamination or site clean-up after use	High	Y
	Social cost	Off	Health impacts of contacts with pollutants/contaminants and of consumption of contaminated products with associated costs of treatment and wage loss	High	Y
		Off	Contamination of agricultural land constrains usage resulting in loss of farm income and property value of land	Low	N
		Off	Costs associated with groundwater contamination	Medium	Y
		Off	Real estate within or close to contaminated sites can decline in value due to perceived threats to health	Low-to-medium	N
	Social cost/non-use value cost	Off	Pollutants/contaminants in soils can be washed out into surface water bodies or use soil particles as vehicles to be transported to water bodies. Impacts on surface water quality and ecology (e.g. fish stocks), with costs emerging from constrained usage of water bodies and consumption of products from these	Medium-to-high	Y
	Mitigation cost	On	Costs of decontamination or site clean-up after use	High	Y
Storing carbon and maintaining the balance of gases in the air	Defensive cost	Off	Defensive costs related to the prevention of contaminant transport	Low-to-medium	N
Providing valued habitats and sustaining biodiversity	Social cost/non-use value cost	Off	Pollutants/contaminants in soils can be washed out into surface water bodies or use soil particles as vehicles to be transported to water bodies. Impacts on surface water quality and ecology (e.g. fish stocks), with costs emerging from constrained usage of water bodies and consumption of products from these	Medium-to-high	Y

Table 5.9: Overview of economic impact categories for Scotland associated with contamination (continued)

Soil function	Cost type	On site/ off site	Description	Impact status(i)	Data status(ii)
Providing a platform for buildings and roads	Private cost/ social cost	Off	Legal restrictions to using land for certain purposes can have negative impacts on land/property values	Low	N
	Mitigation cost	On	Costs of decontamination or site clean-up after use	High	Y
	Private cost	On	Costs of land/property depreciation (estimated with damage function)	Low	N

(i) Impact status – based on 20–25-year timescale assessment of severity of biophysical change, geographical extent, contribution of single economic impact.
(ii) Y = economic estimates are available in Görlach et al. (2004), ADAS (2006) and Defra (2009).
N = no data available.

For more details on scoring and methodology see Annex 2.

Table 5.10: Overview of economic impact categories for Scotland associated with atmospheric deposition

Soil function	Cost type	On site/ off site	Description	Impact status(i)	Data status(ii)
Providing the basis for food and biomass production	Private cost	On	Costs associated with loss in productivity resulting from change in soil biodiversity	Low-medium	N
	Mitigation cost	On	Costs of restoration practices to reduce nutrient levels in soils	Low-medium	N
		on	Costs associated with mitigating the transport of pollutants/contaminants to soils	Low	N
		On	Costs associated with remediating reduced soil pH as a consequence of acid deposition	Low	N
Controlling and regulating environmental interactions	Private cost	On	Costs of monitoring and risk/impact assessments (site specific)	Low	N
		On	Costs associated with loss in productivity resulting from change in soil biodiversity	Low-medium	N
	Mitigation cost	On	Costs of restoration practices to reduce nutrient levels in soils	Low-medium	N
		On	Costs associated with mitigating the transport of pollutants/contaminants to soils	Low	N
		On	Costs associated with remediating reduced soil pH as a consequence of acid deposition	Low	N

Table 5.10: Overview of economic impact categories for Scotland associated with atmospheric deposition (continued)

Soil function	Cost type	On site/ off site	Description	Impact status(i)	Data status(ii)
Controlling and regulating environmental interactions (continued)	Social cost	Off	Costs of monitoring and risk/ impact assessments (national to international)	Low	N
		Off	Costs associated with surface and groundwater contamination	Low-medium	N
		Off	Impacts on freshwater ecology with costs emerging from constrained usage of water bodies and consumption of products from these	Low-medium	N
	Social cost/non-use value cost	Off	Costs associated with reduced habitat quality through feedbacks from soils to above-ground plants	Low-medium	N
Storing carbon and maintaining the balance of gases in the air	Social cost	Off	Increased emissions of greenhouse gases from soil after nutrient enrichment	Low -medium	N
	Defensive cost	Off	Costs of defensive measures to prevent deposition-induced erosion and degradation particularly of organic soils	Low	N
Providing valued habitats and sustaining biodiversity	Social cost/non-use value cost	Off	Costs associated with reduced habitat quality through feedbacks from soils to above-ground plants	Low-medium	N
	Defensive cost	Off	Costs of defensive measures to prevent deposition-induced erosion and degradation particularly of organic soils	Low	N

(i) Impact status – based on 20–25-year timescale assessment of severity of biophysical change, geographical extent, contribution of single economic impact.
(ii) Y = economic estimates are available in Görlach et al. (2004), ADAS (2006) and Defra (2009).
N = no data available.

For more details on scoring and methodology see Annex 2.

Table 5.9 shows that socio-economic impacts associated mainly with point source contamination affect five soil functions. In total, 17 socio-economic impacts were identified. The impact status varies from low-to-high across the impact categories. Economic estimates are available for around half of the impacts in the literature considered by Glenk et al. (2010). It is worth noting that the "controlling and regulating environmental interactions" function has 11 socio-economic impacts of mainly point source contamination which is the highest number seen on any of the soil functions across all of the threats.

There were also 17 socio-economic impacts identified associated with atmospheric deposition although these only affected four soil functions (Table 5.10). The impact status varies from low to medium across the impact categories. However, there were no economic estimates available for any of the impacts identified in the literature considered by Glenk et al. (2010). It is therefore difficult to quantify, or even estimate, the socio-economic impact of atmospheric deposition.

As atmospheric deposition can contribute to eutrophication and acidification, there is a high risk of double-counting socio-economic impacts if these issues are assessed separately. The economic impact of atmospheric deposition is further complicated because as well as potentially having negative impacts on the water environment (e.g. as a result of nitrate leaching from soil into watercourses), in some cases it may bring benefits, for example atmospheric inputs of sulphur to agricultural soils can reduce the need to apply sulphur fertilisers, thus reducing input costs.

Some examples of socio-economic impacts of contamination in Scotland that would be useful to determine to improve the socio-economic analysis are:

- remediation of contaminated soils before development;
- water purification costs;
- reduced water quality;
- loss in fungi of conservation status; and
- restoration costs to reduce nutrient enrichment.

5.5 Description of the environment: state of soil contamination

As well as being potential contaminants, some elements are essential in trace amounts for plants and animals to grow. Thus, a deficiency, as well as an excess, in certain elements can cause soil to be of poor quality.

5.5.1 Soil acidity and nutrient status

In large areas of Scotland, critical loads for acidity and nitrogen are exceeded (Figure 5.1 and Figure 5.2), which suggests that soil functions in these areas could be impacted. The largest impacts are expected in areas of greatest exceedance. For example, the impacts of soil acidification on both the biological and chemical quality of water have been observed in different regions of Scotland, for example Galloway (Helliwell et al., 2007) and the Cairngorms (Soulsby et al., 1997). Nitrate concentrations in rivers have been shown to be related to nitrogen saturation in soils in catchments in south-west and north-east Scotland (Helliwell et al., 2001; Futter et al., 2008).

Extractable phosphorus concentrations in agricultural soils from throughout Scotland sent to the Scottish Agricultural College (SAC) for routine analysis are, on average, of moderate status (SSFIS 1996+). Locally, however, both low and excessively high values are observed. This suggests that in general extractable soil phosphorous concentration in Scotland is of good status for crop growth. However, in some fields it is so high that it is likely to be in excess of crop requirements and is, therefore, at risk of being transported into watercourses. Figure 5.3 shows that there is a potential diffuse pollution risk in the Edinburgh area. Although the soils are, on average, of moderate phosphorous status there are instances where soil phosphorous concentrations exceed this. Meanwhile, in the Thurso area, soil phosphorous status is generally low and thus it may be necessary to add phosphorous to these soils to ensure optimum crop growth. It is important to note that the classification into low, moderate and high phosphorous status in this context relates to soil fertility for crop growth and does not reflect the impact it would have on water quality if the soil was eroded into an adjacent water body.

It should be noted that soils sent to the SAC laboratory for routine analysis are not part of a national soil survey or monitoring scheme and so while the results provide an indication of the state of soil, they cannot be used to infer an overall picture of soil fertility in Scotland.

Figure 5.1: Exceedance of critical loads for terrestrial habitats by acid deposition (sulphur + NOx + NHx) for (a) 1996–1998 and (b) 2006–2008. Maps supplied by Jane Hall, Centre for Ecology and Hydrology. Map resolution: 1 km^2

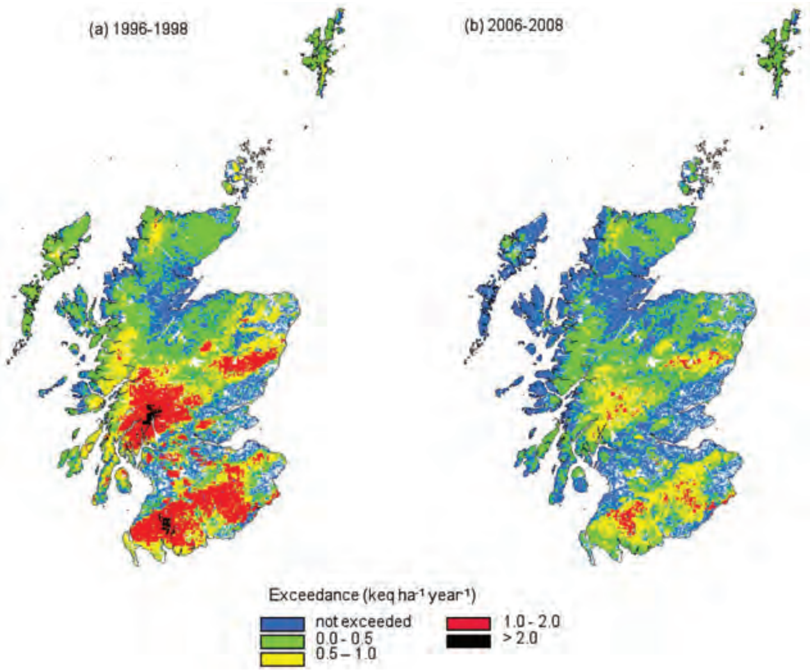


Figure 5.2: Exceedance of critical loads for bog habitats in Scotland by nitrogen (NOx + NHx) deposition for (a) 1996–1998 and (b) 2006–2008. Maps supplied by Jane Hall, Centre for Ecology and Hydrology. Map resolution: 1 km^2

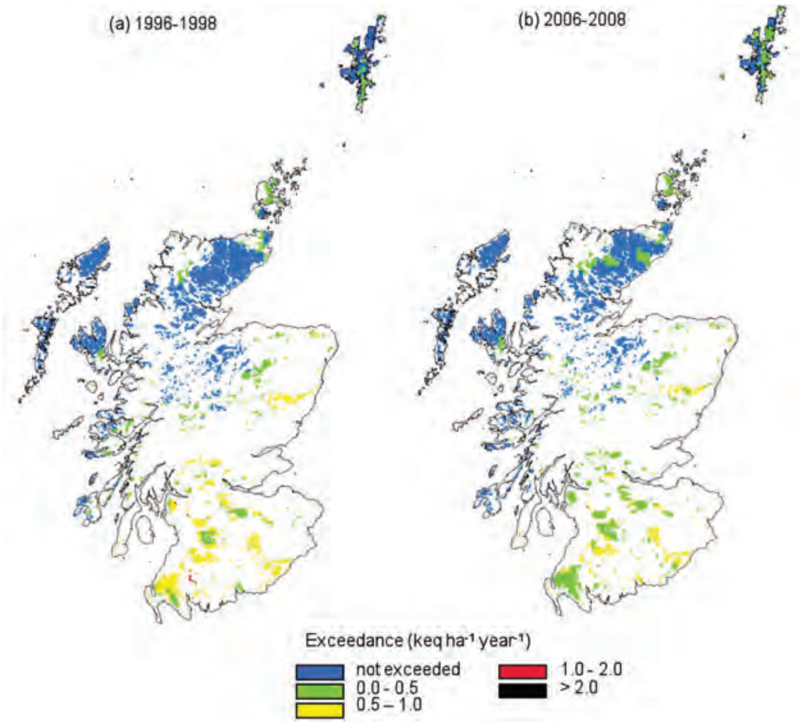
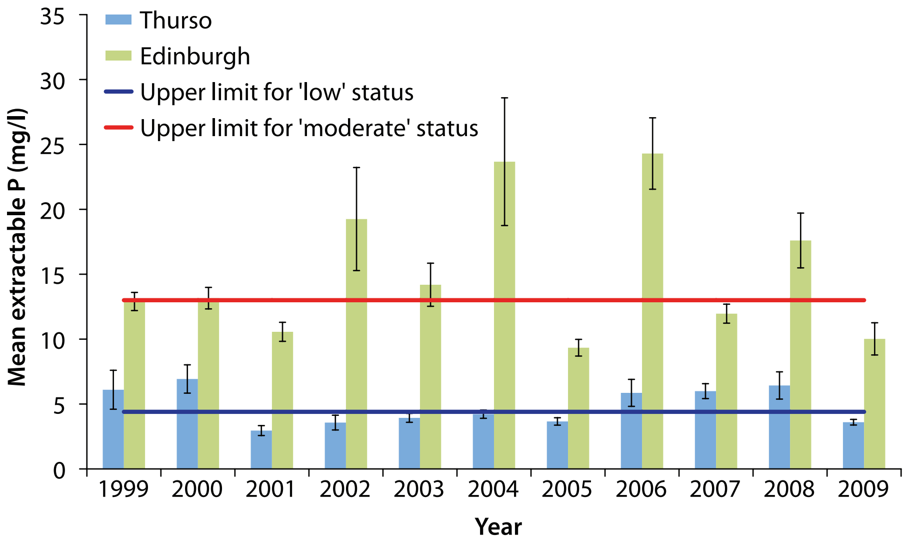


Figure 5.3: Mean extractable phosphorus (P) concentration in agricultural soil samples submitted to two separate Scottish Agricultural College (SAC) advisory offices for analysis. Error bars show standard error of the mean. Data supplied by SAC



5.5.2 Metals status

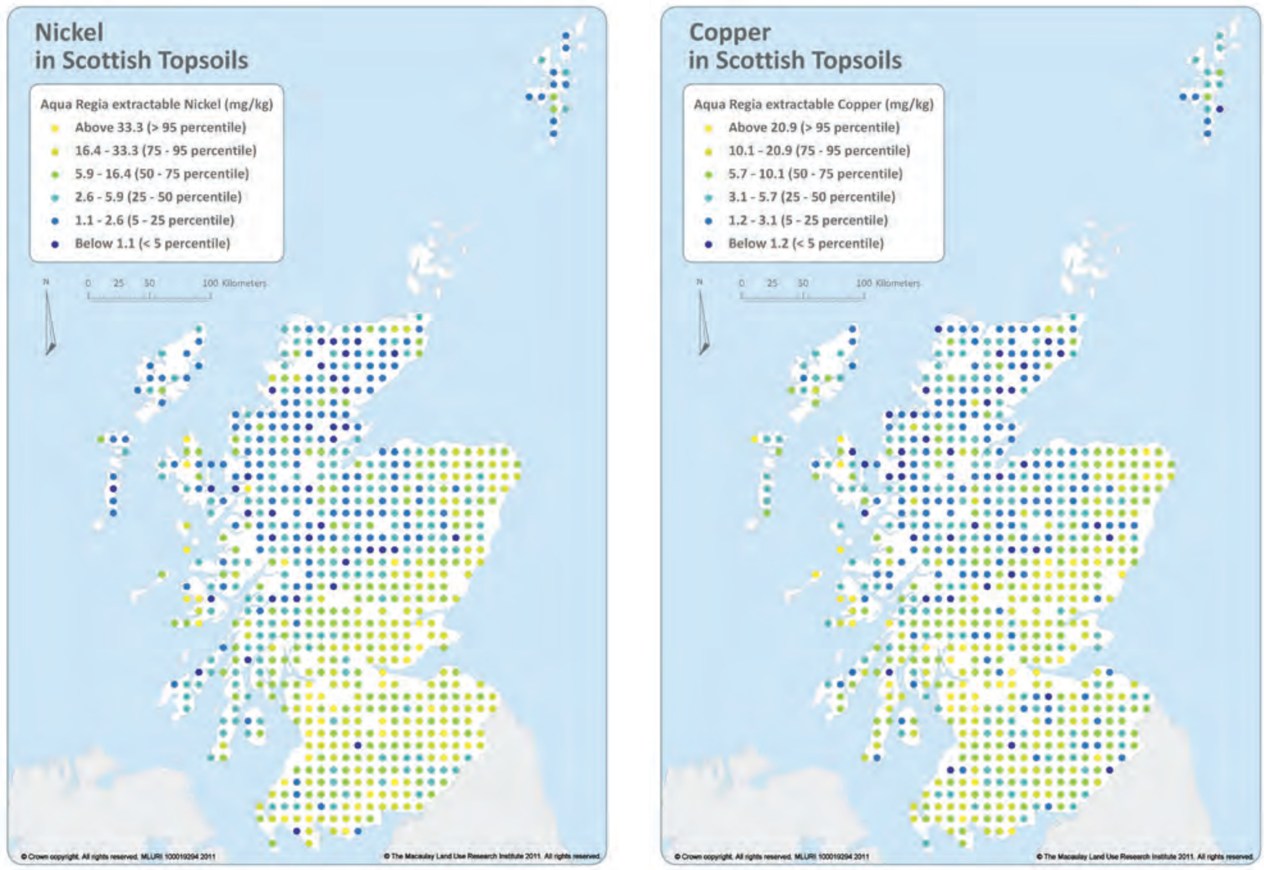
Soil metal concentrations were measured across Scotland as part of the National Soil Inventory of Scotland (NSIS_1), whilst the UK Soil and Herbage Survey (UKSHS) also included determinations of metal concentrations in Scottish rural and urban soils. The averages and ranges of metal concentrations found in these surveys are given in Table 5.11. The wide range of concentrations reflects the diverse geology of Scotland (section 5.3.2).

Table 5.11: Range and mean/median concentrations of metals in Scottish soils as determined by the National Soil Inventory of Scotland (NSIS_I) (surface horizon) and UK Soil and Herbage Survey (UKSHS) (top 5 cm) studies

	NSIS_I (concentration; mg/kg)		UKSHS rural (concentration; mg/kg)		UKSHS urban (concentration; mg/kg)	
Metal	Mean	Range	Median	Range	Median	Range
Cadmium	0.16	0.02–0.97	0.23	0.10–1.80	0.26	0.11–0.62
Chromium	44.7	2.3–215.8	26.15	1.14–135	44.2	17.8–60
Copper	9.4	0.19–63.9	13.55	2.27–96.7	28.7	15.5–62.7
Lead	31.8	3.9–238.8	27.6	2.6–294	90.8	39.8–290
Mercury	No data	No data	0.12	0.07–0.48	0.24	0.07–0.78
Nickel	20.5	0.4–233	11.0	1.16–216	27.2	9.9–51.3
Zinc	53.8	4.0–223.6	55.5	2.63–211	96.2	51–212

Soil nickel concentrations across Scotland determined from the NSIS_1 data are shown in Figure 5.4. In a few parts of Scotland, soil nickel concentrations are high because the soil has been formed from nickel-rich rock material. This can cause soils to naturally exceed the nickel limits set out in the Sludge (Use in Agriculture) Regulations (1989) (50 mg/kg for pH 5<5.5; 60 mg/kg for pH 5.5<6.0; 70 mg/kg for pH 6.0<7.0), as observed in maximum nickel concentrations from both the NSIS_1 and the UKSHS (Table 5.11). This suggests that there will be small areas of Scotland where crop growth could be impaired by nickel toxicity.

Figure 5.4: Nickel and copper concentrations in soils across Scotland, as determined from the Macaulay Land Use Research Institute (MLURI) National Soil Inventory of Scotland dataset (NSIS_1). Maps supplied by MLURI



There are some small areas of Scotland where high soil copper concentrations may impair crop growth (Brown 1973; Ragg & Futty, 1967). NSIS_1 data (Figure 5.4 and Table 5.11) demonstrate that copper concentrations are generally well below Sludge (Use in Agriculture) (1989) limits across almost all of Scotland (80 mg/kg for pH 5<5.5; 100 mg/kg for pH 5.5<6.0; 135mg/kg for pH 6.0<7.0). In fact, because copper is an essential trace element for plants, low copper concentrations are more likely to adversely affect crop growth where soils have <5 mg/kg copper as found, for example, across much of the Black Isle (Romans et al.,1984).

As well as the national scale NSIS_1 and UKSHS studies, several small-scale studies have been carried out to identify particular issues surrounding metal contamination of soils, especially in the context of urban redevelopment. For example, Fordyce et al. (2011) demonstrate that median concentrations of certain metals, including copper, nickel and lead, are higher in urban than in rural soils formed on the same parent materials (Table 5.12), indicating areas of local contamination as a result of human activity, similar to results recorded in the UKSHS (Table 5.11). These data demonstrate both the wide range of soil metal concentrations and that in most instances urban soils have higher metal concentrations compared to those in rural areas as a result of diffuse contamination in urban environments.

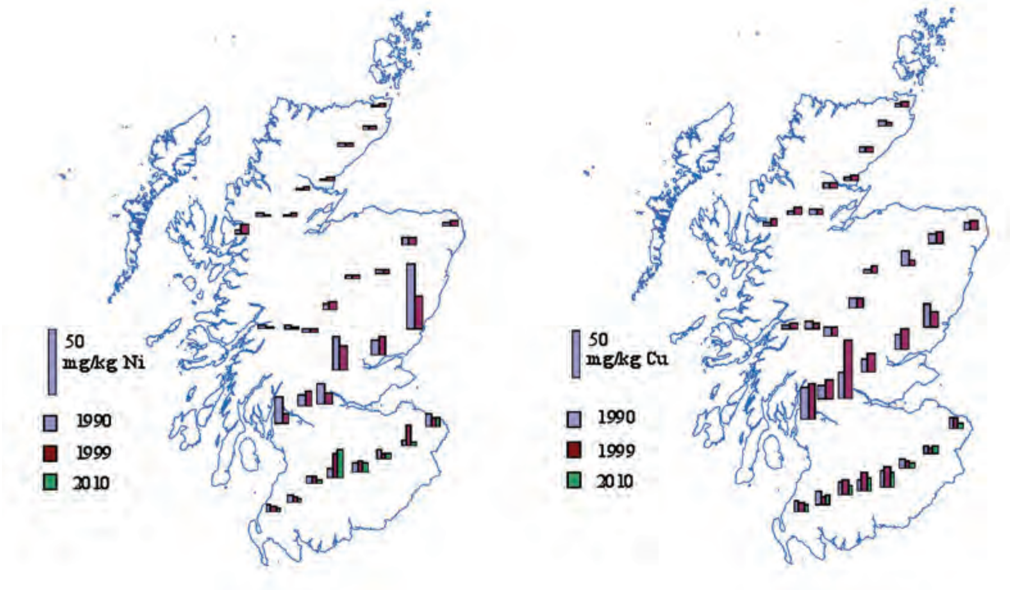
Table 5.12: Range of total metal concentrations in urban and rural topsoils collected across and around the Glasgow conurbation by the British Geological Survey (BGS) Geochemical Survey of Urban Environments (G-BASE urban) project. Based on 1381 urban and 241 rural soils from Fordyce et al. (2011)

Metal conc.	As (mg/kg)		Cd (mg/kg)		Cr (mg/kg)		Cu (mg/kg)		Ni (mg/kg)	
	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median
Urban	1–283	9.2	0.25–16	0.25	38–4286	108	14–3680	51.4	6 –1038	46.9
Rural	4–55	9.1	0.25–2.3	0.25	28–285	98	3–349	31.0	2–227	33.8
Metal conc.	**Pb (mg/kg)**		**Sb (mg/kg)**		**Se (mg/kg)**		**Sn (mg/kg)**		**Zn (mg/kg)**	
	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median
Urban	13–5001	127.1	0.5–174	1.3	0.1–14	0.9	1–659	10.2	39–1781	151.9
Rural	14–956	77.5	0.5–28	0.5	0.1–7	0.9	1–176	6.1	14–918	105.4

Soil guideline values have been designed for the protection of human health and related to a specific land use. If land exceeds soil guideline values for a specific use, then further investigation is required to ascertain whether remediation is necessary before the land can be developed. While some soils in Glasgow exceed soil guideline values as expected in an industrial city, this does not mean that there is an unacceptable risk at the site; it simply indicates that further site-specific investigation and risk assessment is required. Few sites will be unsuitable for development following appropriate remediation.

Concentrations of cadmium, copper, nickel, lead and zinc in upland organic soils were assessed as part of the Macaulay Land Use Research Institute (MLURI) Trends in Pollution in Scottish Soils (TIPSS) project set up to assess the effects of atmospheric deposition of contaminants on soils (Annex 1). Samples were collected from four transects ranging south-west to north-east across Scotland. Mean metal concentrations in all transects were generally low, although concentrations in central Scotland and the Southern Uplands transects are higher than in the two more northerly transects (Figure 5.5), possibly reflecting the greater concentration of metal emission sources in the central belt and from northern England. It is not possible to comment on the state of soil in these transects as there are no relevant limit values to compare with (neither soil guideline values nor Sludge (Use in Agriculture) limits are relevant to the typical functions that upland soils provide). Data from the TIPSS study are presented in more detail in section 5.6.3.

Figure 5.5: Nickel and copper concentration in soils at locations sampled as part of the Trends in Pollution in Scottish Soils (TIPSS) project in 1990, 1999 and 2010. Information supplied by the Macaulay Land Use Research Institute (MLURI) and the Scottish Environment Protection Agency (SEPA)



5.5.3 Organic chemical status

Organic chemicals are not routinely measured in soils unless a threat is identified so there are limited data available from which to ascertain the state of soil. This is despite the fact that agricultural soils receive applications of pesticides (Box 5.2) and wastes that may contain these contaminants. For example, sewage sludge is known to contain organic chemicals and it has been shown that areas of the sea bed where sewage sludge was disposed of in the past are now contaminated with persistent organic chemicals (Webster et al., 2005). There is the potential that soils to which sewage sludge has been applied could also become contaminated with organic chemicals in the future.

The UKSHS is the widest study of organic contaminant status in Scottish soils conducted to date. Principal results from UKSHS include the findings that mean concentrations of total polychlorinated biphenyls (PCBs) (2.25 µg/kg) and total dioxins (5.43 µg/kg) in Scottish rural soils were higher than concentrations in other UK regions. However, PCB and dioxin concentrations in urban Scottish soils were lower than those in England. In contrast, total polycyclic aromatic hydrocarbon (PAH) concentrations in both urban and rural soils were lower in Scotland than in both England and Wales. The implications of these results are not known as there are no guideline values with which to compare the results.

Soils in Scotland's urban areas have been historically exposed to organic chemicals through industrial processes; however, few studies of current levels of soil contamination have been completed. Cachada et al. (2009) found that PCB concentrations in Glasgow topsoils were higher than in four other European cities (Table 5.13).

Table 5.13: Sum of polychlorinated biphenyl (PCB) concentrations in topsoils from five European cities (number of soils in each city = 20). Adapted from Cachada et al. (2009)

	Sum of 19 PCBs[i] (µg/kg)			Sum of 5 PCBs[ii] (µg/kg)		
City	Median	Min	Max	Median	Min	Max
Aveiro (Portugal)	7.9	0.62	73	2.6	0.15	41
Glasgow (Scotland)	22	4.5	78	9.4	1.9	43
Ljubljana (Slovenia)	6.8	2.8	48	2.1	0.67	29
Torino (Italy)	14	1.8	172	6.6	0.72	86
Uppsala (Sweden)	5.7	2.3	77	2.3	0.54	47

(i) Sum of 19 PCBs indicates the total concentration of 19 PCBs measured following a standard technique, United States Environmental Protection Agency method 8082A (USEPA, 2000).
(ii) Sum of 5 PCBs indicates the total concentration of the five most commonly studied PCBs.

The UKSHS reported median concentrations of the sum of six PCBs [the same five as reported by Cachada et al. (2009) plus one additional PCB] of 0.7 µg/kg for rural and 0.9 µg/kg for urban Scottish soils. These are much lower than the values reported by Cachada et al. (2009), which may suggest that that their sample set is more contaminated; however, the impact of these contamination levels on soil functions and human health cannot be assessed again because of a lack of guideline values.

5.5.4 Man-made radioactive substances status

Concentrations of man-made radioactive substances in soils across Scotland are generally very low (RIFE, 2010), but vary from location to location primarily because of differences in rainfall. For example, higher rainfall over south-west Scotland following the Chernobyl accident resulted in higher concentrations of radioactive fallout over this region.

5.5.5 Pathogens status

The overall status of pathogens in soils in Scotland is unknown, as no Scotland-wide studies have been carried out. Furthermore, such a study may not be possible, as pathogen populations in soils are affected by short-term variations in factors such as temperature, soil moisture content and populations of predators.

5.5.6 Contaminated land status

Due to the requirements of legislation, in particular part IIA of the Environmental Protection Act, the area of land in Scotland affected by contamination can be estimated. SEPA (2009) reported that approximately 67,000 sites covering an area of around 82,000 hectares may be affected by contamination. In many cases it is possible to predict which contaminants may be present at these sites, although in 2008, 60% of sites suspected of being contaminated were still to be investigated (SEPA, 2009). The state of contaminated land in Scotland is discussed further in SEPA (2009).

5.6 Description of the environment: trend in soil contamination

5.6.1 Soil acidity and nutrient trends

The implementation of international agreements to limit gaseous emissions of sulphur and nitrogen has resulted in a decline in atmospheric deposition of compounds containing these elements across Scotland and, as a result, a decline of critical load exceedance for acidity. A comparison of Figures 5.1a and 5.1b illustrates the substantial decline in both area and magnitude of the critical load for acid deposition: from 65.8% of Scotland in 1996–98 to 42.8% in 2006–09.

The decline in acidity is supported by data from the Countryside Survey 2007 (CS2007), which shows that average soil pH in the UK increased from 5.67 to 5.87 between 1998 and 2007 (CEH, 2010). Further evidence of a decline in soil acidity in Scotland comes from two Environmental Change Network (ECN) sites in upland areas, Glensaugh and Sourhope, where sulphur concentration is falling and pH is increasing in soil solution (CEH, 2010)

However, over both the UK as a whole and Scotland, nitrogen emissions are declining less rapidly than sulphur emissions and, despite a declining trend in emissions, nitrogen deposition rates have remained steady (CEH, 2010). In fact, while the exceedance of the critical load for nutrient nitrogen fell for many habitats in the UK, it increased in bog habitats in Scotland from 25.3% of the habitat area in 1996–98 to 33.5% in 2006–08 (compare Figures 5.2 a and 5.2b). This trend is partly due to reductions being made in emissions from point sources and individual vehicles (SEPA, 2008) being nullified by increasing emissions from the growing number of vehicles on the road [particularly in numbers of diesel vehicles (CEH 2010)]. Therefore, eutrophication, as a result of nitrogen deposition, remains an ongoing threat to soil quality, soil functions and ecosystem services (Cape et al., 2009).

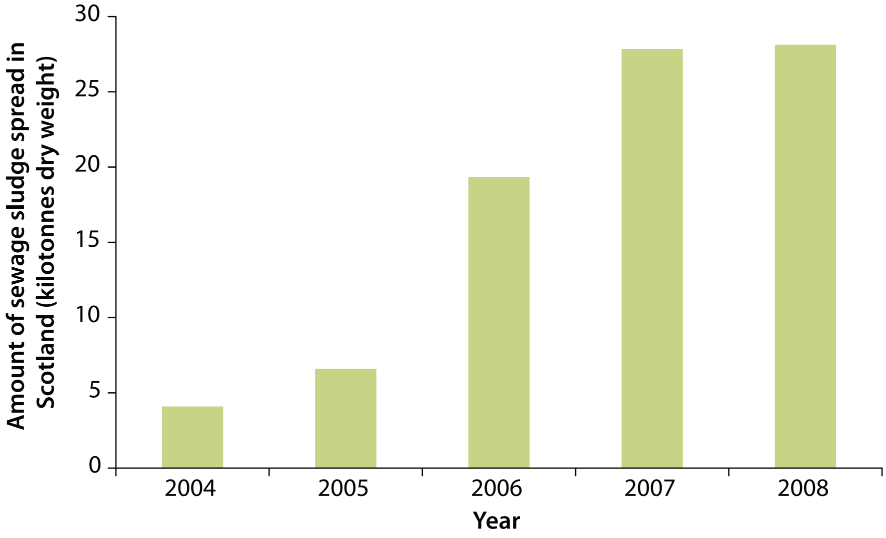
The average phosphorous status of agricultural soils sent to SAC for analysis (SIFSS 1996+) showed that in most Scottish agricultural soils, soil phosphorous status remained moderate between 2000 and 2009 and, therefore, in optimum condition for agricultural use. However, as noted in section 5.5.1, these data can only provide an indication, rather than give an accurate picture, of the fertility of soil in Scotland.

5.6.2 Metals trends

The amount of sewage sludge recycled to agricultural land as a fertiliser has increased dramatically over recent years following the ban on disposal of sewage sludge at sea that came into force in 1998. Between 2004 and 2008, the amount of sludge Scottish Water spread to agricultural land increased from 4,097 tonnes spread over 818 hectares to 28,128 tonnes spread over 3,969 hectares (Figure 5.6) The amount of sludge applied to land is expected to continue to increase (Scottish Water, 2006).

It is anticipated that increased applications of sewage sludge and other wastes that contain metals to land will lead to gradual increases in soil metal concentrations over time. However these activities are controlled through regulation so should not pose a risk to the environment or human health.

Figure 5.6: Amount of sewage sludge applied to agricultural land by Scottish Water 2004–2008.
Data supplied by Scottish Water



Although there has been a decline in heavy industry in Scotland, the legacy of industrial contamination persists. Input of metals to soil from other sources, such as the electronics industry, continue and, in some cases, may be increasing (Box 5.3). There are not enough data available to ascertain trends in either the area becoming contaminated or trends in contamination levels as a result of these activities.

Box 5.3: Platinum group elements (PGEs)

Deposition of atmospheric emissions from transport, and new 'high technology' and green energy industries is an increasing source of metals in soil. The platinum group elements (PGEs), platinum, palladium and rhodium, are commonly used in catalytic convertors and have been identified in roadside and urban soils (Higney et al., 2002). Platinum group elements may also be introduced to agricultural soils through application of organic wastes (Jackson et al., 2010). The toxicity of these elements is not well understood and Kalavrouziotis and Koukoulakis (2009) note a range of potential human health impacts associated with PGEs. Information on the potential environmental impacts of PGEs and their impact on soil functions is limited. Hooda et al. (2007; 2008) found that plants growing in soils contaminated with platinum and rhodium accumulated these metals.

In general, concentrations of PGEs in UK soils are very low and uniform (UK Soil and Herbage Survey); however, Kalavrouziotis and Koukoulakis (2009) suggest that there have been 'significant increases' in PGE concentrations in soils and vegetation over the last 10–15 years. However, there are no data available to determine trends in Scottish soils.

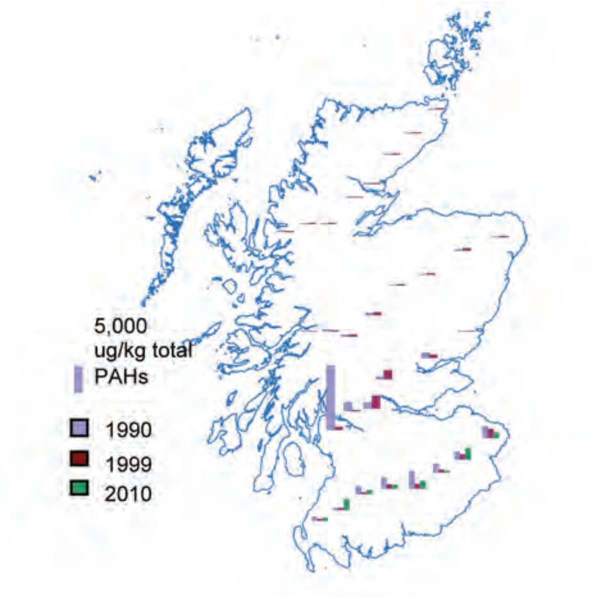
There is limited evidence for trends in metals concentration in soils in upland Scotland. The MLURI TIPSS transects were re-sampled in 1999 and partially re-sampled in 2010. Results for copper and nickel are shown in Figure 5.5. As the soils sampled as part of TIPSS were mostly upland organic soils, metal contamination in these soils is largely thought to be associated with atmospheric deposition. However, the differences in soil concentrations between the years are mostly very small, and analysis of average concentrations from each transect suggests that these are not significant.

5.6.3 Organic pollutants trends

There is not enough data available to make comments on trends in organic chemical concentrations in either urban or agricultural soils in Scotland. Although analyses of organic pollutant concentrations in these soils have been carried out, these have generally been short-term studies from which it is not possible to identify trends.

One attempt to determine trend in upland soils was the TIPSS study. Low concentrations of PCBs and PAHs were found across the country. PCB concentrations were found to be below detection limits in 1999 and 2010, while PAH concentrations were variable (Figure 5.7). Overall, there were no significant differences in PAH concentrations between years. It also appears that concentrations in the southern transects are higher than those in the northern transects, but this is not statistically significant.

Figure 5.7: Total polycyclic aromatic hydrocarbon (PAH) concentrations at each of the Trends in Pollution in Scottish Soils (TIPSS) sample sites. Information supplied by the Macaulay Land Use Research Institute (MLURI) and the Scottish Environment Protection Agency (SEPA)



5.6.4 Man-made radioactive substances trends

Trends in concentrations of man-made radioactive substances in Scottish soils are difficult to determine because of extensive spatial variability and low concentrations. RIFE (2010) provides a brief summary of trends over the last five years.

5.6.5 Pathogens trends

Due to a lack of data, it is not possible to make any statements about trends in pathogen populations in soils.

5.6.6 Contaminated land trend

It is difficult to determine trends in the area or severity of contaminated land, as methods for recording data are not consistent (SEPA, 2009). There are some indications that fewer sites and a smaller area of land were remediated in 2007–8 than in previous years. However, the area of land designated as contaminated may grow in the short term as more sites are investigated. More information can be found in SEPA (2009).

6 Change in soil biodiversity

The previous State of the Environment Soil Quality Report (SEPA, 2001) only refers to soil biodiversity in passing, reflecting a broad lack of knowledge at that time. Since then, research in Scotland (Usher & Davidson, 2006) and elsewhere (Turbé et al., 2010) has highlighted the role and value of soil biodiversity in supporting a number of biological processes such as carbon and nutrient cycling and plant establishment. The Scottish Soil Framework (Scottish Government, 2009) recognises that soil biodiversity is key to soil protection while the EU Soil Thematic Strategy (European Commission, 2006) identified that a loss of soil biodiversity would have significant implications for soil quality and ecosystem services. A full assessment of Scottish biodiversity including many soil-dwelling species was completed by Scottish Natural Heritage (Mackey & Mudge, 2010) as part of Scottish activities for 2010 International Year of Biodiversity.

6.1 Definition and scope

Soils are home to a huge diversity of life which is many times greater, both in terms of number and diversity of organisms, than the biodiversity above ground (Giller, 1996) and includes all organisms[2] that spend part, or all, of their life cycle in the soil for feeding, nesting, hibernating, or foraging, such as:

- microbial organisms, for example bacteria, fungi and protozoa;
- insects and other invertebrates, for example nematodes, mites, earthworms, ants, bees and beetles;
- higher animals including mammals, birds and reptiles, for example badgers, puffins, snakes and moles.

Soil biodiversity is dependent on a variety of factors (Figure 6.1) and can be expressed by the genetic characteristics of individual organisms, species and communities or what individuals, species and communities do. This latter functional diversity drives the biological processes that occur in soils such as the breakdown of organic matter. It is important to recognise that a loss in soil species can increase or decrease the rate of biological processes which, ultimately, can have positive or negative effects on the environment. However, despite recent technological advances, the relationships between soil organisms and soil functions remain largely unknown.

Figure 6.1: Generalised effects of soil properties, land use and land management practise on soil biodiversity

High soil biomass and increased species diversity	Low soil biomass and decrease species diversity
• Moist but good aeration	• Dry or water-logged
• Intermediate temperature	• Extreme temperatures
• Soil pH 5-8	• Very acidic or alkaline
• Deciduous forest	• Coniferous forest, heathland
• Permanent grassland	• Arable
• Return of crop residues, organic amendments	• Excessive inorganic fertiliser and pesticides use

[2]Surface vegetation (i.e. vascular plants, bryophytes, lichens and algae) although important for soil biodiversity, is not considered here.

There are distinctive soil organisms and communities within Scottish habitats that reflect the geographical isolation of the United Kingdom. For example, although fungal species diversity is lower in Scottish soils than on the continent of Europe, many endangered fungal species are found only in Scotland (Joint Nature Conservation Committee, no date).

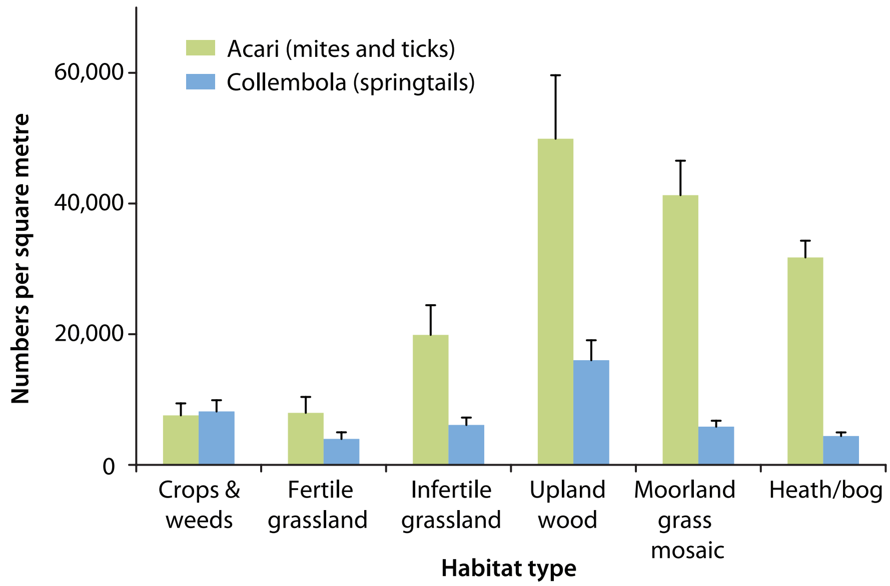
6.2 Drivers and pressures

There are many direct and indirect pressures on Scottish soil biodiversity. Some are specific to a particular habitat, land use or management practice, and can have a local, regional or even national influence. None of the pressures operate in isolation, thus the influence of multiple pressures on soil biodiversity must also be considered. Table 6.1 assesses the relative importance of causes of change in soil biodiversity in Scotland; acknowledging that the evidence and understanding are often limited. Annex 3 summarises where pressures are known to have, or likely to have, an effect on soil biodiversity in Scotland.

6.2.1 Land use and land management

Abrupt and often drastic changes caused by land use change (e.g. deforestation, cultivation) are likely to have large implications for soil organisms and, therefore, the functions provided by them. The expected differences in soil biodiversity as a result of land use change can be seen in Figure 6.2 which shows that there are more invertebrates, in particular mites, in natural and semi-natural soils than in agricultural soils. Continuous pressures that are low in magnitude, such as encroaching shrubs, atmospheric deposition or climate change, may take several years to produce detectable, and often irreversible, changes in soil biodiversity. For example, reductions in the diversity of soil fungi in sensitive habitats because of nitrogen deposition have only recently become noticeable despite this pressure persisting for decades (Box 6.1).

Figure 6.2: Average numbers of soil mites and Collembola in the topsoils of Scottish habitats (mean + standard error). Data derived from Countryside Survey[3] and adapted from Black et al. (2003)



[3]Countryside Survey data owned by National Environment Research Council - Centre for Ecology & Hydrology

Box 6.1: Scottish fungi

Fungi are vitally important to nutrient cycling and plant nutrition. The majority of plants have symbiotic relationships with mycorrhizal fungi and the diversity of both is intimately linked. However, many fungi are microscopic and most live below ground except for when they fruit. Among the perceived pressures to fungi are loss of habitats, contamination, compaction, physical disturbance of the soil surface and poor understanding of fungal ecology and its role in ecosystems.

Scaly tooth (*Sarcodon squamosus*) – pinewood tooth fungus

Pink waxcap (*Hygrocybe calyptriformis*) – a grassland fungus

Because most of the fungi remain underground it is difficult to identify fungal diversity and to monitor their status. Over 12,000 species of fungi are found in a wide range of habitats in Scotland, including species like the brightly coloured Hygrocybe 'waxcap fungi' which live on undisturbed grassland and the Hynoid 'tooth fungi' which form mycorrhizal associations in native pine woodland. Of the 16 species of fungi listed on the EU list of species of priority conservation interest recorded in the UK, 14 are recorded in Scotland with 9 of these predominantly found in Scotland. Nine are considered 'endangered' while four are considered to be 'rare' or 'vulnerable' in Europe (van der Linde, 2009).

Some species of fungi are protected in Scotland under European and national legislation and are monitored under a rolling six-year programme [Site Condition Monitoring (SCM; Scottish Natural Heritage, no date b)]. The first cycle of SCM ran from 1999 until 2005 and the second cycle from 2006 to 2010. Overall, all sites assessed for their fungal features are in favourable condition. However, this reflects the benefit of targeted conservation management practices on those sites and does not imply similar conditions for other fungal communities elsewhere. This information may help define best practices for the conservation of species in the wider countryside.

Land management practices are often repeated disturbances with the result that soil biodiversity is dependant on the frequency and intensity of the disturbance (Stockdale et al., 2006). Examples of these are:

- Scottish agricultural soils are intrinsically acidic and require liming to promote crop growth. This has a major influence on soil biodiversity as most soil organisms are sensitive to changes in pH. The change is immediate and remains for as long as the influence of liming remains in the soil;
- ploughing has a major and immediate impact on soil biodiversity by disrupting burrows, habitats and fungal hyphae, with repeated ploughing serving to delay recovery;

- increasing densities of grazing livestock impacts soil biodiversity through increased soil compaction and changes to nutrient availability;
- agrochemicals can either increase or decrease biodiversity as some organisms can use the chemicals as a food source, whereas others suffer direct toxic effects or indirect negative effects through the food chain;
- gathering plant, fungi or animal material may cause a decline in soil species. For example, unsustainable collection of wild mushrooms has become an increasing problem throughout Scotland and has led to the development of a voluntary harvesting code (Scottish Natural Heritage, 2009).

6.2.2 Climate change

The predicted changes in temperature and rainfall patterns in Scotland are likely to have significant effects on Scottish soil biodiversity. Soil organisms, and their associated biological processes, including soil carbon cycling, are sensitive to changes in both soil temperature and moisture (Turbé et al., 2010). Many soil organisms will be able to adapt or migrate whilst others will be more vulnerable, particularly if they are linked to rare, isolated or fragmented soils and habitats where migration options may be limited (e.g. coastal and montane habitats). However, little is known about the likely changes to Scottish soil biodiversity under current climate change scenarios.

6.2.3 Invasive non-native species

These can be predators, parasites, cause disease or compete for resources and thereby reduce or even eliminate native soil species. For example, in certain areas of Scotland, the New Zealand flatworm has been responsible for a decline in earthworm numbers resulting in a decline in the number of moles, which feed on earthworms (Jones et al., 2001). Alien plant species (e.g. Rhododendron) which replace native vegetation can have potential knock-on consequences for soil biodiversity through changes to food quality and quantity, and by introducing suppressive chemicals into soils.

6.2.4 Contamination

As described in Chapter 5, contamination covers a wide range of chemicals that come from local or diffuse sources and can cause changes in soil biodiversity in a number of ways for example direct toxicity, or indirectly via vegetation change and impacts on reproduction rates.

- Soil acidification has resulted in losses of soil biodiversity in mainland Europe.
- Soil concentrations of zinc at current regulatory thresholds for sewage sludge application can cause losses in soil biodiversity, with implications for grassland productivity (Chaudri et al., 2008; Box 6.2).
- Although organic pollutants have been demonstrated to cause significant harm to soil organisms within experimental studies, there is little evidence that these pollutants have had a major influence on soil biodiversity in Scottish soils when used appropriately and following current guidance and legislation.

Pathogens, when derived from external sources, for example flooding or organic amendments, can also be seen as a type of contamination and can cause similar responses to the chemical contaminants.

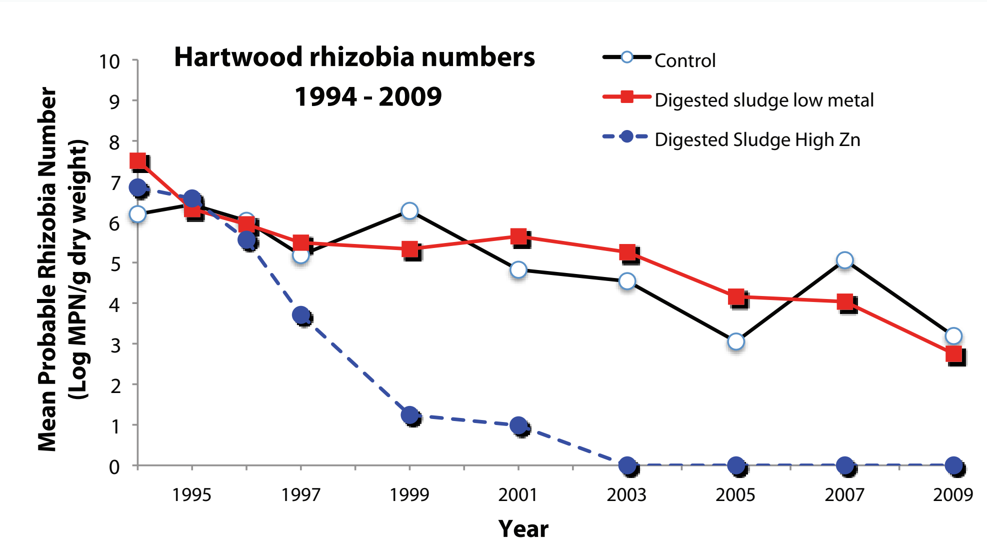
In conclusion, every pressure that impacts on one or more of the following is likely to change soil biodiversity:

- soil physical properties such as soil structure, soil temperature, and soil water content, altered by land use, land management, climate change, etc;
- soil chemical properties such as soil acidity, the availability of nutrients and the presence of toxic compounds, altered mainly by land management and diffuse or localised contamination;
- quality and quantity of food for soil organisms, which is affected by vegetation cover and the application of nutrients and organic materials to land.

Box 6.2: Sensitivity of rhizobia to heavy metals in soils

The Long-term Sludge Experiments (Sludge Exp) have been running at two Scottish farms and at seven other sites in England and Wales to investigate how different levels of metals (zinc, copper and cadmium) in sludge may influence soil and soil organisms. At Hartwood, zinc rich sludge additions have resulted in a dramatic reduction in rhizobia numbers (Figure B6.2) (Campbell et al., 2009).

Figure B6.2: Change in rhizobium count (measured by mean of probable number) at Hartwood Long-term Sludge experiment (1994-2009)



Rhizobia are soil bacteria that are important to the productivity of Scottish agriculture and the maintenance of semi-natural habitats. They play a vital role in supplying nitrogen to leguminous plants such as clover, peas and beans by fixing this nutrient from the atmosphere. Rhizobia are particularly sensitive to even relatively low concentrations of zinc in soil. Zinc can be introduced through the application of sewage sludge and other organic materials, for example compost. In addition, other symbiotic organisms may be affected, for example the biomass of arbuscular mycorrhizal fungi was also found to be negatively correlated with zinc and copper in metal-rich sludges (Campbell et al., 2009). However, the inhibitory effects of these metals vary across soil types in Scotland and the UK, and further research is being carried out to understand why soil organisms may be affected more at one location than another. Meanwhile, these results strengthen the case for close adherence to current best practice and careful compliance with existing legislation regarding the application of sewage sludge to land.

Table 6.1: Relative importance of pressures leading to a change in soil biodiversity (scored on a 25-year timescale using expert judgement)

Pressure	Magnitude of pressure(i)	Reversibility of pressure(ii)	Spatial extent of pressure(iii)	Trends of pressure(iv)	Uncertainty(v)
Climate change	3	2	3	+1	3
Land management practices					
• agriculture - cultivation	2	1	2	0	2
• agriculture - application of material/chemicals	2	2	2	+1	2
• forestry - cultivation/ harvesting	1	1	1	+1	3
• forestry - tree species selection	3	2	2	0	2-3
• drainage - not resulting in land use change	2	2	2	0	2
• muir burning	1	1	1	0	3
Compaction (or stocking density/grazing)	2	1–2	1	0	2
Land use change					
• expansion of agriculture	3	2	2	0	3
• expansion of forestry	3	2	2	+1	2–3
Loss and damage of habitat	3	2–3	2	+1	2–3
Contamination (those not included in agriculture) mainly atmospheric deposition and point sources	2–3	2–3	1 or 3	0	2–3
Development/transport	3	3	1	+1	3

(i) Magnitude of pressure: 1, not significant; 2, significant; 3, very significant.
(ii) Reversibility of pressure: 1, short-term and reversible; 2, medium-term and reversible; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in pressure: -1, predicted to decrease in intensity; 0, predicted to be stable; +1 pressure predicted to increase in intensity.
(v) Uncertainty of pressure: 1, pressure well characterised and quantified; 2, pressure moderately well characterised but data primarily qualitative; 3, pressure poorly characterised.

For more details on scoring and methodology see Annex 2.

6.3 Consequences of change in soil biodiversity: environmental impacts

Not only are most soil organisms very small, their individual activity range is also very limited. However, changes in both the composition and activity of soil biodiversity have far- reaching consequences for the environment and human well-being. Table 6.2 assesses the relative importance of soil biodiversity on soil functions.

6.3.1 Providing the basis for food and biomass production

Soil biodiversity plays a fundamental role in the maintenance of biomass production from all soils by:

- regulating nutrient and water supply to plants;
- helping to maintain a good soil structure;
- acting as biocontrol agents, for example regulating pests or pathogens;
- contributing to plant pollination.

Loss or change of biodiversity can impact on all of the above and therefore reduce crop growth, yields and quality. For example, loss of rhizobia bacteria (Box 6.2) will result in reduced capture of atmospheric nitrogen, thus increasing reliance on nitrogen from the application of fertiliser. A loss of soil organisms can also jeopardise the maintenance of good soil structure. Particular soil microbes excrete compounds that act like glue to hold soil particles together, while earthworms mix and reorganize soil particles and organic matter, aiding water movement, soil drainage and aeration by forming channels. In addition, a reduction in the number of native pollinators that nest in soil (e.g. bumble bees), could result in a decline in food production.

Certain soil organisms can become significant plant pests and pathogens if the natural relationship between predators and their prey is disrupted. Some management practices can promote this disruption, for example continuous monoculture or lack of crop rotation. The resulting proliferation of such harmful species can reduce yields or crop quality.

6.3.2 Controlling and regulating environmental interactions

As mentioned above, good soil structure relies on soil biodiversity and also provides improved micro-habitats for many soil organisms. Therefore, change of soil biodiversity may result in poor soil structure which is likely to reduce water infiltration and water-holding capacity. In turn, this is likely to increase the risk of surface run-off and erosion, and contribute to flooding. In addition, it may reduce the filtering capacity of the soil and increase the risk of pollutants draining into watercourses. Soil biodiversity is also important for nutrient turnover as well as nutrient storage in soil.

6.3.3 Storing carbon and maintaining the balance of gases in the air

Soil biodiversity is fundamental to the capture and release of soil carbon and greenhouse gas emissions. The cold, wet and acidic conditions of many Scottish soils limit the activity of soil microbes, thus reducing the decomposition of organic matter and resulting in soils with high organic matter content. A changing climate could have wide-reaching implications on the rate of decomposition of organic matter, resulting in less organic matter accumulation and possible loss of soil carbon.

Although wet conditions reduce carbon dioxide (CO_2) release, these conditions favour specialised soil microbes to produce the more potent greenhouse gases - nitrous oxide (N_2O) and methane (CH_4). These organisms are likely to be present in most soils, albeit in a dormant state. They only become active under suitable soil conditions, which can be trigged by human activity. Nitrous oxide production is dependant upon the availability of nitrogen in soils which is naturally found at low levels in most soils. However, nitrogen is more commonly available in fertilised agricultural soils resulting in potentially high N_2O emissions. Methane is naturally produced in the anaerobic layers of peat. Re-wetting drained peatlands may increase CH_4 emissions whilst reducing CO_2 emissions (Couwenberg, 2009). This demonstrates that environmental impacts on one greenhouse gas, via changes to soil biodiversity, must be balanced against other greenhouse gases to gain a full insight into potential impacts to soil carbon sequestration and net greenhouse gas emissions.

Soil invertebrates and microfauna play an important role in protecting and stabilising soil organic matter by mixing organic and mineral material in the soil (e.g. in burrows, faecal material and more stable soil aggregates). The intensive mixing of organic and mineral compounds in earthworms' guts is also particularly important for the stabilisation process. The reduction in the population of such soil invertebrates can result in a long term decrease of soil organic matter and therefore soil carbon.

6.3.4 Providing valued habitats and sustaining biodiversity

Most native plants live in symbiosis with mycorrhizal fungi which are more efficient in reaching water and nutrients than plant roots. These fungi play a particularly important role in maintaining native habitats and in nutrient-poor or potentially drought-risk soils. Certain iconic Scottish plant species are entirely dependent upon single fungal species for their survival, for example bluebells, heathers, and orchids. Thus, any loss of such associations will have implications for the habitat or the survival of certain plants. Fungi, in their own right, are also an important biodiversity component of many habitats (Box 6.1).

Soil biodiversity is also an important part of a wider food web and any changes in this can affect food supply for above-ground animals such as birds and mammals. Improving habitats for soil organisms can help to sustain above-ground biodiversity and dependent industries such as grouse shooting or conservation interests.

6.3.5 Providing raw materials

Soil microbes grown in the laboratory have long been a highly productive source of pharmaceuticals such as antibiotics or drugs for cancer treatment (Edwards et al., 2009). New laboratory techniques may allow further exploitation of this valuable resource. However, there is a risk that loss of biodiversity in the meantime will mean species and their potential usage will be irretrievably lost before discovery.

Soil organisms are vital in the formation and retention of peat. Loss of biodiversity in these soils may compromise their carbon sequestration potential and, in very long timescales, any future increase in peat reserves.

6.3.6 Other functions

Soil biodiversity does not have a major effect on the functions of preserving cultural and archaeological heritage and providing a platform for buildings and roads.

Table 6.2: Consequence (i.e. impact) of change in biodiversity on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact[i]	Reversibility of impact[ii]	Spatial extent of impact[iii]	Trend in impact[iv]	Uncertainty[v]
Providing the basis for food and biomass production	2	2	3	0	3
Controlling and regulating environmental interactions	2–3	2	3	0 –+1	3
Storing carbon and maintaining the balance of gases in the air	3	2	2–3	+1	3
Providing valued habitats and sustaining biodiversity	3	3	2–3	+1	2–3
Preserving cultural and archaeological heritage	1–2	3	1	0 –+1	3
Providing raw materials	3	3	1	0	3
Providing a platform for buildings and roads	Does not apply to this function				

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function- threatening; 3, serious impairment of function.
(ii) Reversibility; 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in impact: -1 predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

6.4 Consequences of change in soil biodiversity: socio-economic impacts

Recent work (Glenk et al., 2010) has sought to identify the socio-economic impacts of soil degradation and Table 6.3 summarises their findings for change in soil biodiversity. Figure 2.3 explains the different cost types.

Table 6.3 shows that a change in soil biodiversity affects five soil functions. Glenk et al. (2010) identified 11 socio-economic impacts of a change in soil biodiversity across these functions; however, there were no data available for these in the literature they considered. It is therefore notable that whilst different types of costs and different soil functions affected can be identified for Scotland, there is practically no quantitative information to evaluate the implications. However, qualitative information suggests that cost impacts could be high.

It is difficult to separate economic impacts of loss in soil biodiversity from other issues such as organic matter decline, soil erosion, contamination and compaction as there is such an interplay between organic matter, soil biodiversity and these other issues. In this way, the value of soil biodiversity is often incorporated into end-products provided by soil-related regulatory and production services, for example crop yields or carbon emissions.

Table 6.3: Overview of economic impacts for Scotland associated with a change in soil biodiversity

Soil function	Cost type	On site /off site	Description	Impact status[(i)]	Data status[(ii)]
Biomass, food and fibre production	Private cost	On	Soil biodiversity underpins a number of important soil functions and thus is an important factor determining soil fertility with impacts on agricultural productivity	Medium to high	N
		On	Because of its central role for several soil functions, change in soil biodiversity can result in loss of buffering and recovering functions. Susceptibility to other (soil) threats increases, with consequences for private land owners	Variable	N
	Mitigation cost	On	Cost of increased inputs to agricultural production (fertilisers, pesticides) and more capital or labour intensive management practices	Medium to high	N
Controlling and regulating environmental interactions	Private cost	On	Because of its central role for several soil functions, change in soil biodiversity can result in loss of buffering and recovering functions. Susceptibility to other (soil) threats increases, with consequences for private land owners	Variable	N
	Social cost	Off	Change in soil biodiversity can result in loss of buffering and recovering functions and services	Variable	N
	Defensive cost	Off	Replacement costs for lost buffering (regulatory services), for example technical remediation instead of bioremediation	Variable	N
Storing carbon and maintaining the balance of gases in the air	Social cost	Off	Change in soil biodiversity can result in reduced potential of soils to sequester carbon or affect release of greenhouse gases (possibly also private cost)	Variable	N

Table 6.3: Overview of economic impacts for Scotland associated with a change in soil biodiversity (continued)

Soil function	Cost type	On site /off site	Description	Impact status(i)	Data status(ii)
Providing valued habitats and sustaining biodiversity	Non-use value cost/ private cost/social cost	Off	Changes in genetic resources present in soil can limit the gene pool available for potential future use (private cost/social cost); soil biodiversity may be valued for non-use or bequest reasons (moral, ethical) (non-use cost)	Variable	N
	Non-use value cost	Off	In extreme cases, changes in soil biodiversity will result in different land use/vegetation patterns and hence impact on landscape appearance	Variable	N
Protection of cultural and archaeological heritage	Non-use value cost/ private cost/social cost	Off	Changes in genetic resources present in soil can limit the gene pool available for potential future use (private cost/social cost); soil biodiversity may be valued for non-use or bequest reasons (moral, ethical) (non-use cost)	Variable	N
	Non-use value cost	Off	In extreme cases, changes in soil biodiversity will result in different land use/vegetation patterns and hence impact on landscape appearance	Variable	N

(i) Impact status – based on 20–25 years timescale assessment of severity of biophysical change, geographical extent, contribution of single economic impact.
(ii) Y = economic estimates are available in Görlach et al. (2004), ADAS (2006) and Defra (2009)
N = no data available

For more details on scoring and methodology see Annex 2.

6.5 Description of environment: state of soil biodiversity

Some information on the status of soil biodiversity in Scotland can be inferred from data collected by Scottish conservation agencies and voluntary sector activities. Numerous lists of species of conservation status in the UK have been produced: Red Lists, Biodiversity Action Plan Priority Lists, species listed in European Directives, Schedules of the Wildlife & Countryside Act 1981 and the Nature Conservation (Scotland) Act 2004. In Scotland, there are thousands of such protected species, ranging from plants and fungi, to insects and mammals, of which around 200 are 'soil species' in terms of the definition used in this report (Annex 4).

Following the publication of the Scotland Biodiversity Strategy in 2004 (Scottish Executive, 2004), biodiversity indicators were defined to provide insights into the general state and trends of biodiversity (Scottish Government, 2007). These indicators cover a wide range of taxonomic groups but, at the time of writing this State of Scotland's Soil report, no specific indicators for soil biodiversity have been proposed. The key policy tool for conserving Scotland's biodiversity still remains the designation and management of protected sites [i.e. Special Areas of Conservation and Sites of Special Scientific Interest (SSSIs)], which are areas of land, inland water and sea that have special legal protection to conserve important habitats and species. Through surveillance and monitoring, the status and trends of species and habitats, and the pressures that affect them, are recorded at these sites. Soil biodiversity features in designated sites are generally of good status because these sites were selected for their inherent value in the first instance and the specific site-management practices for maintaining or improving the site condition. For example, tooth fungi, which are notified features for six SSSIs in Scotland, have been reported during SNH site condition monitoring as being in 'favourable condition' (Scottish Natural Heritage, no date a).

Although the number of soil biodiversity features on protected sites is very small compared with the vast number of soil species present in Scottish soils, this cannot be seen as an indication that soil biodiversity is generally in good status. It reflects more the historical disregard for soil organisms. The European Atlas of Soil Biodiversity (Jeffrey et al., 2010) suggests that there is a low threat to soil biodiversity throughout Scotland. However, on closer examination, this reflects a lack of data rather than a current view of the status of Scottish soil biodiversity.

Due, in part, to concerted research efforts and method improvements, knowledge of Scottish soil biodiversity has increased significantly in recent years, for example what is typical and unique for Scottish soils and how it is changing over time in response to pressures or simply through ecological succession. The main data sources are summarised in Annex 5. However, it is still too early to provide a general picture of the status of Scottish soil biodiversity as typical species composition have not yet been established for habitats and there are no defined thresholds beyond which changes in soil biodiversity are unacceptable.

In parallel, recent research approaches to monitor the status, and change, in soil quality have focussed on the selection of suitable biological indicators for example the SQuID project (Ritz et al., 2009) with field trials of potential indicators. The selection process has highlighted that certain indicators may be more suitable for detecting the impacts of pressures, while several indicators would be needed to monitor for the effects of several pressures.

SEPA's soil compliance monitoring includes using earthworms as a soil quality indicator to monitor the impacts of organic waste applications to land (Box 6.3). Organic waste materials can enhance soil quality through the addition of organic matter; however, they may also contain a variety of potential pollutants that may have an immediate or a cumulative impact on soil organisms. Since 2007, sampling from approximately 100 fields shows no significant effects on earthworm numbers, although long-term applications of some materials may change the species composition (Figure 6.3). This raises some as yet unresolved questions such as: at what threshold point does a change in earthworm composition become unacceptable; how reversible are the impacts of waste applications or are they irreversible?

It can be summarised that the amount of available data and knowledge on Scottish soil biodiversity has increased considerably in recent years, and could continue in the future with the development of new characterisation methods and indicators. However, it is still not yet possible to report on the current status of the majority of soil biodiversity (genetic, taxonomic or functional) in Scotland.

Box 6.3: Earthworms

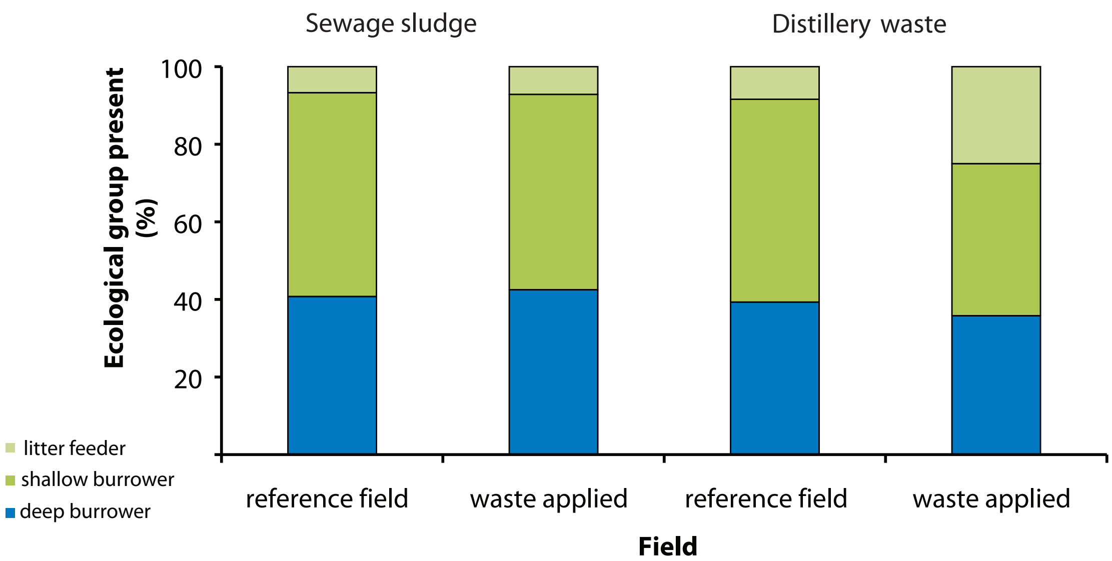
Earthworms are the largest soil invertebrates and are considered as "soil engineers" because of their beneficial influence on soil properties. Changes in abundance and community structure of earthworms affect several soil characteristics such as porosity, aeration, water-holding capacity, density, recycling and distribution of organic matter and nutrients. Earthworms are also an important food source for birds and mammals.

Three main ecological groups of earthworms can be distinguished: (i) litter feeders (epigeic species) that live close to the soil surface or in the litter on it and create very few, if any, burrows; (ii) shallow burrowers (endogeic species) that dig extensive branch-like systems of ephemeral horizontal burrows and feed on organic matter found in soil; and (iii) deep burrowers (anecic species) that live in more or less permanent vertical burrows and mix organic matter that they have collected on the soil surface with the mineral soil below.

Earthworm

Earthworms are useful indicator organisms for soil degradation as they stay locally, can have a relatively long lifespan (up to 10 years), and are widespread and common in agricultural soils as well as in some forest soils. As they live and feed in the soil, they are exposed to any potentially harmful substances applied to the soil. However, they are also affected by other external factors such as land management practices and climate. Thus, any changes in earthworm populations have to be analysed carefully. Up until now no Scottish or EU wide thresholds have been developed.

Figure 6.3: Relative abundance of the three ecological earthworm groups in fields receiving sewage sludge, distillery waste and their respective reference fields [(SEPA's soil compliance monitoring (SEPA SCM)]



6.6 Description of the environment: trend in soil biodiversity

Data sources for establishing past trends are even more limited than for status with a lack of repeated sampling of previous surveys and studies. Future views of the trends and risks to soil biodiversity can therefore only refer to baselines from the present day. However, it must be acknowledged that losses of Scotland's soil biodiversity may have already occurred as a result of historical pressures such as habitat losses or contamination. A lack of historical data also prevents assessment of the impact of the pressures described in section 6.2. The Countryside Survey (CS) of Great Britain has identified significant trends in soil invertebrates between 1998 and 2007, with significant increases in the numbers of mites and Collembola and decreases in the overall diversity of soil invertebrates (Emmett et al., 2008). However, the reasons for, or implications of, these trends are unclear.

Even if pressures impact on only a small number of soil organisms, complex knock-on effects will result in far-reaching changes in soil biodiversity, for example via the food web or in the loss of key functional species. Additionally, changes to soil biodiversity may be subtle and take several years to become obvious or significant, which has to be taken into account when considering restoration projects of semi-natural and native habitat or determining the sustainability of a new land use over the following years and decades. For example, when restoring peatland ecosystems, it may take several decades to effectively restore soil biodiversity and its role in regulating carbon cycling, if at all (Colls, 2006).

The predicted future risks based on the expected development of the pressures identified in section 6.2 are:

- impacts of nitrogen deposition are likely to continue until deposition decreases significantly, particularly through feedbacks from observed changes in above-ground plant communities;
- at present about 50 non-native plant species are considered to be invasive in Scotland. As a result of climate change this number is likely to increase as plants migrate north.

Currently it is not possible to predict:

- if soil acidity recovery is resulting in recovery of soil biodiversity. Research suggests that this may only take place over the long term;
- effects of climate change on biodiversity as there have been very few experiments relevant to Scotland carried out so far.

The implementation of new technologies and methodologies currently being developed should allow for a better understanding of soil biodiversity and a quantification of its functional roles in future.

7 Soil erosion and landslides

7.1 Definition and scope

Soil erosion by water or wind is a natural process where soil particles become detached and are transported within the landscape. Features of soil erosion are common in many parts of both upland and lowland Scotland. Landslides (the movement of rock, earth or debris down a slope), such as debris flows, also occur naturally in Scotland especially on hill slopes over-steepened by glaciation (Ballantyne, 2004). The rate of soil loss via erosion and the incidence of landslides can be increased by removing the vegetation cover that protects the soil (e.g. ploughing to grow crops, deforestation) or by engineering works. Tillage erosion also leads to the redistribution of soil downslope.

The erosion of upland organic (peat) soils is prevalent in some parts of Scotland (e.g. the Monadhliath Mountains). The mechanisms that lead to erosion in these soils are not fully understood although historic overgrazing by sheep and deer may be a contributory factor (Lilly et al., 2009). There is also evidence that changes in climate over many years may be partly responsible for the development of gully systems in these areas (Lilly et al., 2009).

This chapter considers the drivers of soil erosion and landslides in Scotland and their impacts on the environment, the economy and society. Although erosion of beaches, migration of dune systems and river bank erosion are other forms of erosion found in Scotland, they do not form part of this review.

7.2 Drivers and pressures

There are a large number of short-term drivers, such as weather patterns, land use/land management and construction, that initiate and influence current rates of soil erosion and landslide development. These drivers do not operate equally across all landscapes and their impacts occur at different scales, for example, gullying in an agricultural field compared with mass movement and debris flows on steep-sided valleys. The relative importance of the pressures on erosion and landslides is given in Table 7.1.

7.2.1 Climate and climate change

Water erosion can be caused by surface run-off that can be initiated when rainfall intensity exceeds the infiltration capacity of the soil or, more commonly in Scotland, when further rain falls on ground already saturated as a result of previous heavy or prolonged rainfall. Rapid snow-melt can also lead to overland flow and erosion (Wade & Kirkbride, 1998). Not all soils have the same capacity to absorb rainfall or snowmelt, so the risk of erosion differs depending on the soil type. This risk can be exacerbated where there is a slowly permeable layer or plough pan that restricts infiltration. Run-off often occurs in gullies and, once initiated, any run-off tends to be focused in these, increasing the risk of further erosion.

Wind erosion occurs in the lowlands where the soil is left bare following cultivation and is particularly prevalent on soil with sandy to silty textures (Batey, 1988) in spring following a dry spell. It is also a feature of some high mountain environments, particularly where vegetation cover is sparse.

Rainfall is an important factor in triggering debris flows in Scotland (Winter et al., 2005). Prolonged rainfall leads to saturation, a build-up of pore water pressure and a consequent reduction in effective strength that can trigger slope failure (Wieczorek, 1996). The susceptibility of a slope to failure also depends on other factors such as geology and topography; debris flows are more likely to occur in unconsolidated and coarse-grained superficial deposits (Ballantyne, 1986). Many recent landslides in Scotland have been initiated around natural drainage channels (Milne et al., 2009) perhaps indicating that the current pattern of drainage is unable to prevent excess pore pressure from building up within the unconsolidated sediments. It is also clear that old landslides can be reactivated during extreme rainfall events.

Although rainfall intensity is an important factor, it is important to recognise that not all storm events lead to soil erosion or landslides. There is uncertainty about future climate but increased global temperatures are likely to lead to an increase in extreme rainfall events that may, in turn, lead to increased erosion and landslides. Ballantyne (2004) suggests the trend of increasing annual precipitation favours an increase in the extent and frequency of debris flows. Winter et al. (2005) cite increased rainfall and storminess, as a result of climate change, to be a likely cause of upland landslides in Scotland.

7.2.2 Land use and land management

One of the most important factors in the protection of soils from erosion is vegetation cover, as roots bind soil particles together and plants protect soil from direct raindrop impact, as well as disrupting overland flow. Where vegetation cover is sparse, or soils are bare, the incidence of landslides and soil erosion (by wind and water) is greater. Vegetation cover can be removed by ploughing, grazing, burning, deforestation and trampling, and in the absence of vegetation cover, the exposed soil becomes more susceptible to weathering. Heavy rainfall can directly impact on soil aggregates and cause them to break into finer particles that are more easily eroded. Slopes that are not stabilised by plant roots are more susceptible to slippage; however, root strength will have little impact on the stability of deep-seated landslides. Landslides can also be unintentionally induced by engineering works like drainage alteration and the undercutting of steep slopes.

Cultivation

Soil erosion is normally a feature of agricultural land. Gullies in cultivated fields often develop in specific areas, for example along tramlines where the soil has been compacted (Box 7.1; Chapter 8). Other vulnerable areas within fields are between crop rows and where flow pathways converge at gates, for example.

Arable soils are particularly susceptible to both wind and water erosion where fine seed beds have been prepared and before the crop has emerged, particularly if the crop rows are aligned up and down the slope. Soils with little organic matter are often more likely to break down into smaller particles either as a result of direct impact by rain drops or when the aggregates become saturated. The smaller particles are then more easily transported by overland flow.

Tillage erosion occurs where ploughing takes place across a slope in the same direction gradually moving the soil downslope (Van Oost et al., 2006) and, to a lesser extent, by ploughing up and down a slope, which causes a gradual downward movement of soil under the influence of gravity.

Grazing

Grazing by domesticated and wild animals can alter the ground vegetation. In some cases, for example around feeding stations, bare patches of soil are created that increase the risk of erosion. In the uplands, heavy grazing by sheep and deer causes a decline in heather cover which is then replaced by tussock-forming grasses with poorer soil binding abilities. However, one difficulty in establishing links between soil erosion (in particular, the erosion of peat) and grazing is that historic stocking densities, which are generally unknown, may have had more influence on the risk of erosion than current stocking densities. Also, both sheep and deer will preferentially graze specific areas, resulting in localised areas experiencing greater grazing pressures and an increased risk of erosion. Innes (1983) considered that at Beinn Achaladair, overgrazing by sheep may have been a contributory factor in the occurrence of landslides.

Box 7.1: Soil erosion in arable catchments of the Lunan Water

SEPA has carried out a detailed study to quantify soil erosion in three typical Scottish arable fields in subcatchments of the Lunan Water. Rates of erosion and deposition were calculated using a radioactive tracer technique (caesium 137; Bowes, 2002) and are summarised in Table B7.1.

Table B7.1: Mean, minimum and maximum erosion and deposition rates calculated for three arable fields in the Lunan catchment (Bowes, 2010)

Site	Deposition rate (tonnes per hectare per year)			Erosion rate (tonnes per hectare per year)		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Baldardo	11	0	27	22	0	59
Newmill	8	0	23	18	0	77
Burnside	15	0	35	12	0	35

Erosion rates were found to be much higher than the tolerable rate for soil erosion in Europe (0.3–1.4 tonnes per hectare per year; Verheijen et al., 2009), with twice as much soil being eroded as deposited at Baldardo and Newmill. Although some of the eroded soil was redistributed within the field, a significant amount must have been lost. It is likely that these rates of erosion and deposition would affect crop yields and would be unsustainable over the long term. In addition, soil lost from the field could enter adjacent watercourses and become a risk to water quality.

Soil erosion and deposition in the Lunan catchment

At Baldardo, all erosion features that appeared between October and December 2006 were surveyed. The rill network was 1.47 km long and discharged an estimated 11.8 tonnes of soil. More than half of the tramlines, all parallel to direction of slope, were over-deepened by surface run-off. The total length of eroded tramlines was 14.1 km and they discharged an estimated 92.3 tonnes of soil. This highlights the importance of tramlines compared to rills as sediment sources and conduits under certain circumstances.

Burning

Burning is a management tool commonly used to control vegetation structure and improve the productivity of heathland on upland farms and estates. Damage can be caused by uncontrolled or inappropriate burning that removes too much vegetation cover. Accidental or deliberate wildfires have the greatest potential to cause serious damage in single events. A severe burn can make the surface organic layer water repellent resulting in greater run-off and greater potential for soil erosion and landslides. Innes (1983), suggested increased landslide activity in the last few hundred years was partly related to burning, although this view is disputed by Brazier and Ballantyne (1989).

Forestry

Soil erosion from forest areas is primarily associated with disturbance during the planting and harvesting phases. The bed of new drainage ditches can be scoured and run-off during harvesting can remove the loosened soil.

Deforestation can lead to temporary increases in erosion through increased run-off and, by altering the hydrology of sites, can also affect slope stability. The loss of live tree roots may weaken soil and make it more prone to shallow landslides (Gray & Sotir, 1996; Guthrie, 2002).

Drainage

Changes in drainage patterns in upland peats may lead to an increase in pore pressures at the base of the peat leading to failures, for example peat slides (Scottish Executive, 2006). Artificial drainage systems, designed to drain agricultural land, can also preferentially transport fine soil particles to rivers and streams (Heathwaite et al., 2005).

Recreation

Recreational pressures such as hill walking and mountain biking on some hill and upland areas can cause erosion and lead to the extension of paths across sensitive environments where natural regeneration of the vegetation is slow. These areas then become vulnerable to continued erosion.

7.2.3 Construction

The undercutting of formerly stable slopes, by natural means or by the actions of man, is a major trigger for landslide processes. The inadvertent removal of the toe of a presently inactive landslide during a civil engineering project (e.g. construction and realignment of roads and railways) can lead to reactivation of previously unrecognised relict landslides. Forestry road construction in the uplands impacts upon slope stability by interrupting surface drainage and altering the sub-surface movement of water. The redistribution of material on a slope through cut and fill activities, and concentrating run-off into discrete channels, can initiate gully erosion and debris flows (Swanson & Dyrness, 1975; Sidle, 1991; Sidle, 1992). Windfarm construction on peat has also caused peat flows in Ireland (Lindsay & Bragg, 2004).

Table 7.1: Relative importance of pressures leading to soil erosion and landslides (scored on a 25-year timescale using expert judgement)

Pressure	Magnitude of pressure[i]	Reversibility of pressure[ii]	Spatial extent of pressure[iii]	Trend in pressure[iv]	Uncertainty of pressure[v]
Climate change	2	3	3	+1	2
Land management practices					
• cultivation (agriculture)[1]	3[1]	2	2	0	1
• cultivation (forestry)[2]	3[2]	2	2	+1	1
• stocking density/grazing	2	1	2	0	2
• drainage	1	2	2	+1	2
• burning	1	2	2	0	2
Recreation	1	1	0	+1	2
Development/transport	2	3	1	+1	1

(1) Low and (2) Moderate magnitudes for landslides
(i) Magnitude of pressure: 1, not significant; 2, significant; 3, very significant.
(ii) Reversibility of pressure: 1, short-term and reversible; 2, medium-term and reversible; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in pressure: -1, predicted to decrease in intensity; 0, predicted to be stable; +1 pressure predicted to increase in intensity.
(v) Uncertainty of pressure: 1, pressure well characterised and quantified, 2, pressure moderately well characterised but data primarily qualitative; 3, pressure poorly characterised.

For more details on scoring and methodology see Annex 2.

7.3 Consequences of erosion and landslides: environmental impacts

Events such as landslides or soil erosion can result in serious environmental impacts. Fortunately, in Scotland, many of these effects are generally relatively small-scale, although they can be locally devastating. Off-site impacts are primarily the effect on water quality. Soil particles eroded into watercourses may have potential pollutants attached, such as nutrients or metals. The loss of aquatic life, including fish stocks, can also occur if debris reaches a water course. The potential impacts of sediment (and associated pollutants) entering the water environment are not reversible. Therefore, erosion and landslides can be a major contributing factor to water bodies not achieving good status under the Water Framework Directive (WFD 2000/60/EC).

Soil erosion and landslides can also impact on some key soil functions (Table 7.2), in particular food and biomass production.

7.3.1 Providing the basis for food and biomass production

Much eroded topsoil is trapped at downslope field boundaries or deposited on gentle within-field slopes and is, therefore, not an overall loss. Severe soil erosion does occur sporadically and generally involves the loss of fertile topsoil and, in severe cases, the loss of subsoil from deep gullies. The loss, or even the redistribution of topsoil, can lead to a potentially significant threat to the productivity of the soil, resulting in a reduction in crop yields by restricting rooting depth and reducing the water holding capacity of the soil. The within-field redistribution of topsoil may also lead to uneven ripening of crops and a reduction in yield. Although erosion of cultivated soils is rarely so severe that remedial action cannot be undertaken to restore the land, this continual loss of valuable topsoil is not sustainable and will eventually impact on productivity. Although landslides are rarely a feature of cultivated land, biomass production may be locally impacted by landslides in woodlands.

7.3.2 Controlling and regulating environmental interactions

The loss of topsoil from many Scottish soils will limit both their water-holding and infiltration capacities. It will also potentially reduce the ability of these soils to buffer and filter pollutants, as well as increasing run-off that may lead to an increase in flood risk.

7.3.3 Storing carbon and maintaining the balance of gases in the air

Topsoils tend to be relatively rich in organic matter, thus erosion will result in a loss of soil carbon (Chapter 3), both as particles and through dissolution. A greater potential threat is the erosion of peat soils as these are an important store of carbon. This loss of carbon may impact on climate change as it could increase the amount of carbon dioxide already in the atmosphere.

In addition, if the overall water-holding capacity of soil is reduced by erosion, it will require less rainfall for the soil to reach saturation potentially leading to greater emissions of nitrous oxide (a potent greenhouse gas) from cultivated soils.

7.3.4 Preserving cultural and archaeological heritage

The loss or redistribution of topsoil through wind, water or tillage erosion can lead to exposure and subsequent damage to archaeological features preserved within the upper parts of cultivated soils.

7.3.5 Other functions

While soil erosion has little impact on providing valued habitats and sustaining terrestrial biodiversity, nutrient-rich eroded sediment can have a detrimental effect on aquatic ecosystems and significantly reduce their biodiversity. There is little impact on the provision of raw materials, although landslides can seriously affect current road and rail infrastructures.

Table 7.2: Consequence (i.e. impact) of erosion and landslides on soil functions (scored on a 25-year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	2	2	2	+1	2
Controlling and regulating environmental interactions	2	2	2	0	2
Storing carbon and maintaining the balance of gases in the air	2	2	2	+1	2
Providing valued habitats and sustaining biodiversity	2	2	2	0	2
Preserving cultural and archaeological heritage	3	3	1	+1	1
Providing raw materials	1	1	1	0	2
Providing a platform for buildings and roads	3	3	1	+1	2

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in impact: -1 predicted to decrease over timescale; 0, predicted to be stable; +1 predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2 impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

7.4 Consequences of erosion and landslides: socio-economic impacts

As well as impacting on the environment, erosion and landslides also have social and economic impacts. Recent work (Glenk et al., 2010) has sought to identify the socio-economic impacts associated with erosion and landslides and these are shown in Table 7.3. Figure 2.3 explains in more detail the different cost categories considered in this interpretation.

Table 7.3 shows that the socio-economic impacts associated with erosion and landslides identified by Glenk et al. (2010) affect six broad soil functions. They identified 13 detrimental socio-economic impacts of erosion and landslides and assessed their overall impact in Scotland. They also made an evaluation of the reliability of their assessment by considering the availability of data from Scotland to substantiate their assessments. (Economic estimates were available for 10 of the 13 of the impacts in the literature considered by Glenk et al. (2010); however, these were not necessarily Scottish). Amongst the likely impacts of soil erosion they considered were loss of agricultural productivity (e.g. through the loss of fertility and soil carbon, loss of seed or damage to plants, loss of fertilisers and pesticides and consequent reduction in crop yields) and the impact on environmental interactions (e.g. soil losses from agricultural fields, either by wind or water, and landslides resulting in blocked roads and drainage ditches). Impacts on health include the transport of pathogens from fields to watercourses and the effect of wind-induced dust clouds on sufferers of respiratory diseases. Whilst different types of costs and the soil functions affected can be identified, it is clear that there are little actual Scottish data available to enable quantitative assessments to be made.

Most available estimates focus on the impacts of soil erosion on agricultural production (loss of soil from erosion per hectare linked to loss of crop production). There are few data on the cost of soil erosion to Scottish farmers; however, estimates from England, Europe, North America and Australasia suggest costs in the range of £0.10 to £38.19 per hectare per year; the main variables being the rate of erosion and the value of the crop planted. The inherent uncertainty in these estimates can only be reduced by increased monitoring of soil erosion rates in relation to land use.

Current methods to reduce the impact of soil erosion concentrate on the use of buffer strips to catch sediment before it enters the stream network. The economic costs of retaining buffer strips has been estimated at £15.50 per hectare per year, although there is also the potential for social benefits in terms of carbon sequestration, flood control, increased biodiversity and wildlife corridors.

A large social cost relates to soil organic matter losses and climate change impacts (Chapter 3). However, a component part of soil erosion losses includes the evaluation of the loss of organic matter when topsoils are eroded. A value of £36.00 per hectare was applied to the loss of soil organic matter and subsequent losses of CO_2 from arable land, giving an aggregate annual value of £60.5m (2009) based on organic matter loss rates between 1980 and 1996.

The Environmental Accounts for Agriculture mention an erosion damage cost estimate for Scotland of £1.3m in 2008 and the cost of drinking water treatment in Scotland was estimated at £19.8m in 2008. A proportion of this cost was incurred removing eroded sediment and pollutants (including pathogenic microbes) from drinking water supplies.

Aside from the economic impacts of soil erosion and landslides, they can also have a direct effect on daily life. For example, landslides have increasingly blocked main routes through parts of the Scottish Highlands, for example the A83 (Box 7.2). While these impacts are relatively localised, they cause disruption to road and rail links, often leading to long detours that affect remote Highland communities through the loss of tourism and loss of income for local businesses. Landslides triggered by heavy rainfall in Glen Ogle in 2004 resulted in motorists being trapped (Winter et al., 2005); vehicles narrowly escaped being swept away, thus there was the potential for the loss of life in these circumstances.

Table 7.3: Overview of socio-economic impacts for Scotland associated with erosion and landslides

Soil function	Cost type	On site/ off site	Description	Impact status[(i)]	Data status[(ii)]
Providing the basis for food and biomass production	Private cost	On	Loss of agricultural productivity	Low-to-medium	Y
		On	Costs of sediment removal from ditches	Medium	Y
	Mitigation cost	On	Costs of erosion prevention, for example field buffers	Low	Y
Controlling and regulating environmental interactions	Social cost	Off	Impacts on health	Low	N
		Off	Cost associated with erosion-related water treatment	Medium	Y
	Private cost/ social cost	Off	Damage from floods, landslides or mudslides	Medium	Y
	Defensive cost	Off	Expenditure to reduce off-site impacts of erosion	Low	N

Table 7.3: Overview of socio-economic impacts for Scotland associated with erosion and landslides (continued)

Soil function	Cost type	On site/ off site	Description	Impact status[i]	Data status[ii]
Storing carbon and maintaining the balance of gases in the air	Social cost	Off	Loss of carbon-rich topsoils, increased wetness leading to greater losses of greenhouse gases. Loss of carbon through peat slides	High	Y
Providing valued habitats and sustaining biodiversity	Non-use value cost	Off	Adverse impacts on natural ecosystems (e.g. eutrophication of waterbodies)	Variable	Y
Protection of cultural and archaeological heritage	Non-use value cost	Off	Soil erosion may expose buried archaeological remains	Variable	Y
Providing a platform for buildings and roads	Social cost	Off	Costs of sediment removal (from roads, roadside ditches, reservoirs, navigable waterbodies)	Medium-to- high	Y
	Social cost	Off	Damage to infrastructure (roads, water supply systems) by landslides	Low	Y
	Social cost	Off	Impact on recreational activities (indirect effects as a result of adverse impacts of erosion on waterbodies or landscape amenity values)	Variable	N

(i) Impact status – based on 20–25-year time scale assessment of severity of biophysical change, geographical extent, contribution of single economic impact.
(ii) Y = economic estimates are available in Görlach et al. (2004), ADAS (2006) and Defra (2009); N = no data available.

For more details on scoring and methodology see Annex 2.

Landslides can also damage buildings. Residential properties in the Aberdeenshire village of Pennan, for example, were damaged by a succession of landslides and debris flows between August 2007 and November 2009, and minor damage to gardens and foot paths has occurred from rock falls before and after. Elsewhere, almost 100 houses were evacuated in Bervie Braes, Stonehaven in February 2010 as a result of debris flows with consequent disruption to the daily lives of the residents. Landslides can also disrupt the commercial life of urban areas. For example, a landslide in April 1998 on an embankment closed Gillespie Road in Edinburgh for three months, leading to disruption of the busy thoroughfare.

Box 7.2: Landslides

Heavy rain in October 2007, September 2009 and September 2010 triggered debris flows that dislodged safety barriers and closed the A83. On each occasion, saturation of the soil superficial deposits and a loss in effective strength caused a thin layer of material to become mobilised travelling a considerable distance within an existing drainage track.

Generally, the landslides were less than two metres deep and travelled distances of over 400m. The Scottish Highlands are particularly prone to this type of landslide because of their steep slopes and granular soils and superficial deposits. Following debris flows in and around Glen Ogle in 2004, debris flow potential across Scotland was assessed, identifying over 60 roads at high risk, including some key arterial links.

Landslide above A83 at Rest and Be Thankful (Fergus MacTaggart, P710737, British Geological Survey ©NERC)

The Glenk et al. (2010) review of the social and economic costs of erosion and landslides highlighted that the variation in soils, terrain, land use, and the impact on the ecosystem goods and services demanded by society, means that it is difficult to accurately determine the cost of soil erosion and landslides.

Further work to quantify costs associated with the rates of soil erosion and impact on land use are required to get an accurate estimation of private on-site costs and to determine the costs of carbon loss. The cost of removal of sediments from drinking water in Scotland should be collated, as should the costs of clearing, maintaining and renovating roads and railways following landslides. Economic costs associated with stabilisation of potential landslides along with the cost of the loss of life and property also needs further investigation.

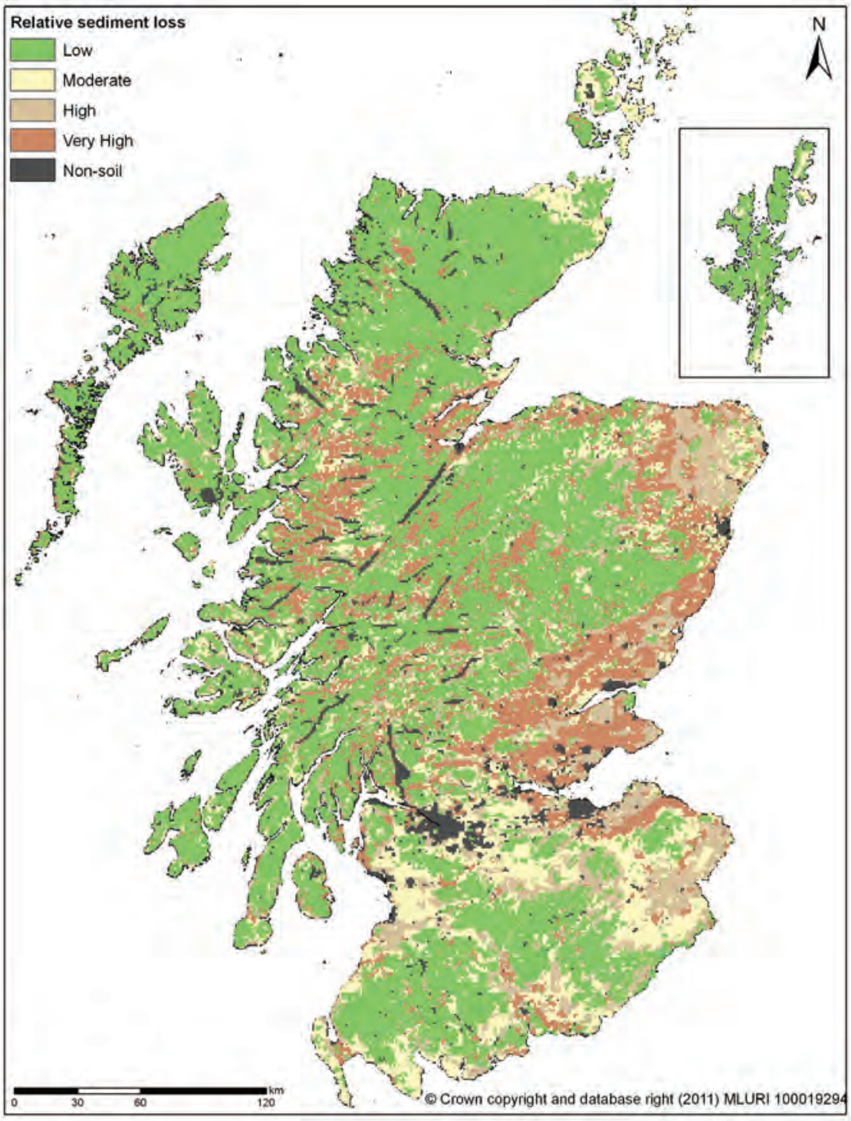
7.5 Description of the environment: state of soil erosion and landslides

The extent of erosion in Scotland is not known in detail at a national scale and most studies are of localised events or at the field-scale. Bowes (2002) measured erosion and deposition rates due to water and tillage erosion at four sites in the Midland Valley. He found losses around buried archaeological sites attributable to tillage erosion alone of between 13 and 22 tonnes per hectare per year (between 19 and 30 tonnes per hectare per year overall), which put the archaeological sites at risk of being destroyed. These rates are greater than a tolerable soil loss of 0.3 – 1.4 tonnes per hectare per year (Verheijen et al., 2009) but are site-specific and may only occur sporadically. Davidson and Grieve (2003) summarised soil loss from specific, notable erosion events. Up to 80 tonnes per hectare were eroded in one erosion event (Frost and Spiers, 1984), but these are relatively rare and localised. Recently, Bowes (2010) assessed the erosion losses in three fields in eastern Scotland (Box 7.1). The fields were selected as they had a history of erosion; however, the results show a pattern of both erosion and deposition, with net mean erosion losses approximately double the deposition gains in two of the fields (erosion losses of 18 and 22 tonnes per hectare). Severe gullying (which followed the pattern of tramlines) was recorded at one of these sites.

If no other erosion occurred at these sites throughout the year, then the annual rate is still below the tolerable loss; however, once initiated, erosion gullies can continue to focus run-off, making subsequent erosion more likely.

A nationally applied soil erosion risk model developed by Kirkby et al. (2004) suggests annual erosion rates of less than one tonne per hectare for the majority of Scotland under current (1971–2000) rainfall patterns and land uses (Figure 7.1), although the model predicts greater losses for the arable areas of eastern Scotland (more than two tonnes per hectare per year).

Figure 7.1: Estimated current sediment losses due to water erosion in Scotland using the Pan-European Soil Erosion Risk Assessment (PESERA) soil erosion risk model



It is clear that there is no systematic assessment of actual soil erosion in Scotland. The evidence for, and measurements of, erosion are generally site specific and are often a response to a severe erosion event. Modelled erosion rates are difficult to validate and, to a large extent, depend on the spatial resolution of the data available.

Figures 7.2 and 7.3 show the distribution of known failures and the calculated susceptibility to landslides in Scotland. Both figures show a greater occurrence and susceptibility to landslides in the heavily glaciated glens of western Scotland. Following events in 2004, debris flow potential across Scotland was assessed and it was estimated that approximately 3% of Scotland is highly susceptible to debris flows (Winter et al., 2005). However, it is not known how much material is lost in each debris flow. In upland areas it is estimated that around 7% of Scotland's peatlands are eroded (Towers et al., 2006; Lilly et al., 2009).

Figure 7.2: Distribution of recorded landslides in Scotland, taken from the British Geological Survey's National Landslide Database

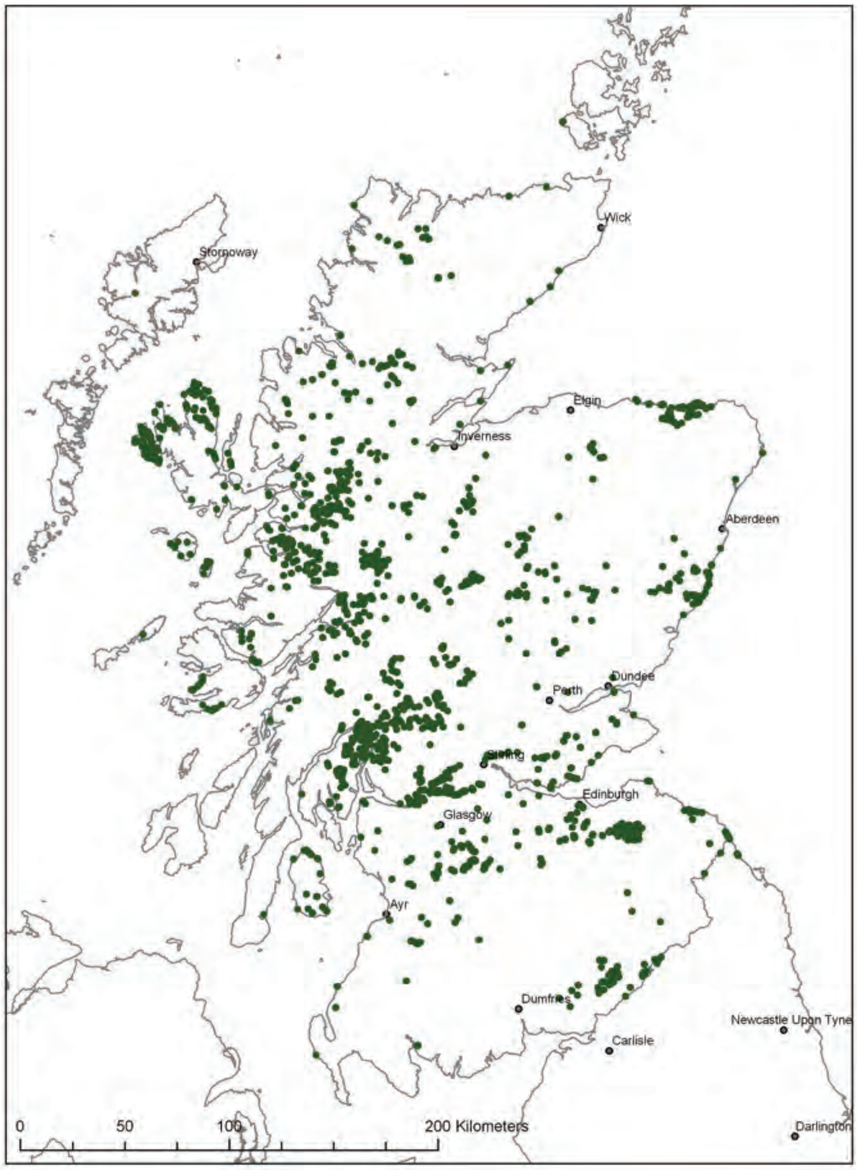
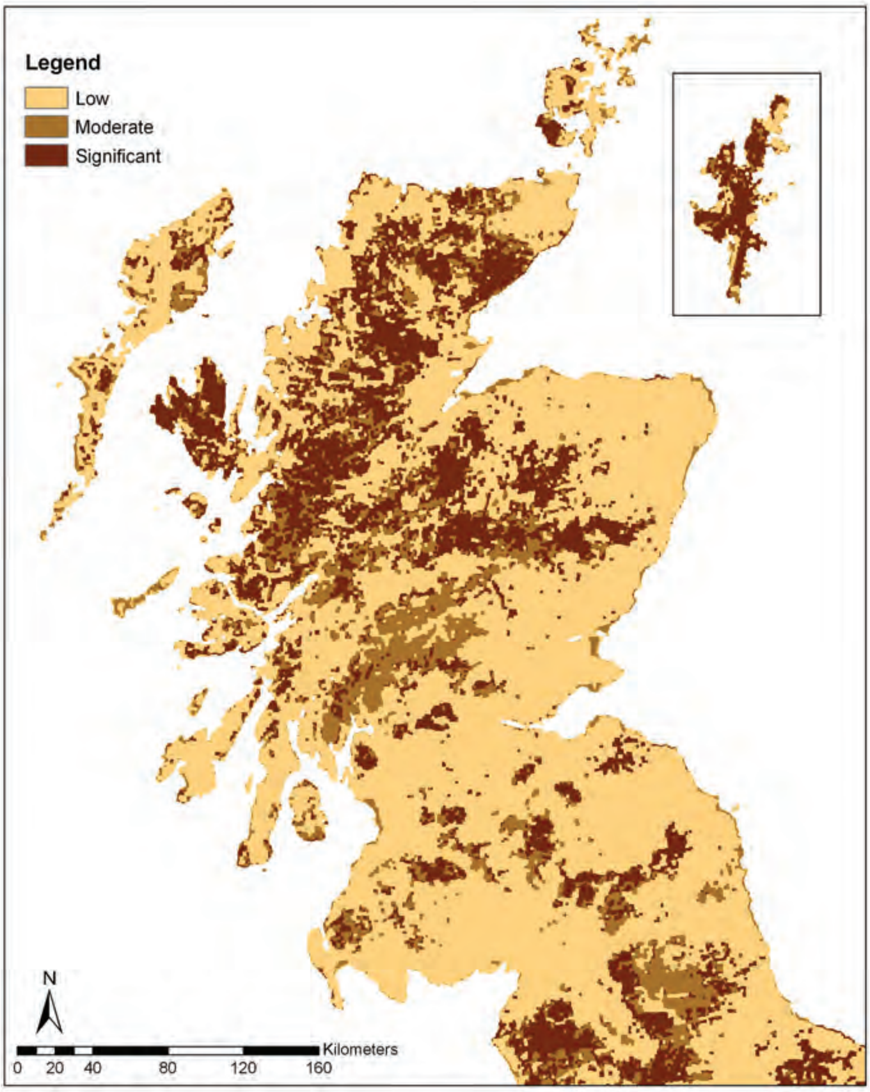


Figure 7.3: Landslide susceptibility for Scotland



7.6 Description of the environment: trend in soil erosion and landslides

The Harmonized Monitoring Scheme (HMS), which provides long-term data on suspended sediments in many Scottish rivers, shows that while some rivers have shown an increase in suspended sediment loads through time, others have shown a decrease. In general, the greater the proportion of arable cropping in a catchment, the greater the increase in suspended sediment load (Lilly et al., 2009); however, there was also a strong geographical distribution with catchments draining into the Moray Firth showing an increase in suspended sediment, whilst those catchments in the central belt showed a decrease. Unsurprisingly, Lilly et al. (2009) also found a correlation between the proportion of peat or moorland in a catchment and the total organic carbon content of rivers. Although suspended sediment gives an indirect indication of trends in soil erosion, direct estimates are difficult to obtain.

Landslides in Scotland (in the form of debris flows) have occurred in clusters over the last 7,000 years which may be related to climatic factors such as the frequency of extreme rainfall events, for example, although deforestation is also likely to be an important factor. Debris flows in the Lairig Ghru in the Cairngorms appear to occur with a return period of around 20 years, with each episode of debris flow activity thought to be linked to intense rain storms (Baird & Lewis, 1957; Innes, 1982; Luckman, 1992). Landslide and debris flow activity is reported to have increased over the last 200–500 years (Innes, 1985; Ballantyne, 2004) and it is thought that localised extreme rainfall was the major contributing factor to the landslides in 2004 (Winter et al., 2005). Triggering of peat slides is also commonly attributed to intense rainfall events such as that in September 2003 which initiated around 35 slides on the Shetland Isles (Dykes & Warburton 2008).

It is difficult to predict future trends in soil erosion and landslides. There is considerable uncertainty in the most recent UKCP09 climate change predictions particularly for the western seaboard, although most predictions agree that there will be increased rainfall over eastern Scotland during the winter months. This increase is likely to increase the erosion losses if current land use patterns remain the same.

Other vulnerable soils include eroded or bare peat, when drier summers may make these soils less able to absorb the greater autumn rainfall predicted, leading to increased run-off and increased erosion. Where significant cracking develops in these peat soils, infiltration may increase, causing a sudden rise in pore water pressure leading to failure and landslides.

Lilly et al. (2009) also suggested that overgrazing is probably the major driver of peat erosion in uplands and, although sheep numbers have decreased in recent years, the numbers of wild deer have not. This, combined with drier summers, may increase the susceptibility of peat soils to erosion.

With the uncertainty in climate predictions for the west of Scotland, it is difficult to determine if there is likely to be an increase in landslides in this area; however, it is assumed that both antecedent rainfall and intense rainfall events contribute to debris flow and landslide initiation, thus the future scenarios of more frequent and intense rainfall events would seem to indicate an increased likelihood of failures.

Retaining stubble in fields previously sown to spring cereals will help to reduce erosion. Other mitigation strategies such as adherence to policies like Cross Compliance (Good Agricultural and Environmental Condition), the Forests and Water Guidelines and the Water Framework Directive should help to minimise soil erosion in the future. Nisbet et al. (2002) reported on a study to test the effects of the Forests and Water Guidelines in controlling diffuse pollution from forestry in Argyll. They demonstrated that adherence to these guidelines meant that water quality was relatively unaffected during plant and harvesting phases.

8 Soil compaction

8.1 Definition and scope

Soil compaction generally refers to the loss of porosity through mechanical damage to soil. Porosity in soil provides space for the storage and transport of water and air, a habitat for soil biota, and eases the penetration of plant roots. This chapter will extend the definition to encompass all forms of mechanical damage that decrease the capacity of soil to carry out its essential functions.

Topsoil compaction refers to damage to the ploughed layer of soil where mechanical remediation, weathering and biological processes can assist with structural recovery following damage. Subsoil compaction refers to damage below the plough layer, where remedial measures to alleviate structural damage are not possible, or less effective, resulting in more persistent damage.

Soil compaction is recognised as a threat to soil quality (Schafer et al., 1992; van den Akker et al., 2003). It occurs when an external mechanical stress from equipment or livestock exceeds the mechanical stability of soil (Bailey et al., 1995). Various properties control the susceptibility of soil to compaction including: previous stress history (Keller & Arvidsson, 2007), texture (O'Sullivan et al., 1999), organic matter content (Zhang et al., 2005) and soil structure (Horn & Fleige, 2009). Most of these properties also regulate the capacity of soil to recover from compaction either through subsequent cultivation (Watts & Dexter, 2000) or the inherent resilience under natural weathering (Gregory et al., 2007). Most dry soils compact little, whereas wet soils can be highly susceptible to compaction.

Subsoil compaction is viewed as a far greater threat to soil quality by some experts (van den Akker et al., 2003) than topsoil compaction as the latter can be improved to some extent by soil cultivation and natural processes (Zhang et al., 2005; Barre et al., 2009).

8.2 Drivers and pressures

There are limited data available on soil compaction in Scotland; however, information is available from northern European countries with a similar maritime climate to Scotland and this is thought to be transferable. Countries such as Denmark and Sweden have conducted considerable research on soil compaction as it is a recognised threat to the functioning of soils in these countries due to the combination of climate, soil type and farming practice.

The greatest driver of increased soil compaction is machinery weight, as larger equipment is used to reduce the need for manpower and allow for fewer passes on fields. There is also a desire to minimise damage to soil by cultivation as a measure to decrease harmful impacts on soil carbon and biodiversity. This is at odds with the notion that topsoil compaction can be 'ploughed out'.

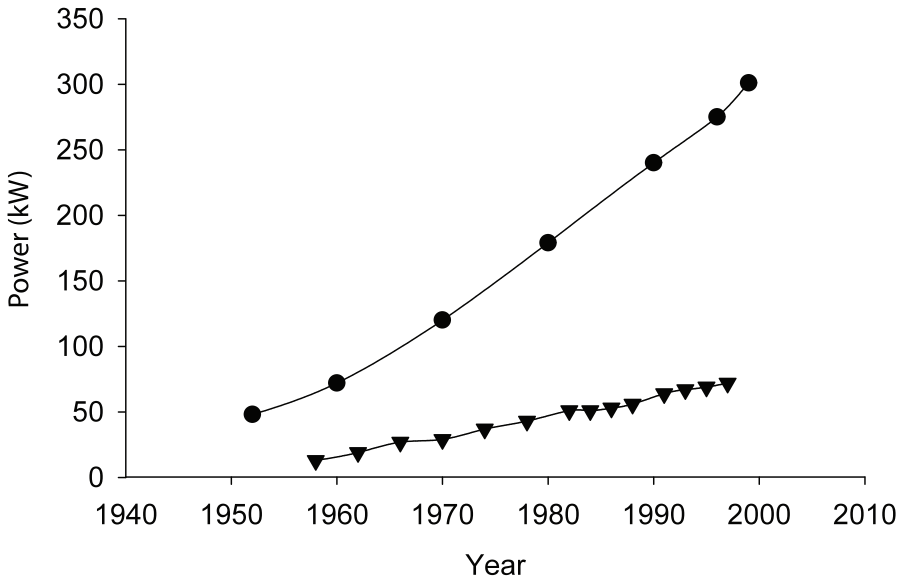
The impact of pressures on compaction is shown in Table 8.1.

8.2.1 Machinery weight

Over the past few decades, agricultural machinery in Europe has considerably increased in power and hence weight (Kutzbach, 2000). Machinery continues to increase in weight, with some harvesting equipment for root crops used in Scotland weighing 40 tonnes. As machinery weight increases, greater stresses are transmitted deeper into the soil profile. In Figure 8.1 the large increase in machinery power in Germany since 1950 is illustrated which suggests machinery weight has also increased. Data on machinery weight in Scotland has not been compiled but it is likely to show a similar trend to those above.

In Denmark, wheel loads greater than 3–4 tonnes are considered likely to cause persistent compaction in the subsoil. As such loads are common, particularly on larger farms, all managed soils are therefore considered to be at risk of subsoil compaction (Schjønning et al., 2009). Research conducted in 2008 at the Scottish Crop Research Institute in collaboration with the University of Kiel, Germany, found subsoil compaction from a 3.4 tonne tractor.

Figure 8.1: Increase in the maximal power of combines (●) and average farm tractor power (▼) of sales in Germany. Simplified from Kutzbach (2000)



Machinery used for forestry operations can also cause soil compaction. Tree harvesters can weigh 20 tonnes, but larger harvesters have longer boom lengths, thereby requiring less movement during operation. The occurrence of soil compaction in forestry has been documented in Scotland (Wood et al., 2003); however, current practice aims to minimise damage.

8.2.2 Climate change

Soil water content is a major driver in the risk of soil compaction. This depends on the amount of rain that falls and how quickly it drains away. A general rule of thumb is to limit traffic on soil to days when the soil is relatively dry (i.e. less than field capacity). The most recent climate change predictions for Scotland suggest that in future there will be more erratic weather conditions, with a greater number of extreme rainfall events that produce large amounts of precipitation. This will make it much more difficult for farming, forestry and other land-based industries in Scotland to plan and carry-out field operations when soils are dry enough to minimise the risk of soil compaction. Cooper et al. (1997) predicted a marked reduction in workable days because of climate change and this is already being noticed by farmers who find it difficult to schedule cultivation, spraying and harvesting operations because of weather. Good timing of management operations are considered to be essential to protect soil vulnerable to compaction (Ball et al., 1997).

8.2.3 Land use and management

Increased demand for food

Food demand may increase in Scotland because of water shortages elsewhere, the impacts of climate change and a growing population (potentially including refugees displaced from areas affected by climate change). Increased food demand could lead to greater intensification of the agricultural production base, including the use of more heavy machinery and marginal land that is more susceptible to soil compaction for arable production.

Stocking density also causes soil compaction, so increased livestock numbers driven by a greater demand for meat could influence compaction in grazing areas in Scotland.

Land drainage

Subsidies to support the renewal of land drainage have declined in recent years resulting in areas of land where drains have ceased to function. This has resulted in wetter soils in localised areas within fields that are more susceptible to compaction.

New soil cultivation technology

Reduced tillage involves cultivating soils to shallower depths to reduce fuel usage and mechanical damage to pore structure. Under long-term use it has been shown in some regions to produce soils more resistant and resilient to soil compaction. However, under the wet conditions of Scotland, shallow tillage pans can develop that reduce the depth of root proliferation. Reduced tillage is growing in use in Scotland and therefore increasing the threat of compaction.

Exacerbation of damage from previous compaction

Compaction can impede drainage, resulting in wetter soils and a greater susceptibility to subsequent damage. The extent of this problem has not been characterised for Scotland.

Recreation

Hillwalking, mountain biking, equestrian activities and off-road vehicles can lead to compaction damage in natural areas of Scotland. Visitor numbers to natural areas are increasing, resulting in greater pressure from activities on existing paths and elsewhere.

Local densities of deer have increased in some regions, with evident damage to vegetation from over-grazing in localised regions. With no natural predators in Scotland, wild deer populations have tended to increase. At the national level, roe, red and sika deer populations have risen significantly in recent decades, although the effects of the harsh winter of 2009–2010 have yet to be determined at the time of writing. Damage to vegetation can increase the vulnerability of soils to trampling and damage (Deer Commission Scotland, 2008).

Table 8.1: Relative importance of pressures leading to soil compaction (scored on a 25- year timescale using expert judgement)

Pressure	Magnitude of pressure(i)	Reversibility of pressure(ii)	Spatial extent of pressure(iii)	Trend in pressure(iv)	Uncertainty of pressure(v)
Climate change	2	2	2	+1	3
Land management practices					
• agriculture - machinery weight	3	3	1	+1	2
• forestry - machinery weight	1	3	2	+1	2
• stocking density/grazing	2	2	2	0	2

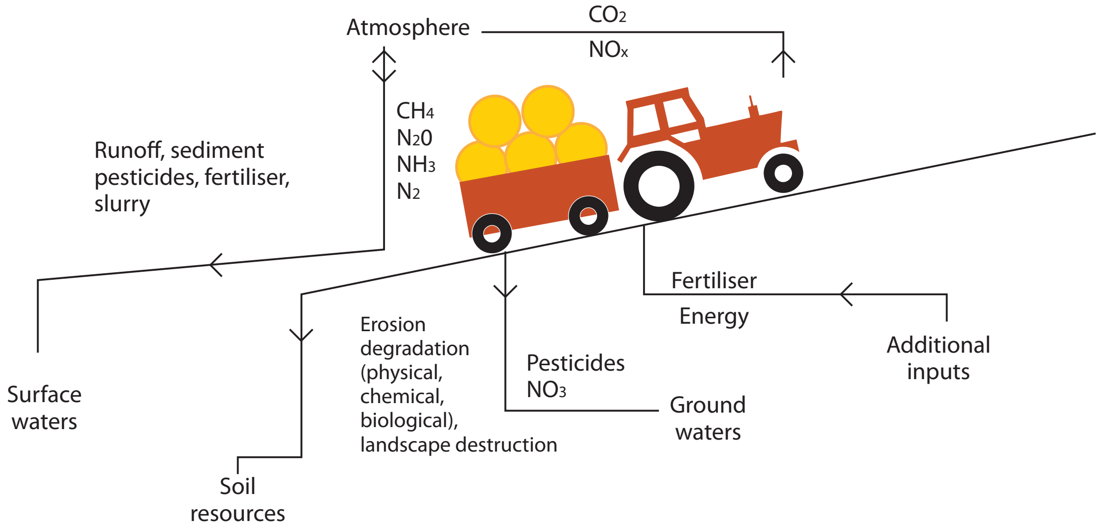
(i) Magnitude of pressure: 1, not significant; 2, significant; 3, very significant.
(ii) Reversibility of pressure: 1, short-term and reversible; 2, medium-term and reversible; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in pressure: -1, predicted to decrease in intensity; 0, predicted to be stable; +1, pressure predicted to increase in intensity.
(v) Uncertainty of pressure: 1, pressure well characterised and quantified; 2, pressure moderately well characterised but data primarily qualitative; 3, pressure poorly characterised.

For more details on scoring and methodology see Annex 2.

8.3 Consequences of soil compaction: environmental impacts

A general overview of the potential environmental impacts of soil compaction in relation to soil functions is shown in Figure 8.2 and described below. Table 8.2 shows the potential impact of compaction on soil functions. Loss or damage to soil porosity decreases infiltration rates and storage of water and gases, with implications for run-off, erosion and microbial processes that lead to greenhouse gas emissions. Moreover, compacted soils require greater energy to cultivate (greater fuel use) and smaller root systems often develop on crops so fertiliser applications need to be increased. Schjønning et al. (2009) provides evidence of potential decreased crop yields in similar soil and climatic conditions to Scotland.

Figure 8.2: A conceptual diagram showing the various implications of soil compaction to the environment (Soane & Vanouwerkerk, 1995; Lipiec et al., 2003). This diagram omits the potential negative implications on crop productivity



8.3.1 Providing the basis for food and biomass production

Soil compaction results in poorer conditions for plant growth as a result of increased mechanical impedance for roots, decreased aeration, and decreased water storage in soil (daSilva & Kay, 1996). These conditions generally result in reduced crop yields. Waterlogging is directly related to compaction (Douglas & Crawford, 1998). It has negative impacts on plant production, often resulting in crop failures in agriculture and negative impacts on tree growth (Wairiu et al., 1993) in forestry. Compaction reduces root spreading and, hence, access to nutrients (Miransari et al., 2009). Microbial processes occurring in compacted, waterlogged soils can dramatically reduce the amount of nitrogen available for plants (Boone & Veen, 1994). Douglas and Crawford (1993) demonstrated the combined impacts of soil compaction and applied nitrogen on crop production in Scotland. This is also illustrated in Figure 8.3 which shows that more nitrogen is required to obtain the same crop yield in compacted than in non-compacted soils.

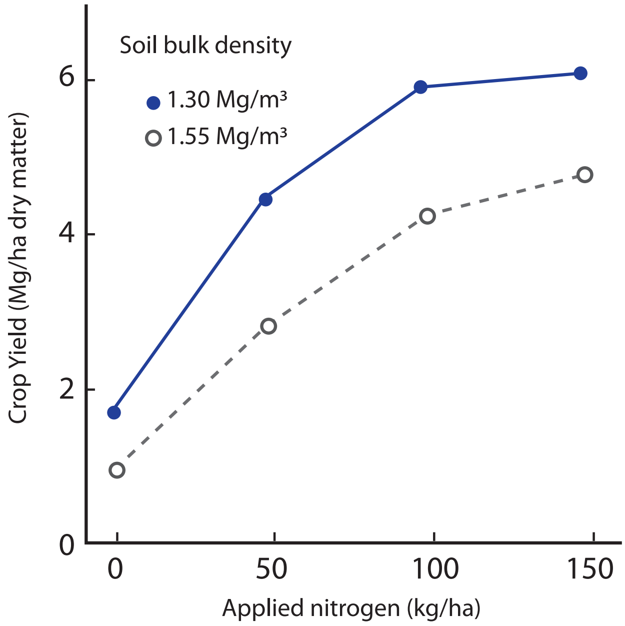


Figure 8.3: The relationship between the amount of nitrogen applied and crop yield under different compaction regimes. A compacted soil (bulk density of 1.55 Mg/m³) may require more nitrogen to obtain a similar yield to a non-compacted soil (bulk density of 1.30 Mg/m³). From Soane and Vanouwerkerk (1995)

8.3.2 Controlling and regulating environmental interactions

The decrease in the ability of water to move through soil caused by compaction reduces the drainage of water through the soil and the ability of the soil to store water (O'Sullivan & Simota, 1995; Wood et al., 2003). Although the evidence base for the UK is limited at present, soil compaction could be a major factor influencing flood events, particularly as the frequency of extreme rainfall events is predicted to increase.

Increased run-off caused by soil compaction can lead to greater soil erosion (Chapter 7). The presence of compacted tramlines can increase run-off by 46% and phosphorus loss by 400% in arable soils (Withers et al., 2006). Run-off containing sediment and phosphorus may then enter watercourses causing a deterioration in water quality.

Soil damage through compaction disrupts the pore structure, sometimes resulting in the formation of macropores. The presence of macropores increases preferential flow of contaminants and pathogens to groundwater (Artz et al., 2005).

8.3.3 Storing carbon and maintaining the balance of gases in the air

The production of the greenhouse gases nitrous oxide and methane are enhanced by anaerobic conditions that are heavily influenced by soil pore structure (Ball et al., 1999). Reduced aeration because of compaction can therefore result in increased emissions of both these gases.

As compacted layers impede root penetration, the presence of fewer roots at depth could decrease the amount of carbon stored at depth. This is particularly significant in considering the adoption of reduced tillage. Although the concentration of soil carbon in the topsoil can increase, storage over the whole profile may be unaffected as fewer roots penetrate to depth. This has been demonstrated in tillage trials at SCRI and in other regions with a similar climate to Scotland (Sun et al., 2010).

8.3.4 Providing valued habitats and sustaining biodiversity

A deterioration of soil structure caused by soil compaction will impact soil biota and organisms higher up the food-chain (Batey, 2009). Soil pore space is the habitat for the most diverse and abundant group of organisms on earth (Harris et al., 2003). Through compaction, this habitat is altered significantly. There is conflicting evidence on the impact of soil compaction on soil biodiversity (Shestak & Busse 2005; Gregory et al., 2007), but it is generally acknowledged that the functional capacity of microbes to cycle nutrients or mineralise carbon diminishes in compacted soils (Ball et al., 1999). Soil fauna find burrowing more difficult in compacted soils and this has knock-on effects on the creation of biopores (McKenzie et al., 2009). Birds that feed on soil organisms may find pecking of the soil more difficult in compacted soils (Gilroy et al., 2008) and burrowing birds may find nesting more difficult (Heneberg, 2009) (Chapter 6).

8.3.5 Preserving cultural and archaeological heritage

Damage to buried archaeological remains can occur as a result of soil compaction (Holden et al., 2006), although limited information on potential damage is available. Some geotechnical research to assess potential damage has examined how specific soils and types of artefacts interact under loading (Dain-Owens et al., 2007). Fragile remains such as glass and ceramics can be broken, voids in the remains can be compressed (e.g. drains, graves) and water can be squeezed out of surrounding soil. The latter process has implications for the degradation of metal artefacts because of changes to the oxidation status of soils. There is also anecdotal evidence that vibrations caused by machinery can cause considerable damage (Holden et al., 2006).

8.3.6 Providing a platform for buildings and roads

Soil compaction is often desirable in engineering projects because it improves foundation and embankment stability. The stresses imposed on soil can be extreme and involve vibration, which has negative impacts on most of the soil functions listed above, although the impacts often occur at depths below those of significance for environmental processes. The axle weight from construction traffic during the building of utility corridors or other engineered infrastructure can cause considerable damage to soil, particularly if the timing and location of traffic is not controlled (Batey, 2009).

8.3.7 Provision of raw materials

Compaction does not significantly affect the provision of raw materials.

Table 8.2: Consequence (i.e. impact) of compaction on soil functions (scored on a 25–year timescale using expert judgement)

Soil function	Magnitude of impact(i)	Reversibility of impact(ii)	Spatial extent of impact(iii)	Trend in impact(iv)	Uncertainty(v)
Providing the basis for food and biomass production	2	2	2	+1	3
Controlling and regulating environmental interactions	2	2	2	+1	3
Storing carbon and maintaining the balance of gases in the air	2	2	2	+1	3
Providing valued habitats and sustaining biodiversity	2	2	2	+1	3
Preserving cultural and archaeological heritage	3	3	1	-1	1
Providing raw materials	Does not apply to this function				
Providing a platform for buildings and roads	Does not apply to this function				

(i) Magnitude of impact on function: 0, no impact; 1, not significant; 2, significant but not function threatening; 3, serious impairment of function.
(ii) Reversibility: 0, no impact; 1, easily reversed within a season; 2, can be reversed within a few years but only by significant changes; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3 national.
(iv) Trend in impact: -1, predicted to decrease over timescale; 0, predicted to be stable; +1, predicted to increase over timescale.
(v) Uncertainty: 1, impact well characterised and quantified; 2, impact moderately well characterised but data gaps may exist; 3, impact poorly characterised.

For more details on scoring and methodology see Annex 2.

8.4 Consequences of soil compaction: socio-economic impacts

Recent work (Glenk et al., 2010) has sought to identify the socio-economic impacts of soil degradation and Table 8.3 summarises their findings. Figure 2.3 explains the different cost types. It is notable that whilst different types of costs and the soil functions affected can be identified, actual data to enable quantitative assessments to be made are very scarce.

Table 8.3: Overview of economic impacts for Scotland associated with compaction

Soil function	Cost category	On site/ off site	Description	Impact status(i)	Data status(ii)
Biomass, food and fibre production	Private cost	On	Compaction affects biophysical properties of soil with adverse impacts on agricultural productivity	Medium-to-high	Y
	Mitigation cost	On	Cost of measures to prevent compaction or restore the physical (and biological) soil structure in compacted soil	Low-to-medium	Y
		On	Increased nutrient inputs to counter reduced productivity	Low-to-medium	Y
Controlling and regulating environmental interactions	Social cost	Off	Increased surface run-off due to reduced water infiltration capacity can result in higher risk of flooding, soil erosion and related water pollution	Low- to-medium	N
		Off	Reduced water infiltration can affect the replenishment of groundwater aquifers (long-term effect)	Low-to-medium	N
	Defensive cost	Off	Costs associated with measures to manage increased surface run-off	Low-to-medium	N
Storing carbon and maintaining the balance of gases in the air	Social cost	Off	Anaerobic conditions due to wetter soils can result in increasing levels of nitrous oxide emissions	Variable	N
Providing valued habitats and sustaining biodiversity	Non-use value cost	Off	Impacts on landscape values; biodiversity, etc.	Low-to-medium	N
Protection of cultural and archaeological heritage	Non-use value cost	Off	Impacts on landscape values; biodiversity, etc.	Low-to-medium	N

(i) Impact status – based on 20–25 year timescale assessment of severity of biophysical change, geographical extent, contribution of single economic impact.
(ii) Y = economic estimates are available in Görlach et al. (2004), ADAS (2006) and Defra (2009).
N = no data available.

For more details on scoring and methodology see Annex 2.

Table 8.3 shows that socio-economic impacts associated with soil compaction affect five soil functions. In total, nine socio-economic impacts were identified. The impact status varies from low to high across the impact categories. Economic estimates are available for a third of the impacts in the literature considered by Glenk et al. (2010); these were all for the on-site impacts of compaction, and most were dated or not specific to Scotland. There is an obvious lack of reliable data for off-site costs. Many of the costs are extremely difficult to quantify as the direct impact of compaction cannot be separated from other soil degradation processes. The degradation of soil through compaction, erosion and carbon loss, for instance, could have massive implications for flood risk, but data are not currently available to assess the socio-economic risk. This lack of available data fits within a general context where the cost impact is relatively low, with the potential exception of the private cost from biophysical properties of soil being affected by compaction generating adverse impacts on agricultural productivity and the social cost linked to anaerobic conditions, resulting in adverse impacts on climate change.

In addition to the results highlighted in Glenk et al. (2010), a study carried out in New Zealand has assessed the economic impact of compaction on farm gate returns (Shepherd, 1992). This accounts for the increased need for fuel, fertiliser, manpower and other resources in farm costs and decreased income if yields are decreased. A similar analysis could be carried out in Scotland by using paired plot experiments comparing compacted to uncompacted soils to provide the required data for socio-economic analysis. It would also be necessary to quantify the cost of remediating soil compaction, either through short-term management practices, such as subsoiling, or longer-term approaches where structural properties of the soil are recovered through managing organic matter and biophysical mechanisms.

8.5 Description of the environment: state of soil compaction

A systematic study of the extent of soil compaction in Scotland has not been carried out to date. As a result, it is not possible to provide a quantitative assessment of the current state. Ball et al. (2000) examined 156 sites in eastern Scotland and found many soils to be susceptible to compaction. In a survey of 1421 farmers across Scotland, Soane (1987) noted the widespread concern of farmers about compaction, particularly due to the harvesting of root vegetables. The occurrence of soil compaction in forestry has been documented in Scotland (Wood et al., 2003), but this has been only for a limited number of sites. Maps of compaction damage under different land uses are not available.

The re-sampling of the National Soil Inventory for Scotland (NSIS_2) includes measurements of soil physical properties that can be used as indicators of compaction damage and risk. However, these were only taken for mineral soils and only in the top 10 cm, so subsoil damage cannot be assessed. The 20 km grid used cannot capture localised damage to soils.

A risk map of subsoil compaction for Europe was prepared by Jones et al. (2003) based on information about annual soil moisture dynamics and expert rules governing compaction susceptibility. They designated most Scottish upland soils as having a 'Very High' susceptibility to compaction. Some arable soils in Scotland had 'High' susceptibility to compaction, similar to Scandinavia. More advanced models exist; however, there is not enough information available about Scottish soils to use them, and they do not describe soil compaction well because of difficulties in interpreting data (Gregory et al., 2006) and the complexities of the mechanical behaviour of soil.

8.6 Description of the environment: trend in soil compaction

Section 8.2 described many of the pressures that may exacerbate the threat of compaction to soil functions in Scotland, including increasing machinery weight, shallower cultivation depth and climate change. Water content is the greatest temporal variable influencing soil compaction, so any changes in the frequency and intensity of precipitation, as predicted in future climate change scenarios, could have major implications for soil compaction (Cooper et al., 1997). Scotland's winters have become wetter, particularly in the north and west with only the north-east bucking this trend (Barnett et al., 2006). If this trend continues as predicted, then it is likely to lead to soils becoming wetter in the spring when access for field operations is required, leading to an increased risk of compaction.

Collation of information on machinery weights and management practices from the forestry and agricultural sectors would provide statistics directly relevant to Scotland, but this has not been done to date. International trends, however, suggest increasing machinery weights over time.

Given the lack of information on the current state of soil compaction in Scotland, predicting any future trends is fraught with uncertainty. However, implementation of policies such as the Scottish Soil Framework (Scottish Government, 2009) and measures under Cross Compliance (Good Agricultural and Environment Condition) to protect agricultural soils are positive approaches to decrease the impact of compaction. What remains uncertain, however, is the amount of damage caused by different land management practices under different environmental conditions.

9 Emerging issues

Scotland's soils are faced with numerous pressures and conflicting demands. While many of these are well documented and their impacts recognised, there is a range of emerging issues that present current and future challenges to soils that Scotland (and the rest of the world) must address. Emerging issues associated with climate change, global population increase, greater food demand, food security, impacts of renewable energy schemes and the likely future increase in agricultural use of wastes have been discussed in other chapters. Five further emerging issues are presented here, although numerous others were considered and could be argued to be worthy of inclusion. The issues presented have been highlighted because they meet one or more of the following criteria:

- wide occurrence or dispersion with similarly widespread potential impacts;
- unknown environmental effects;
- high degree of potential danger;
- require development of soil guideline values and/or assessment mechanisms;
- not captured in other sections of this soil report.

9.1 Genetically modified organisms

Genetically modified organisms are plants, animals or microorganisms that have had their genomes altered through genetic engineering techniques in order to produce desirable characteristics. Inserted genes can come from the same species or from other species; however, officially, genetic modification is the incorporation of DNA that does not naturally occur in the host organism. Genetically modified organisms have many widespread applications. One of the most well-known applications of genetic engineering is in agriculture, which has seen the introduction of genetically modified crops that are herbicide tolerant and pest-resistant. New developments include drought and disease tolerant crops and plants that are more efficient users of nutrients.

9.1.1 Potential benefits of genetically modified organisms

Crops that can tolerate stress or can use nutrients more efficiently have the potential to reduce the need for pesticides and fertilisers. Genetically modified food crops with improved nutritional value or that can provide medical benefits are also being developed as a possible means of alleviating malnutrition and threats of disease, particularly in developing countries. In addition, there is growing interest in using genetically modified organisms for environmental decontamination.

9.1.2 Risks and uncertainties of genetically modified organisms

Genetically modified organisms employed in agricultural applications are released into the environment and have the potential to impact on ecological systems. The interaction between genetically modified plants and soil is not well understood. Although considered to be a rare event, it is possible for genetic material from plants to be incorporated into the genetic material of soil microbes. This, in turn, could affect soil health and ecosystem functioning; however, the risks are not yet clear. Genetically modified crop varieties could also enable changes in crop management that may affect the soil biota. A number of studies have been undertaken to look at the impacts of herbicide-tolerant and insect-resistant crops on soil biology (e.g. Griffiths et al., 2005; Griffiths et al., 2008) with no clear evidence of any permanent impacts observed. More research is needed in this area.

Gene transfer between genetically modified microorganisms and native soil microbial communities would be more likely to occur than transfer between genetically modified plants and soil organisms. The potential negative impacts on native soil microorganisms, which play fundamental roles in crop residue degradation, and on nutrient cycles are still uncertain (Giovannetti et al., 2005).

9.1.3 Genetically modified organisms, the EU, UK and Scotland

Within the EU, organisations aiming to release genetically modified organisms into the environment for commercial or research purposes must submit an environmental risk assessment that addresses a range of environmental issues, including effects on soil microorganisms and macrofauna.

However, the Scottish Government maintains a moratorium on the cultivation of genetically modified crops in Scotland, under the precautionary principle, in order to protect Scotland's natural environment and the rural economy. Genetically modified crops remain controversial and much debate continues within Europe.

9.2 Asbestos in soil

Asbestos is a naturally occurring fibrous mineral that is characterised by fibres that split along their length to generate finer fibres. Up until the 1980s, asbestos was widely used in all types of buildings because of its high strength, sound-proofing ability and resistance to heat and fire. Its use has been banned in many parts of the world (including the EU) and has only been routinely removed from buildings before demolition since about 1990.

9.2.1 Asbestos contamination of soils

Asbestos contamination of soils may arise where building rubble has been buried on site, mixed with topsoil, used as hardcore, or used in landscaping. Asbestos has even been found in locations with no industrial history, for example in rural sites as a result of demolition rubble from forgotten farm buildings. The extent of soil contamination with asbestos is not known, but some public and commercial building sites now coming up for redevelopment may have been built upon the demolition rubble of pre-1980s asbestos-containing building materials. Soil disturbance and movement during site redevelopment may possibly unearth and redistribute previously buried asbestos.

9.2.2 Health risks from asbestos in soils

Asbestos in soil poses a hazard where it can become airborne, for example, by human disturbance or by wind. Gardeners and small children playing with soil might experience substantial exposure to airborne fibres as a result of handling dry soil. However, fibre release from damp soils is minimal. Health risks from gardens are therefore generally low because of the infrequency of prolonged dry weather and the relatively small number of hours in a year that individuals are exposed. However, if climate change leads to hotter drier summers, as predicted, this could, conceivably, lead to an increased risk of exposure arising from drier soils.

Redevelopment of asbestos-contaminated sites can promote exposure to airborne fibres. It is important to consider asbestos wherever redevelopment of Brownfield sites has occurred or is planned, whether or not the land has been used industrially.

9.2.3 The need for guidelines governing asbestos in soil

Currently there are no soil guideline values for asbestos and approaches vary among the different local authorities. Generic guidelines based on soil type, local climate, land use and depth within soil profile would thus be greatly beneficial. This would enable a consistent regulatory approach to asbestos contamination across the UK and reduce the costs of investigation at asbestos-contaminated sites.

9.3 Nanomaterials

Nanomaterials, particularly those that are deliberately engineered, are an emerging issue with potential implications for the environment, including soils. Nanomaterials are a diverse group of minute substances, defined as having at least one dimension under 100 nano-metres (one nanometre, nm, equals $1x10^{-9}$ m). For comparison, the diameter of human hair commonly ranges from 30,000 to 100,000 nm. If a nanomaterial has two dimensions under 100 nm it can also be described as a nanoparticle.

9.3.1 Nanomaterial applications

The small size of nanomaterials gives them enhanced and specific physical, chemical and biological properties compared with the same materials at a larger scale. These properties have driven rapid development of a wide range of engineered nanomaterials that are now commonly utilised in a whole host of products including sunscreens, cosmetics, paints and water purification systems. In particular, nanomaterials composed of silver have found many applications in consumer goods because of the metal's antimicrobial properties; wound dressings, and even toothpaste and baby products, containing nano-silver are now available. Engineered nanomaterials composed of iron are being used in environmental remediation projects to address contamination issues [e.g. for nitrates and trichloroethene (Klaine et al., 2008; United States Environmental Protection Agency, 2009)]. Conservative estimates of future (2011–2020) global production of manufactured nanomaterials exceed 100,000 tonnes per year (Royal Society, 2004).

9.3.2 Environmental effects and fate of nanomaterials

Engineered nanomaterials can enter the wider environment through direct discharge into waste streams, or through the breakdown and disposal of nanomaterial-containing products. Land application of storm and reclaimed water, as well as sewage sludge, can also introduce nanomaterials to soils.

The effects and fate of nanomaterials in soils are yet to be determined, but many research programmes are currently underway to address this knowledge gap. In aquatic systems, some evidence suggests that nanomaterials can be more toxic than the same material at a larger scale (e.g. Gaiser et al., 2009). However, the situation in soils is more complicated, as soils (particularly those with appreciable amounts of clay and organic matter) have a capacity to adsorb, bind and aggregate these materials, which may reduce the toxicity of nanomaterials. Early indications are that soil microbiota are not particularly sensitive to carbon fullerene nanomaterials, but that some toxic effects can be induced (Johansen et al., 2008).

9.3.3 Regulation developments and research in the UK regarding nanomaterials

Regulation and monitoring of nanomaterials in soils are difficult tasks as their behaviour in soils is still so poorly understood. In order to set environmentally relevant risk-based regulatory standards and to monitor compliance with these, the toxic effects of nanomaterials in soil systems first need to be defined.

The UK government has established a range of nanomaterial research programmes (e.g. the Environmental Nanoscience Initiative, ENI). Scottish organisations are involved in this work and appropriate policies and monitoring strategies for Scotland will ultimately be developed from the outcomes.

9.4 Biochar

Biochar is a porous, stable form of carbon produced by partial combustion of organic materials under low oxygen conditions. It can be produced from wood, crop residues, sewage sludge, greenwaste and other similar materials. The production of biochar effectively locks up the carbon stored in the feedstock material and therefore has a great potential for long-term carbon storage.

9.4.1 Benefits of biochar

In addition to carbon storage, biochar has potential use as a soil conditioner. The benefits of adding biochar were first observed in studies of soil in the central Amazon basin, which showed much higher fertility than adjacent soils.

Biochar additions can increase crop yields, in some cases more than doubling them. This may be as a result of the very high surface area of biochar which promotes the retention of water and nutrients in amended soils that can be used by plants. Yield increases may also partly arise from nutrient elements in the biochar that are concentrated and rendered chemically available during biochar formation (e.g. potassium, phosphorus and micro-nutrients such as zinc). In addition, incorporation of biochar may stimulate microbial activity, promoting nutrient cycling. Biochar application may, therefore, reduce the need for other additions to soil such as fertilisers and lime. The capacity of biochar to retain nutrients in soil may also decrease nitrate leaching, which would be an important benefit for soils in nitrate vulnerable zones.

To date, however, most studies have been conducted on highly impoverished tropical soils that generally respond well to any amendments; obtaining beneficial effects from biochar in the highly productive agricultural systems of industrialised countries is more challenging. Reported yield increases in the EU have ranged from 0–20%. Also, the vast majority of studies globally have used biochar formed from wood charcoal, thus current understanding about biochar produced from other organic materials is limited. Research is therefore needed to progress knowledge on biochar's benefits and on the types of biochar that are best suited to particular applications.

9.4.2 Risks, uncertainties and the need for regulation regarding biochar

The wider impacts and long-term effects of biochar on soil are uncertain. While positive effects have been identified, it has also been suggested that biochar could release metals and polycyclic aromatic hydrocarbons (PAHs) to soils in the longer term. This could be of particular concern for biochar formed from conversion of waste products (which can contain higher levels of pollutants than clean feed-stocks).

There is also uncertainty about long-term effects on soil nutrients; while some short-term beneficial effects on nutrients have been recorded, sorption of nutrients by the reactive high surface area of biochar may ultimately reduce nutrient availability over the long-term. The residual fixed nitrogen content of biochar may also pose challenges for loading limits in nitrate vulnerable zones.

Environmental regulators need to review biochar for any potentially adverse impacts it may have on soil and soil ecosystems. Nevertheless, if produced and incorporated judiciously, biochar has the potential to offer great benefits to soils and society.

9.5 Extreme events

Extreme events can affect the soil environment and can be naturally occurring, for example volcanic eruptions, or caused by human activities, for example major industrial accidents.

The eruption of the volcano in the Eyjafjallajökull region of Iceland in March and April 2010 highlighted the potential disruption and impact that unexpected extreme events can have on the environment and society. While no adverse effects on Scottish soils arose from that incident, future eruptions of larger volcanoes in Iceland or elsewhere could, potentially, have an effect on our soils. Volcanic eruptions release acidic gas and salts that can eventually be deposited on soil surfaces via direct atmospheric fallout or via their incorporation into rain or snow.

These acidic components have the potential to alter soil pH and the concentrations of salts in the soil containing sulphate, chloride, sodium and fluorides. If deposited in substantial amounts, such changes could potentially lead to negative impacts on soil organisms. Fluoride, in particular, has caused animal and plant toxicity in areas impacted by high deposits of volcanic ash (Bellomo et al., 2003; Cronin et al., 2003). Knowledge of current pH levels and fluoride concentrations in soils is, therefore, important for determining the degree of any impact from future volcanic eruptions.

In 1986, an accident at the Chernobyl nuclear power plant in the former USSR (now Ukraine) sent a plume of radioactive debris into the atmosphere. Fallout from the resulting dust cloud affected an extensive area of Europe, including parts of upland Scotland. Contamination by caesium and strontium was of particular concern as they remain in the soil for many years. Because of the particular chemical and physical properties of the peaty soil types present in upland areas, the radiocaesium was able to easily pass from soil to grass and then accumulate in sheep. To prevent sheep with high levels of radioactivity from entering the food chain, restrictions were put in place on 2,900 Scottish farms in June 1986 and lifted later that year. However in 1987, raised levels of radioactivity were detected in new lambs and restrictions were reintroduced on 73 farms. Monitoring was put in place and restrictions slowly removed over time. These restrictions were finally lifted from the last remaining farm in June 2010 (i.e. 24 years after the incident).

Other large-scale industrial accidents have been responsible for extreme land pollution events in the past via the release of pollutants into the atmosphere and subsequent deposition on land, such as the dioxin plume resulting from the Seveso disaster in 1976. These can have a regional or a transboundary impact on both the environment and human health.

9.6 Emerging issues in perspective

The relative importance of the threats to soils from the emerging issues identified are summarised in Table 9.1. The impacts of emerging issues on soil functions are generally not yet fully known and therefore it is not possible to make a meaningful assessment of their impact on soil function.

Table 9.1: Relative importance of the pressure caused by emerging issues on soil (scored on a 25-year timescale using expert judgement)

Pressure	Magnitude of pressure(i)	Reversibility of pressure(ii)	Spatial extent of pressure(iii)	Trend in pressure(iv)	Uncertainty of pressure(v)
Genetically modified organisms	2	3	3	0	3
Nanomaterial applications	2	3	3	+1	3
Asbestos in soil	3	3	1	-1	2
Biochar	1	3	1	+1	3
Extreme events (e.g. volcanic eruptions)	1	3	2	0	3

(i) Magnitude of pressure: 1, not significant; 2, significant; 3, very significant.
(ii) Reversibility of pressure: 1, short-term and reversible; 2, medium-term and reversible; 3, effectively irreversible.
(iii) Spatial extent: 0, very limited; 1, local; 2, regional; 3, national.
(iv) Trend in pressure: -1, predicted to decrease in intensity; 0, predicted to be stable; +1, pressure predicted to increase in intensity.
(v) Uncertainty of pressure: 1, pressure well characterised and quantified; 2, pressure moderately well characterised but data primarily qualitative; 3, pressure poorly characterised.

For more details on scoring and methodology see Annex 2.

10 State of Scotland's Soil – analysis of the impact of the threats on soil functions

So far, the report has focused on the main threats to soils identified in the Thematic Strategy for Soil Protection (European Commission, 2006) and Towers et al. (2006). A conceptual model has been applied to Scottish soils to explain the wider context and implications of the threats to soil (Figure 2.4). The socio-economic implications of those threats to soil functions have also been considered.

Assessments of the drivers, pressures and consequences of each individual threat have been considered in detail in Chapters 3 - 9, while potential responses are discussed in Chapter 11. This chapter (Chapter 10) further develops the expert judgement approach used by Towers et al. (2006). This evaluation involved the creation of a scoring system which took into account:

- the relative importance of the various pressures that drive the threats to soils over a 25-year timescale by considering the magnitude of the pressures, the potential timescale of reversibility of the pressures, the spatial extent of the pressures, and the trend in their intensity over time;
- the cumulative impact of each threat on each of the soil functions, by considering the magnitude of the impact on soil function, how difficult it would be to reverse the effects of the threat on each function, the spatial extent over which the threat manifests itself, and the trend in its impact.

This expert judgement was combined with the socio-economic evaluation of Glenk et al. (2010) to provide a risk-based evaluation of the relative importance of the threats to soil and their impact on the wider environment and society. The analysis carried out in this chapter is illustrated by a series of tables:

- Table 10.1 presents cumulative scores for all of the various pressures identified in Chapters 3–9 with the pressures being ranked according to the total scores. This identifies the pressures that contribute to a number of threats and those that are more specific to just one;
- Table 10.2 presents cumulative scores for the magnitude, reversibility, spatial extent and trend in impact for each of the threats to all soil functions and ranks them in order of total score. This identifies the threats that impact most across all the soil functions;
- Table 10.3 describes the number of functions affected by each threat across four spatial scales: national; regional; local; and specific locations;
- Table 10.4 presents cumulative scores derived from the socio-economic impact assessments and ranks the threats in order of total score;
- Table 10.5 sums the totals from Tables 10.2 (environmental significance) and 10.4 (socio-economic impacts) and ranks the threats according to these summations.

The scoring methodology is explained in more detail in Annex 2.

10.1 The relative significance of pressures that drive the threats to soil functions

The pressures leading to the various threats are discussed in detail in Chapters 3–9. This section assesses the relative significance of pressures across all threats. Table 10.1 presents the aggregated pressure values, the calculations for which are described in Annex 2. These aggregated pressure values are then added together for all soil functions and ranked in the last column of Table 10.1 in order to ascertain which are the most significant. Until now, these pressures have been viewed in the context of single threats; here their cumulative effect across all the threats is assessed.

Table 10.1: 'Aggregated pressure values' for each threat showing the relative significance of the pressures leading to soil threats

Pressure	Changes in soil biodiversity	Loss of soil organic matter	Erosion and landslides	Contamination	Emerging issues	Compaction	Soil sealing	Total
Climate change	9	10	9			7		35
Development/transport	8	9	7				8	32
Agricultural cultivation[1]	5	6	7					18
Forestry cultivation	4	6	8					18
Agriculture (application of chemicals)	7			10				17
Stocking density/grazing	5		5			6		16
Expansion of agriculture	7	6						13
Expansion of forestry	8	5						13
Drainage	6		6					12
Waste management				7			3	10
Loss and damage of habitat	9							9
Contamination (those not included in agriculture), mainly atmospheric deposition and point sources	9							9
Nanomaterial applications					9			9
Muir burning	3		5					8
Agriculture (machinery weight)						8		8
Recreation		5	3					8
Fossil fuel combustion/transport				8				8
Forestry (tree species selection)	7							7
Forestry (machinery weight)						7		7

Table 10.1: 'Aggregated pressure values' for each threat showing the relative significance of the pressures leading to soil threats (continued)

Pressure	Changes in soil biodiversity	Loss of soil organic matter	Erosion and landslides	Contamination	Emerging issues	Compaction	Soil sealing	Total
Renewable energy							7	7
Global cycling				7				7
Peat exploitation		6						6
Genetically modified organisms					6			6
Asbestos in soil					6			6
Biochar					6			6
Extreme events (e.g. volcanic eruptions)					6			6
Forestry (application of chemicals)				5				5
Industrial emissions				5				5
Total	87	53	50	42	33	28	18	

[1] For agricultural cultivation, the score against loss of soil organic matter represents the average of the individual scores given for arable cultivation and grassland cultivation, as these types of pressures are combined for other threats.

Climate change and the development of land and provision of transport infrastructure clearly emerge as the two most significant pressures (in red in Table 10.1), as they both drive a total of four different threats to a relatively high degree, as indicated by the cumulative scores. In the case of climate change, it is worth pointing out that the pressure can also be driven by a threat, for example loss of soil organic matter can release more carbon into the atmosphere in the form of greenhouse gases which, in turn, increases the risk of climate change, thus resulting in a cycle of increasing environmental impact.

A series of pressures (in green in Table 10.1), all of which are related to land management and land use practices, can also be identified as having a greater significance than other pressures. The rest of Table 10.1 consists of a list of disparate pressures that are of lower significance, many of which provide the driver to a single threat to soil functions.

The bottom row in the table indicates that changes in soil biodiversity is subject to, and influenced by, the largest number of pressures and these pressures potentially impact to a high degree. This is followed by loss of soil organic matter and erosion and landslides. In contrast, soil sealing is subject to only a relatively small number of pressures.

10.2 The relative environmental significance of the threats to soil functions

The relative significance of threats to soil functions is derived from the assessment of magnitude, reversibility, spatial extent, and trend scored by expert judgment in the previous chapters. The calculation of the cumulative function values shown in table 10.2 are explained in Annex 2. These 'cumulative function values' are then added together to produce a column of total environmental scores which are ranked in order to determine which threats have the most environmental significance. The final column in the table gives cumulative scores for uncertainty. These are not ranked but are included for illustrative purposes.

Table 10.2: 'Cumulative function values' for magnitude, reversibility, extent, trend and uncertainty, showing the relative environmental significance of threats to soil functions

Threat[1]	Cumulative magnitude	Cumulative reversibility	Cumulative extent	Cumulative trend	Total environmental score	Cumulative uncertainty
Loss of soil organic matter	16	21	15	6	58	13
Changes in soil biodiversity	16	15	14	4	49	18
Soil sealing	18	18	6	6	48	6
Erosion and landslides	15	15	11	4	45	13
Compaction	11	11	9	3	34	12
Contamination (excluding contaminated land)[2]	6	8	5	-2	18	19
Contaminated land	12	8	4	-7	17	14

[1] The threat posed by newly emerging issues is not included in this analysis, as it is difficult to produce meaningful scores at this stage because of a lack of evidence.

[2] The row for contamination represents an average of scores for contamination (excluding contaminated land) from the values for acidification and eutrophication, metals, pathogens, radioactive substances and organic chemicals with scores of 27, 22, 16, 14 and 12 respectively.

When the cumulative function values are added together, loss of soil organic matter emerges as the most significant threat, followed by changes in soil biodiversity, soil sealing and erosion and landslides, all with similar scores. It is worth noting, however, that these threats do not act in isolation from one another, for example a loss of topsoil through erosion could lead to a loss of organic matter which, in turn, results in a loss of biodiversity. The total environmental scores (total of cumulative function values for the given threat) merely give an indication of relative significance.

The threat posed by contamination appears to be showing a marked decline in significance since the publication of earlier reports (e.g. SEPA, 2001). For the specific threat posed by acidification and eutrophication, this is partly because of a declining cumulative trend in impact, but also because acidification and eutrophication only have a significant impact on a relatively small number of soil functions.

Threats exhibiting a declining trend in impact are in the lower half of the table. In contrast, the impacts caused by loss of organic matter, sealing and erosion and landslides are among those that are increasing. The increasing trends in relation to loss of organic matter and erosion and landslides, for example, could largely be explained by the effects of land use change, land management change and climate change, while the increasing impact of soil sealing is most readily explained by increasing urbanisation and road building.

Considering the cumulative scores for spatial extent, the most widespread threats are loss of organic matter and changes in soil biodiversity, both of which affect four of the seven principal soil functions on a national scale. Acidification and eutrophication, erosion and landslides and compaction are most significant on a regional scale, whereas soil sealing and contaminated land do not affect soil functions on anything more than a local scale (see Table 10.3).

The cumulative scores for uncertainty in the last column of Table 10.2 show that there is an overall high level of uncertainty about contamination although the individual threat of acidification and eutrophication is much better understood. Despite these threats being ranked low in the list, this lack of certainty may indicate that there is merit in carrying out more monitoring and assessment of, for example, the application of waste materials to land.

There is also a significant level of uncertainty about the impact caused by changes in soil biodiversity. This perhaps reflects the fact that although the importance of soil biodiversity in controlling soil ecosystem functions is well documented, little is known about the distribution and nature of individual soil species and taxa, and their role in supporting the principal soil functions.

The scale at which threats manifest themselves on multiple functions must be considered together with their associated level of uncertainty. Threats that act on a local scale but have a high level of uncertainty (e.g. contaminated land) may need to be regarded differently to those that act on a national scale and have a high level of uncertainty (e.g. change in soil biodiversity). These differences are likely to lead to different approaches to mitigation and remediation of those threats, and in the application of the precautionary principle.

Table 10.3: Number of soil functions affected by threats at different spatial scales

Threat	Number of soil functions affected: National scale	Regional scale	Local scale	Negligible impact
Loss of soil organic matter	4	0	3	0
Changes in soil biodiversity	4	0	2	1
Erosion and landslides	0	4	3	0
Compaction	0	4	1	2
Contamination (excluding contaminated land)	0	1	3	2
Soil sealing	0	0	6	1
Contaminated land	0	0	4	3
Individual contamination threat				
Acidification and eutrophication	1	3	1	2
Metals	0	2	2	3
Pathogens	0	1	2	4
Radioactive substances	0	1	2	4
Organic chemicals	0	0	3	4

10.3 Socio-economic assessment of the threats to soil functions

The individual socio-economic impact status assessments presented in the socio-economic tables in Chapters 3–8 were converted into numerical values for the purposes of this assessment (see Annex 2 for details). These values were used to produce two interim scores that were combined to provide a final socio-economic score, as shown in table 10.4.

The first interim score expressed the cumulative total of the highest score for each soil function (Method 1). This can be considered as a worse-case scenario as although each particular threat can cause one or more different socio-economic impacts on any particular soil function, it only presents the socio-economic impact that results in the highest score for each soil function (Method 1 score in Table 10.4).

The second interim score seeks to provide an appropriate weighting for each threat by taking into account the number and magnitude of different socio-economic impacts on each function and the number of functions associated with the threat (Method 2). It does this for each threat by taking the average of the socio-economic impact values and multiplying this by the number of soil functions that are impacted (Method 2 score in Table 10.4). See Annex 2 for details.

These two interim scores are added together to provide a total socio-economic score which can then be ranked (Table 10.4).

The socio-economic tables in Chapters 3–8 also contain a data status column that can be used to give an overall measure of uncertainty by considering the number of socio-economic impacts for which economic estimates are not available in the literature considered by Glenk et al. (2010) as a percentage of the overall number of impacts. These measures of uncertainty are provided in Table 10.4 for illustrative purposes only and are, therefore, not ranked.

Table 10.4: Relative significance of socio-economic impacts caused by threats to soil functions

Threat	Method 1 score[i]	Method 2 score			Total socio-economic score [v]	Uncertainty (%)
		Average impact score [ii]	Number of functions impacted[iii]	Weighted score [iv]		
Erosion and landslides	23	2.7	6	16	39	23
Changes in soil biodiversity	19	3.2	5	16	35	100
Loss of soil organic matter	16	3.0	5	15	31	63
Sealing	16	2.4	6	14	30	88
Contamination (contaminated land)	17	2.5	5	13	30	53
Compaction	13	2.3	5	12	25	67
Contamination (atmospheric deposition)	8	1.5	4	6	14	100

(i) Cumulative total of highest socio-economic impact score for each soil function (for each threat).
(ii) Average score of all socio-economic impacts (for each threat).
(iii) Number of functions with socio-economic impacts (for each threat).
(iv) Weighted score (rounded to nearest whole number) for each threat (average impact score multiplied by the number of functions impacted).
(v) Total socio-economic score (scoring system 1 score plus weighted score from scoring system 2)

For further details on scoring and methodology see Annex 2.

In terms of socio-economic impacts, the principal threat to soil functions is erosion and landslides. This possibly reflects the disruption to society caused by such events, and the fact that the individual soil functions facing the biggest impacts from erosion and landslides are those on which socio-economic well-being most depends (e.g. provision of food and provision of a stable platform for buildings and transport infrastructure).

Changes in soil biodiversity pose the second most important threat in terms of socio-economics, followed by loss of soil organic matter, soil sealing and contamination (contaminated land), all of which have similar scores. The inclusion of the weighting factors in Method 2 has little influence on the ranking that would have resulted from only considering the scores in Method 1 (Table 10.4). Contamination (contaminated land) slips down the order by a couple of places, but still retains a score that is almost the same as the two main threats.

It was not possible to provide a socio-economic impact score for contamination (excluding contaminated land) because Glenk et al. (2010) did not score this, or any of the categories within, separately; however, they did provide a socio-economic analysis of contamination caused by atmospheric deposition but this cannot be equated simply to any of the separate environmental impact categories.

Levels of uncertainty associated with the socio-economic impacts are generally high, which is simply a reflection of the lack of quantitative data. In particular, there are very high levels of uncertainty associated with changes in soil biodiversity, soil sealing and contamination as a result of atmospheric deposition.

It is important to note the following caveats when considering and interpreting the socio-economic scores:

- most estimates found in the literature have not been developed in a Scottish context. Therefore, even a low level of uncertainty does not guarantee the absolute relevance of these estimates to Scottish soils;
- the assessments are mainly biophysical and do not consider the policy framework relative to the threat (existing legislation, for example, or available funding). This needs to be considered and the final rankings in Table 10.4 should not be used as generalities in a wider context;
- this socio-economic assessment focuses mainly on costs and does not consider the benefits of mitigation and defence actions. These could, however, play a very important role in policy decisions. The direct and indirect benefits of mitigation should be at least as high as the costs occurring without the mitigation in order for mitigation to be considered worthwhile. Therefore, decisions should not be made on the impact scores alone, as they do not consider indirect benefits fully;
- the level of data available for this study was limited (very limited data for Scotland, for example). This means additional work is required to gather data more relevant to Scotland.

Overall, it is important to note that the rankings in Table 10.4 should not be used as the sole basis for policy choices. Nevertheless, it is important to highlight that this is the first time such an assessment has been carried out in Scotland and it is a very important step forward.

10.4 Combined assessment of environmental and socio-economic impacts of soil threats

Finally, it is possible to consider the overall effects of the threats on soil functions by combining the total environmental score (Table 10.2) with the total socio-economic score (Table 10.4). The overall score is presented in Table 10.5.

The totals in the last column of Table 10.5 are ranked from high to low, and indicate that the three principal threats to soil functions are:

- loss of soil organic matter;
- changes in soil biodiversity;
- erosion and landslides.

These are also the threats that are driven by the greatest number of pressures considered in this report (Table 10.1).

This analysis agrees reasonably well with recent analyses [e.g. those in the Scottish Soil Framework (Scottish Government 2009) and in Towers et al. (2006)]. It is a step forward from earlier analyses in that it has been scored by a larger team with wider perspectives than previously and, importantly, includes a socio-economic input for the first time. This reinforces the importance of keeping soils physically intact, the need to maintain appropriate levels of organic matter in soils and the need to protect biodiversity and its role in soil functioning.

There are significant levels of uncertainty associated with this analysis, particularly in relation to contamination (excluding contaminated land), soil biodiversity, and socio-economic impacts in general.

This merely highlights the continued need for a comprehensive monitoring and analysis strategy for Scottish soils.

Table 10.5: Relative environmental and socio-economic significance of threats to soil functions

Threat[1]	Total environmental score (from Table 10.2)	Total socio-economic score (from Table 10.4)[1]	Combined score
Loss of soil organic matter	58	31	89
Changes in soil biodiversity	49	35	84
Erosion and landslides	45	39	84
Soil sealing	48	30	78
Compaction	34	25	59
Contaminated land	17	30	47
Contamination (excluding contaminated land)	18	n/a	n/a
Individual contamination threat			
Acidification and eutrophication	27	n/a	n/a
Metals	22	n/a	n/a
Pathogens	16	n/a	n/a
Radioactive substances	14	n/a	n/a
Organic chemicals	12	n/a	n/a

[1] Socio-economic scores are not currently available for metals, pathogens, radioactive substances and organic chemicals; only atmospheric deposition and contaminated land were rated as a threat by Glenk et al. (2010)

11 Future prospects for Scotland's soil resource

Since the publication of the first SEPA State of Soil Report ten years ago (SEPA, 2001), the importance of soil has become more widely recognised. Land is now expected to provide multiple benefits (Scottish Government, 2010), and healthy soil is fundamental to delivering these. Policy development needs to take full account of the wide range of benefits and ecosystem services that soils provide, while also recognising the interactions and possible conflicts between different policy areas (Box 11.1).

Box 11.1: Soils in Scotland – what do we need to know?

- In what circumstances are Scotland's soils a source or sink of carbon? How much are soil carbon stocks changing? (Chapter 3)
- Are greenhouse gas emissions from soils reducing or increasing? By how much? (Chapter 3)
- What are the effects of soil management practices on mitigating climate change, diffuse pollution and flood-risk? (Chapters 3, 6, 7, 8)
- Which soils are being used as a platform for development and what is the ecosystem impact? (Chapter 4)
- How do we maintain or improve the ability of soils to produce high yields of good quality produce sustainably? (Chapters 3, 5)
- How do we maintain healthy soil biodiversity able to support ecosystem services? (Chapter 6)
- How do we maintain a good soil structure and also control soil erosion and landslides? (Chapters 7, 8)
- What harm is being caused through contamination of land and how is this best controlled? (Chapter 5)
- How do we incentivise land managers to carry out good soil management practices?
- Are all of the above contributing to the sustainable use of soil and its protection for future generations?

NB, these are examples and not an exhaustive list.

The report highlights that good soil quality is key to the delivery of multiple benefits. Soil management can justifiably be recognised as a key part of the solution to wider issues such as climate change, food security, water quality and flood risk mitigation. It is therefore vital that soils are protected so that they can continue to provide their essential functions.

While the multifunctional role of soils is recognised as being important, it is clear that certain soils in particular areas of Scotland have specific characteristics that predetermine what functions they can best provide, and will be considered as being of higher value for those specific functions. For example, the blanket bogs of northern Scotland are a vast carbon store on a European scale, as well as being of high conservation value for the biodiversity they support. The prime agricultural land of eastern Scotland produces world-leading crop yields. It can be argued that these soils, and others with specific values, should be prioritised for protection to ensure those functions continue into the future.

In the future, the challenges facing Scotland's soil will be to understand and deal with a number of issues including:

- the need for policy integration: understanding the role of soil in existing policy and developing recommendations for future soil policy to ensure soil is sufficiently protected;
- tackling the lack of systematic Scottish soil data: understanding what is already available, identifying gaps and making recommendations for future soil monitoring needs;
- understanding soil management and providing recommendations for targeting management options to address the key threats to soil.

Addressing these issues will increase our understanding of soils and thus improve soil protection and soil quality. Sustainable soil management should be recognised as part of the solution to a number of the key issues that the world faces; combining these three areas of policy, data and the implementation of practical solutions will help progress this approach.

11.1 Understanding the role of soil in existing policy and recommendations for future policy development

A recent review of soil policy in the Scottish Soil Framework (Scottish Government, 2009) showed that in Scotland, and in the wider EU, soil has not been given the same level of protection as the water and air environments. This is partly due to the long timescales over which soils respond to pressures and to difficulties associated with regulating a resource that is primarily in private ownership. It is also due to the fact that although there are many existing EU provisions that have some elements of soil protection, there is currently no Directive that specifically protects soils in their own right. This is a major gap in the current soil protection regime and the importance of soil as a non-renewable resource essential to a sustainable environment needs to be more fully recognised by overarching soil protection measures.

The Scottish Soil Framework (Scottish Government, 2009) recognises the need for greater policy integration across the areas where soils are involved, including planning, agriculture, climate change, biodiversity and waste. The Soil Focus Group (Scottish Government, 2009), which includes representatives from organisations representing land owners and land managers, as well as government, government agencies and the main research providers, is working towards this end. Greater policy integration should identify better opportunities for multiple benefits, capitalising on the multifunctional role of soils; for example, organic matter addition to soil not only has benefits for climate change but also improves soil structure, increases water-holding capacity, and reduces the impact of a number of threats to soil such as erosion.

The Draft Land Use Strategy for Scotland (Scottish Government, 2010) identifies an integrated approach to land use as being key to ensuring sustainable use of the land resource. Many of the objectives of the Draft Land Use Strategy rely directly on healthy soils. It is essential to ensure that there are no pollution swapping implications of measures implemented to achieve multiple benefits; indeed this is the main argument for increased policy integration.

Policy recommendation one: review and, if necessary, revise current legislation and guidance documents and codes of practice to ensure adequate soil protection.

There are a number of specific areas that perhaps require early attention. These are listed below.

Good Agricultural and Environmental Condition (GAEC)

As explained in earlier chapters (3, 7 and 8), inappropriate soil management options can increase the risk of soil degradation through loss of soil organic matter, erosion and compaction. In order for land managers to receive their Single Farm Payments under the Common Agricultural Policy, they must keep their land in Good Agricultural and Environmental Condition (GAEC). A number of the measures under GAEC have been developed to help protect soil and, in particular, to prevent soil erosion and compaction and to maintain soil organic matter. However, there is scope to further develop these measures to improve soil protection. Any new measures developed would have to be adequately implemented and enforced, and would require developing guidance and training for inspection staff to equip them with the expertise required to assess and offer advice on soil protection measures.

> **Policy recommendation two:** review and, if necessary, develop further guidance and measures on Good Agricultural and Environmental Condition (GAEC) and ensure farmers and inspectors receive adequate information and/or training.

Maintenance of soil organic matter content

However, GAEC only covers soils where land managers are in receipt of the Single Farm Payment. In particular, it does not cover the vast majority of Scotland's highly organic soils. There is evidence that these soils may be increasingly vulnerable to processes such as erosion (Chapter 7) which can, in part, be due to land management practices such as drainage and burning, and to effects associated with climate change (Chapter 3). However, there is currently little protection of soil carbon from land use change and land management practices. Therefore there may be a need for certain activities to be controlled, for example intensive drainage of peat soils.

> **Policy recommendation three:** review and, if necessary, further develop guidance and measures to protect soil organic matter across all soils. This includes guidance for agriculture, forestry, biofuels, renewable energy (including windfarms) and other developments that may impact on soil carbon.

Climate change

It is clear that climate change may have a serious impact on soils in a number of different contexts (see Tables 3.1, 6.1, 7.1 and 8.1, for example) but the existing soil protection policy framework is not set up to consider the potential impacts of climate change on soils or, for that matter, on the potential impact of soils on climate change. It is essential that policies are integrated to ensure that land users know exactly what soil use and management practices are beneficial for storing carbon in soils and preventing greenhouse gas emissions from soils, including how to prevent pollution swapping. There is also a need for planning authorities to put more weight on the protection of soil functions, particularly in relation to carbon storage.

> **Policy recommendation four:** soil policy needs to be integrated with the Climate Change (Scotland) Act (2009) and better focussed on adaptation and mitigation measures, taking into account pollution swapping issues.

Scotland Rural Development Programme (SRDP)

The Scotland Rural Development Programme (SRDP) already contains several measures to support management practices that help protect soils. However, it would be useful to consider, taking into account the findings of this report, what additional measures could be developed under SRDP to provide incentives for land managers to protect soil.

> **Policy recommendation five:** review and, if necessary, develop further Scotland Rural Development Programme (SRDP) measures to help protect soils.

Application of organic materials to land

There is increasing pressure to apply organic materials to land as waste is diverted from landfill. Organic materials (e.g. livestock manures, composts, sewage sludge) can be a useful source of organic matter and nutrients, and can help promote crop growth (see Chapters 5 and 6). Existing legislation covers the application or sewage sludge to land and some non-agricultural organic wastes to land where an agricultural or ecological benefit is obtained; however, only certain land uses and potential pollutants are covered. There is insufficient information available about the effects of applying some organic materials to land and, thus, there is a need to develop research to assess the impact on soil of applying such materials. There is also a need to develop a strategic management tool that will quantify and locate, temporally and spatially, the regional and national capacity of soil to accept organic materials. This should include on-farm produced organic materials; although they are not classified as wastes, they are the main constraint on future opportunities for recycling off-farm wastes. Any risks of pollution swapping also need to be considered.

> **Policy recommendation six:** review and, if necessary, revise Regulations and/or improve guidance on the application of organic materials to land.

Diffuse pollution

Soil management has been identified as the largest contributor to the diffuse pollution of watercourses in Scotland (see, for example, Chapters 7 and 8). The Water Framework Directive (WFD) established the need to control inputs of pollutants to surface or groundwater and to control activities posing a risk to the water environment. However a large number of rivers and groundwater bodies are at risk of not meeting the WFD environmental objectives due to diffuse pollution as a result of poor soil management. Good soil management is therefore key to controlling rural diffuse pollution. Reducing soil erosion and compaction, for example, will not only improve soil quality but will have the additional benefits of reducing sediment and phosphorus loads in watercourses.

> **Policy recommendation seven:** implement an active awareness-raising campaign amongst land managers of the importance of good soil management to mitigate diffuse pollution (see Rural Diffuse Pollution Plan for Scotland [4]).

[4] http://www.sepa.org.uk/water/river_basin_planning/diffuse_pollution_mag.aspx#DP_Plan

Planning and soil sealing

Land, particularly that close to existing infrastructure, continues to be under pressure from development (see Chapter 4) and, based on evidence from the 1970s and early 1980s, much of this is on high quality agricultural land at a time when, locally and globally, food production and food security is under increasing threat. There appears to be inadequate weight given by planning authorities to protecting prime agricultural land and protecting the soil resource in general across non-prime agricultural land. Measures to mitigate the impact of soil sealing could be introduced, including: examining the footprint of proposed developments; maintaining the functionality of soils on parts of development sites that need not be sealed; and ending practices that treat soil as waste.

The planning system needs to include safeguards on land use and maintaining soil quality, in particular carbon stocks, with appropriate guidance in National Planning Policy Guidelines and Planning Advice Notes. There is also a need for planning officers to be trained on this issue, as most will not have any previous experience of considering soils in detail.

> **Policy recommendation eight:** review and, if necessary, develop further Guidelines and Advice to protect valued soils or specific soil functions during development.

Stakeholder engagement and knowledge exchange

A regulatory approach on its own will not achieve the required level of soil protection. Education and raising awareness of the importance of soils with both land managers and the general public will play a key role in the future sustainable use of soil. Both specialist stakeholder groups and the general public need to be made aware of the value of soil, the benefits of maintaining good soil quality and of the economic incentives and regulation in place to help achieve sustainable soil management.

Land managers need to be made fully aware of their role in the maintenance of soil quality. Awareness of good soil management has an important role to play in minimising physical damage and loss of soil, minimising the impacts of contamination, conserving current carbon stocks and minimising future emissions of greenhouse gases from soils. There is a continuing need to encourage application of the Codes of Good Practice relevant to soil protection, for example the Prevention of Environmental Pollution from Agricultural Activity Code (PEPFAA Code).

> **Policy recommendation nine:** the stakeholder Soil Focus Group should advise on suitable awareness raising campaigns and knowledge exchange needs.

11.2 Tackling the lack of systematic Scottish soil data – present situation and future outlook

Throughout this report it has been recognised that although there is a considerable amount of existing data, there is still a lack of systematic data available to allow an assessment to be made on the state of Scotland's soil and how it is changing through time. There is, therefore, a need for soil monitoring in Scotland and this has been recognised in the Scottish Soil Framework (Scottish Government, 2009). The rationale for soil monitoring needs to be supported by clear evidence of a threat to soil. In addition, a robust monitoring scheme should not be constrained by current issues and should be designed to ensure flexibility to accommodate any future issues that may arise.

The analysis of the impacts and threats in relation to soil functions in Chapter 10 provides information that helps the prioritisation of a soil monitoring programme. These priorities will need to be assessed in the context of resources, logistics and how they relate to the wider environment. Such a scheme should, therefore, be part of a wider national scale surveillance monitoring network that links soil, water, air and vegetation monitoring. Integrating monitoring activities across the environment is the objective of the Scottish Monitoring Strategy being developed by the Coordinated Agenda for Marine, Environment and Rural Affairs Science (CAMERAS).

Firstly, however, it is necessary to identify the gaps in existing data.

11.2.1 Bringing together existing data

Despite the recurring theme of lack of suitable data being available to assess the condition of Scotland's soil and how it is changing through time, this report shows that a considerable amount of high quality soil data has been produced for Scotland (described in Annex 1). This may appear to be a contradiction. However, existing data has been collected for a variety of purposes, using a range of sampling and analysis techniques, by a number of different organisations and so it is not always possible to compare it. In addition, data are stored in a number of formats in a range of locations. There is also a lack of data for current key policy areas, for example the effect of soils on climate change and vice versa.

It is desirable that all existing data are brought together or, at least, a catalogue of available data assembled that includes information on where it can be found to allow easy access to existing data and to allow key data and information gaps to be identified. This would inform any future soil monitoring needs.

The Scottish Government is developing proposals to improve the availability of soil data such as the Soil Indicators for Scottish Soils (SIFSS) interactive tool that allows users to compare their soils with national averages. Another initiative is the collaboration of a range of Scottish organisations in the development of the Scotland's Environment website. Increased access and use of data should have the desired effect of raising awareness of the value of soil across a wider range of stakeholders.

11.2.2 Soil monitoring requirements

Soil monitoring is required in Scotland on two levels. A surveillance soil monitoring network is required that can provide a general overview of the condition of Scotland's soil and how it is changing through time. This should allow monitoring of existing threats on a national scale and potentially identify as yet unknown threats. This will also provide data for trend analysis.

In addition, this report identifies specific existing threats to soil quality that should be monitored in a targeted fashion to enable their progress or recovery to be assessed. The following focused monitoring programmes could be developed. This list should not be seen as exhaustive but indicative of some of the key concerns.

Soil organic carbon content

Recent evidence from outside Scotland (Bellamy et al., 2005) suggests that loss of carbon from peaty soils could represent the most serious risk to Scottish soil carbon stocks. However, it is not known whether the total amount of organic carbon present in soil is changing because most previous studies do not consider the whole soil profile (Chapter 3). This highlights a potentially crucial gap in knowledge. Because of the major implications for climate change of a loss of a small percentage of soil carbon, a monitoring programme should be initiated to measure and monitor organic carbon stocks in soil to ensure measures can be put in place to prevent future carbon loss, if necessary.

Monitoring the impacts of soil quality on water quality

Although good soil management can benefit soils and the wider environment, poor soil management can lead to virtually all of the threats considered in this report, i.e. loss of organic carbon, contamination, changes in biodiversity, erosion and compaction. The resulting loss of soil functions, for example controlling and regulating environmental interactions, can have wider environmental consequences. For example, as described above, diffuse pollution is the largest pollution pressure on the water environment in Scotland and poor soil management is a major contributor. A rural diffuse pollution plan for Scotland has been drawn up to reduce rural diffuse pollution[5]. Current diffuse pollution monitoring focuses on 14 priority catchments; however, there are no direct measurements of soil quality incorporated. Including measurements of soil quality in these catchments would offer an opportunity to assess soil quality and any resulting impacts on the water environment. If any impacts on water quality as a result of soil quality were identified it would allow measures to be put in place to protect soil quality and prevent diffuse pollution occurring.

Monitoring the impact of recycling of organic materials to land

As described above, recycling organic materials on land can be beneficial to soil quality and increase carbon sequestration. However, if poorly managed, application of organic materials to land has the potential to result in the contamination of soil with metals, organic chemicals, nutrients and pathogens. SEPA currently carries out soil monitoring to check compliance with the relevant regulations (SEPA SCM). However, current legislation, and, therefore, current SEPA monitoring, does not cover all organic materials spread on land, or all potential contaminants. Soil monitoring should be extended following a risk-based approach, based on the type of soil and organic materials applied, to ensure soil quality is not damaged by the expected expansion of this activity (see Chapter 5).

11.2.3 Development of monitoring methodologies

It is essential to design an appropriate soil monitoring network with adequate soil quality indicators to meet Scotland's soil monitoring needs. For example, a targeted monitoring network set up to measure soil carbon stocks may well be different to that required for a national soil surveillance monitoring network. Much work has already been carried out to determine suitable soil quality indicators and on the design and implementation of national monitoring schemes (e.g. UK Soils Indicator Consortium: SNIFFER, 2006; Environment Agency, 2008); however, as yet these have not been taken forward. The design of any future soil monitoring networks in Scotland should take account of this work, along with the outputs from the 2006–2011 Scottish Government funded research programme, with respect to the most appropriate field sampling methods, analytical techniques and indicators, and the targeting of specific areas for identified threats. In addition, any future monitoring schemes should meet the needs of the proposed EU Soil Framework Directive (European Commission, 2006). This may require Member States to prepare risk maps for major threats and proposed options for effective mitigation of soil damage over a 25-year period following first identification of potential risk.

The evidence presented in the State of Scotland's Soil report can be used to demonstrate which threats are particularly important in a Scottish context and can thus be used to inform more targeted risk-based mapping (Chapter 10).

11.2.4 Research and development requirements

It is evident from this report that there is a continuing requirement for new research. At a general level some of the key questions that need to be addressed by research and monitoring efforts related to soil are outlined in Box 11.1 One of the key priorities is the development of methodologies to assess the 'ecological status' of soils.

[5] http://www.sepa.org.uk/water/river_basin_planning/diffuse_pollution_mag.aspx#DP_Plan

11.3 Understanding soil management – recommendations for targeting management options for key threats to soil

The analysis of pressures, threats and impacts on soil functions and the wider environment and society and relative ranking of the potential impacts of the threats on soil function developed in this report can be used to refine our understanding of management options and land use choice available to protect the soil resource.

The main threats to soil function identified in Chapter 10 are loss of organic matter, change in soil biodiversity, erosion and landslides and soil sealing. Contamination, by metals and radioactive substances, was identified as having a lesser impact on soil functions primarily due to the relatively low cumulative impact of these issues (Table 10.2). The prioritisation of threats in chapter 10 could inform any future monitoring set up to identify the state of soil quality and how it is changing through time, as well as the effectiveness of measures put in place to protect soil and the wider environment.

Objectives have been identified in Table 11.1 which, if achieved, will contribute to minimising or negating individual threats and/or remediating their impacts. A number of mitigation options and measures have also been identified to help achieve these objectives and ensure the sustainable use of the soil resource. This may require a review of current policy and guidance to promote integration across the wider environment as recommended in this report and in the Scottish Soil Framework (Scottish Government, 2009). The list is not intended to be exhaustive but serves to illustrate the range of opportunities available to ensure soils remain in good health.

It is important to note that there are already a number of good practice guides and voluntary codes in place that are being followed successfully by different sectors, and there are opportunities for them to be further developed, perhaps using the Soil Focus Group as the key mechanism. It is not possible to assess the effectiveness of these measures at the present time because of insufficient soil data and resources for monitoring.

Although each threat has been described individually, it must be recognised that there is a large degree of synergy between them, for example reducing soil compaction reduces the risk of soil erosion.

Table 11.1: Suggested management options for mitigating and remediating impact of threats on soil quality

Threat	Objective	Suggested options
Loss of soil organic matter	Maintenance and enhancement, where appropriate, of soil organic matter content	• Raise awareness of the importance of soil organic matter with land managers • Increase consideration in the planning system for protection of existing soil carbon stock • Maintain/enhance and restore peat-forming processes in degraded peatlands • Consider the value of the addition of organic materials to agricultural land as part of a farm carbon balance • Consider alternative soil management strategies to increase soil organic matter content • Improve farm carbon budgeting models • Reinforce relevant measures under Cross Compliance (GAEC) • Reduce and phase out the use of peat in horticulture
Erosion and landslides	Reduce the likelihood of soil erosion and landslide events	• Development of, and adherence to, good practice guidance relating to soil and land use management [e.g. Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) Code and the relevant Forestry Guidelines]. • Promoting and reinforcing measures under Cross Compliance (GAEC) and the Diffuse Pollution General Binding Rules. • Planning – ensure suitability of sites before development and management of soil overburden control.
Change in soil biodiversity	To develop a more comprehensive understanding of Scottish soil biodiversity and its role in soil functions	• Ensure that measures or regulations aimed at minimising other threats to soil also explicitly consider soil biodiversity • More baseline information on diversity and functionality is required

Threat	Objective	Suggested options
Sealing	Ensure soil is considered at the new development planning stage and encourage the use of alternative technologies that maintain soil functions during development	• Retention of green space within development proposals • Methodologies for retaining some elements of soil functionality even where development takes place such as access tracks and car parking • Landscaping that provides for full soil functionality • Drainage measures that avoid 'hard' solutions and provide for full soil functionality • Sustainable use of soils on development sites • Restoration of suitable Brownfield sites to uses providing full soil functionality and re-use of 'hard' Brownfield land in preference to land that contains unmodified soil • Locations for new developments to consider issues such as flooding risk and erosion • Use of Sustainable Urban Drainage Schemes (SUDS)
Contamination	Better integration of soil in current and new legislation to ensure that soil and the wider environment is protected	• Ensure that legislation and/or guidance on use of organic materials on land is sufficiently protective • Consider whether legislation may need to be extended to include materials and potential pollutants not previously considered, taking into account new evidence • Use of Nutrient Management Plans and soil analysis, particularly in areas at risk of diffuse agricultural pollution • Soil to be included as a receptor with respect to emissions from Pollution Prevention and Control (PPC) plants

Threat	Objective	Suggested options
Compaction	Reduce soil compaction and its associated local and wider impacts	• Follow good soil management guidelines at all phases of the seasonal farming cycle • Avoid overgrazing and trampling by animals (domestic and wild) • Reinforce measures under Cross Compliance (GAEC) • Use of advanced technologies controlling traffic, for example Auto-drive global positioning system (GPS) farming machinery to avoid multiple wheel passes, or other one-pass cultivation systems, for example minimum tillage • Limit axle weight of machinery; this could be soil- and/or season-specific • Raise awareness in identifying and rectifying soil compaction
Emerging issues	Measures can not yet be proposed because of the many remaining uncertainties but, where possible, the precautionary principle should be followed. A watching brief should be kept on new research findings.	

11.4 Concluding remarks

On the protection of Scotland's soil

Soil is a key and very complex natural resource that provides us with essential services for life on our planet including food production, water purification and protection against flooding, valuable habitats, recreation areas and, crucially, climate regulation. Scottish soils are distinctly different to soils elsewhere in the UK and they require specific management guidance and protection strategies.

Scotland's soil supports the agricultural, horticultural and forestry industries and the high quality products they produce. Crucially, soils also make the largest contribution to terrestrial carbon storage in the UK and, therefore, must be managed properly to prevent increasing greenhouse gas concentrations in the atmosphere. In addition, Scotland's beautiful landscapes and habitats of national and international renown are a direct result of soils and their management. The generally good water quality of Scotland is somewhat dependent on soil management and its impact on diffuse pollution. Soil management also impacts flood risk. Scotland's soil, air and water environments are therefore linked and interact. Consequently, it is vital that future policy developments in Scotland take this into account, i.e. that the soil, air and water environments are viewed as a whole and that each component is given equal importance.

On the threats to Scotland's soil

Soil quality in Scotland is at risk from a number of threats that are driven by a range of pressures including climate change, land use management and land management practices (Table 11.2). Clearly, the priority now is to address the main threats and also to consider whether the pressures can be reduced.

Table 11.2: Main pressures and threats acting on soil

Main pressures	Main threats
Climate change Development/transport Agricultural cultivation Forestry cultivation Agriculture - application of chemicals Stocking density/grazing	Loss of soil organic matter Changes in soil biodiversity Erosion and landslides Soil sealing Compaction Contaminated land

Although climate change can adversely affect soil functions, it should also be stressed that soil management plays an important role in mitigating climate change. The implementation of appropriate soil management practices will not only protect soils but will also contribute to protecting the ecosystem services to which these soils contribute. Soils can be part of the solution to many environmental problems and should be viewed in that way.

On the sustainable use and management of Scotland's soil

Soils are fundamental to the well-being of Scotland and particularly so at a time of potentially unprecedented environmental and economic change. This report proposes options for sustainable soil use and management (Section 11.3). These may need further or ongoing refinement in line with any adaptation and mitigation necessary in relation to future climate change.

Not all activities that may be damaging to soil are fully subject to regulatory control. Some activities are subject to guidelines and codes of practice that have varying degrees of statutory status. Promoting the adoption of good practice through awareness raising, dialogue and published guidance continues to be a key mechanism to protect soils.

The need for sound scientific evidence when developing a more strategic approach towards soil protection policy or guidance continues to be essential. There is a strong need to develop a soil monitoring program that allows for the state of soils in Scotland to be better understood, and to determine whether policies result in an improvement or deterioration in soil quality with time.

On the responsibility for Scotland's soil

Responsibility for the future of Scotland's soil, and indeed land, rests with all of Scotland's people. However, organisations and research bodies that have direct involvement with, and responsibility for, soil have a duty to ensure that the wider public are continually informed of its value. The development of this report has brought together soil scientists, policy makers, regulators, economists and land managers, and furthered the considerable consensus and extensive partnership working in Scotland on soil issues. This partnership working on soil should be continued, particularly through the Soil Focus Group and other relevant stakeholder groups.

Soil is the unseen and often forgotten component of the environment but the authors and organisations associated with this report hope that it will raise awareness of soil and all that it delivers to the environmental, economic and social well being of Scotland.

In 1937, the United States President, Franklin Roosevelt, summarised the importance of soil protection when he stated "A Nation who destroys its soil, destroys itself." This important and insightful statement is also relevant for Scotland – both now and in the future.

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Glossary and list of acronyms

BGS	British Geological Survey
Bioavailability	The proportion of an added substance that is available for incorporation or use by, or impact on, biota
Brownfield sites	In the UK a brownfield site is defined as "previously developed land" that has the potential for being redeveloped. It is often (but not always) land that has been used for industrial and commercial purposes and is now derelict and possibly contaminated
CEH	Centre for Ecology and Hydrology
CH_4	Methane – a greenhouse gas
CO_2	Carbon dioxide - a greenhouse gas
Critical load	A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge. A critical load refers to deposition of pollutants
Critical load exceedance	When pollutant loads (or concentrations) exceed the critical load (or critical level) it is considered that there is risk of harmful effects. The excess over the critical load or level has been termed the exceedance
Defensive cost	Cost of defensive measures – cost to prevent and reduce negative off-site effects
Defra	UK Department for Environment, Food and Rural Affairs
Dissolved organic carbon	Dissolved organic carbon is the fraction of aqueous organic carbon which passes through a filter (filters generally range in size between 0.7 and 0.22 μm)
DPSIR	Driver – Pressure – State – Impact - Response
Ecosystem services	A term used to describe the goods, benefits and costs to society delivered through the functioning of an ecosystem
Eutrophication	The result of excessive enrichment with nutrients. Specifically in the water environment, eutrophication may cause an increase in the accelerated growth of algae in the water column and higher forms of plants living on the bottom of the sea. As the algae die and decompose, high levels of organic matter and the decomposing organisms deplete the water of available oxygen, causing the death of other organisms, such as fish
FCS	Forestry Commission Scotland

Greenhouse gas	Refers to all gases in the atmosphere that absorb and emit radiation within the thermal infrared range and are considered as the fundamental cause of the greenhouse effect. Greenhouse gases include: water vapour, CO_2, CH_4, N_2O, chlorofluorocarbons
Greenfield site	Greenfield sites are areas of land, usually agricultural or amenity land, which are being considered for urban development
HS	Historic Scotland
Infill development	Infill development is the use of land within a built-up area for further development
IOM	Institute of Occupational Medicine
Magnitude of pressure/ Impact	Defined in this report as the significance of pressure/impact, e.g. a high magnitude pressure has a very significant impact on the threat in question and a high magnitude impact on function is one that is likely to lead to serious impairment or loss of that function (see annex 2)
Mechanical impedance	A measure of how much a structure resists motion when subjected to a given force
Mitigation cost	On-site (private) costs of mitigation – cost arising from effort to (partially) restore the capacity of soil to provide ecosystem services
MLURI	Macaulay Land Use Research Institute
N_2O	Nitrous oxide - a greenhouse gas
Non-use cost	Non-use costs – all costs that are not related to direct or indirect use of soil
Off-site costs/benefits	Impacts spatially disconnected from the land that are subject to change driven by a soil threat
On-site costs/benefits	Impacts that occur on or within the land itself
Organic soil	In Scotland this corresponds to peat soils characterised by the presence of a surface peat layer containing more than 60% of organic matter and at least 50 cm thick
Organo-mineral soil	In Scotland this corresponds to soil with an upper organic horizon with more than 20 % of organic matter and more than 10 cm but less than 50 cm deep, or more than 10 cm of surface horizon with 30–60% organic matter
Organic-rich soil	Organic and organo-mineral soils
Polycyclic aromatic hydrocarbon (PAH)	PAHs form a class of diverse organic compounds, each of them containing two or more aromatic rings
Particulate organic carbon	Aqueous carbon that is filtered out of a sample
Polychlorinated biphenyls (PCBs)	A group of toxic and persistent chemicals that can cause severe environmental and health effects

Persistent organic pollutants (POPs)	Chemical substances that persist in the environment, bioaccumulate through the food web, and pose a risk of causing adverse effects to human health and the environment
Private cost	On-Site (private) cost – cost associated with loss or decline of soil's capacity to provide ecosystem services (have a direct impact on land owners and land managers)
RERAD	Scottish Government Rural and Environment Research and Analysis Directorate
Reversibility	Defined in this report as the degree to, and timescale within, which a pressure on a threat or impact on a function can be reversed (see Annex 2)
SAC	Scottish Agricultural College
SCRI	Scottish Crop Research Institute
SEPA	Scottish Environment Protection Agency
SG	Scottish Government
SNH	Scottish Natural Heritage
Social cost	Off-site (social) costs – cost arising from negative externalities
Soil acidification	The process whereby soil pH decreases over time. It is a natural process but can also be enhanced by atmospheric deposition of sulphur (S) and nitrogen (N)
Soil acidity or pH	Soil pH is a measure of the concentration of hydrogen ions in the soil water. It is an important factor in the availability of plant nutrients and potential pollutants
Soil organic carbon	Soil organic carbon refers to the organic carbon stored in the soil. It is often expressed as a percentage by weight or as g C/kg soil. Soil organic carbon can be expressed as soil organic matter through a simple multiplication factor, usually taken as equal to 1.72 in mineral soils and closer to 1.92 in organic soils
Soil organic matter	Soil organic matter refers to all organic material present in the soil including the remains of plants and animals at varying stages of decomposition and the living plant and animal material on and below the soil surface
Soil pathogens	A biological agent that causes harm to its host (in this case soil)
Topsoil	Topsoil is the upper, outermost layer of soil, usually the top 5–30 cm. It has usually the highest concentration of organic matter and microorganisms and is where most of the Earth's biological soil activity occurs
Trends	Decrease, increase or no change over timescale of impact or pressures (see Annex 2)
UKBRC	UK Biochar Research Centre
Uncertainty	Defined in this report as how well the pressure on the threat or impact on the function is characterised and quantified (see Annex 2)

Annex 1 Soil monitoring and surveillance schemes and data sources

This annex describes some of the key information on Scotland's soil resource. The most comprehensive dataset is the Scottish Soils database (including the National Soil Inventory of Scotland) held by the MLURI. There are a large number of other data however, that have been collected for specific regulatory (e.g. SEPA), advisory (e.g. SAC), monitoring (e.g. MLURI, CEH, BGS) or research purposes (e.g. Scottish Universities).

This annex list describes the main monitoring schemes and data sources for Scotland under 5 categories:

- C1 - Scottish soil database;
- C2 - Regulatory database;
- C3 - Advisory database;
- C4 - Monitoring / surveillance database;
- C5 - Research and site specific database.

The information presented here is adapted from the following reports:

1. The SNIFFER Project LQ09 "National Soil Monitoring Network: Review and Assessment study" (2006) that was carried out as a stocktaking exercise of all environmental monitoring schemes in place (UK and EU) that may be useful in the context of soil monitoring and to assess whether these existing monitoring schemes could fit into a UK network for soil monitoring, highlighting data and spatial gaps and recommending improvements that could be made.
   - http://www.sniffer.org.uk/Webcontrol/Secure/ClientSpecific/ResourceManagement/UploadedFiles/SNIFFER Soil Monitoring Catalogue LQ09 Dec 2006(1).xls.

2. Towers et al. (2006). Report on the current state and threats to Scotland's soil resource. This provides detailed information on soil profile descriptions and analytical data from samples and sample material. It also includes information on soil maps, soil memoirs and digital soil information available in Scotland.
   - http://www.scotland.gov.uk/Publications/2006/09/21115639/0.

3. Chapman et al. (2009). Expert workshop to establish the current state of knowledge of and future evidence needs for the extent and condition of carbon stocks in Scottish peatlands. Final Report. This includes lists of small survey sites and manipulation sites not listed below.
   Information has been updated to include recent RERAD research programme activities and other surveillance and monitoring schemes.
   - http://www.scotland.gov.uk/Publications/2010/02/19145611/0.

Table A1-1: List of Scottish soil information schemes

	Soil schemes	LQ09 Scheme abbreviation	2006 report abbreviation	In text abbreviation	Cat
1	National Soil Inventory of Scotland	NSIS + NipAqua	NSIScot	NSIS_1	C1
2	National Soil Inventory of Scotland - resampling	n/a	n/a	NSIS_2	C1
3	Representative Soil Profiles of Scotland	RSPS	RSPS	RSPS	C1
4	Soil map unit transect study	SSMUTS	None used	SSMUTS	C1
5	Grid or transect Surveys in Scotland	Grids_Scot	None used		C1
6	Trends in pollution of Scottish Soils	TIPSS	TIPSS	TIPSS	C1
7	Countryside Survey	CS	CS	CS + *year*	C4
8	Monitoring and Assessing Soil Quality. Part of CS2000.	Not described	MASQ		C4
9	Environmental Change Network	ECN	Not described	ECN	C4
10	BioSoil	BioSoil	Not described	BIOSOIL	C4
11	Level I Forest Conditions survey	Level I	Not described		C4
12	Level II Intensive Monitoring of Forest Ecosystems	Level II	Not described		C4
13	ITE/NCC 'Bunce 1971' woodland survey	NCC woods	Not described		C4
14	UK Soil and Herbage Survey	EA_Soils	Not described	UKSHS	C4
15	Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility.	Sludge	None used	Sludge Exp	C5
16	SEPA's soil compliance monitoring	Not described	None used	SEPA SCM	C2
17	SEPA Harmonized Monitoring Scheme – loch and river	Not described	Not described	HMS	C2
18	Scottish Soil Fertility Information System pre-1996	Not described	SSFIS1996	SSFIS1996	C3
19	Scottish Soil Fertility Information System post-1996	Not described	SSFIS1996+	SSFIS1996+	C3
20	Geochemical Baseline Survey of the Environment	G-BASE		G-BASE	C4
21	Geochemical Survey of Urban Environments	GSUE	GBASEURBAN	G-BASE urban	C4

22	Forum of European Geological Surveys European Geochemical Atlas	FOREGS	Not described		C4
23	Land Use/Cover Area frame statistical Survey	n/a	n/a		C4
24	National Countryside Monitoring Scheme	Not described	Not described		C4
25	SQuID	n/a	n/a	SQUID	C5
26	NERC Soil Biodiversity Programme	Not described	Not described	NERC SoilBio	C5
27	SEERAD - Micronet programme on soil microbial ecology.	Not described	Not described	Micronet	C5
28	UK biodiversity action plans	Not described	Not described		C3
29	SNH Site conditions monitoring	Not described	Not described	SCM	C4
30	Scottish Earthworm Survey	Not described	Not described	SEWS	C5
31	Moorland colonisation by birch and pine, and the consequences for biodiversity.	Not described	Not described	MOORCO	C5

n/a not set up at time of reporting in report

Scheme 1 **NSIS_1**

National Soil Inventory of Scotland (NSIS) and Aqua Regia digests of National Soil Inventory Topsoil Samples.

The NSIS is a subset of the National Soils Database of Scotland (MLURI). The sample framework is a 5 km grid based on the National Grid of Great Britain. The data comprise a site and soil profile description at each 5 km intersect of the National Grid. Soil horizon samples were collected at the 10 km intersects and some 5 km intersects. The bulk of the profiles were collected during field work for the 1:250 000 soil survey of Scotland. The remainder were collected in three subsequent years from areas that had been previously surveyed.

The data provide an unbiased sample to characterise soil distribution and quantify variability in soils and properties at a broad, regional scale in Scotland and to quantify heavy metal concentrations in Scottish topsoils.

The data provide good estimates of means and regional variations in a range of soil properties and attributes. They inform the soil classification for Scotland and are used with soil map information to estimate the regional variation in soil properties. Along with data from Scheme 3, they are used with pedotransfer functions to derive other datasets. These data have been used to evaluate the current state of various threats to soil in this project.

Information collected: depth to top of sample; depth to base of sample; loss on ignition; percentage international sand; percentage international silt; percentage international clay; percentages of United States Department of Agriculture (USDA) or British Soil Texture Classification (BSTC) sand and silt; calcium; magnesium; sodium; potassium; exchangeable acidity; sum of cations; base saturation; pH in water; pH in calcium chloride; carbon; nitrogen; C/N ratio; organic matter; total phosphate; and visual assessment of soil moisture at 1 m. In addition to soil parameters measured for NSIS, topsoils were analysed for calcium; sodium; potassium; magnesium; copper; zinc; iron; manganese; aluminium; phosphorous; nickel; cadmium; chromium; cobalt; lead; strontium; molybdenum; titanium; and barium.

- Brown, K.W.M et al. (1987). Design of a database for Scottish Soils, *Journal of Soil Science*, **38**, 267–277.
- Paterson, E., Towers, W., Bacon, J.R. and Jones, M. (2003). Background levels of contaminants in Scottish soils. Final Contract Report to SEPA. [online] www.sepa.org.uk/science_and_research/idoc.ashx?docid=a4f15184-32cf-411e-8c66-1434d47f324e&version=-1 (checked 28 February 2011).

Scheme 2 **NSIS_2**

National Soil Inventory of Scotland–resampling

This is a partial resampling of NSIS_1 on a 20 km grid based on the National Grid of Great Britain. One hundred and eighty-five sites were revisited and, depending on soil type and profile characteristics, between 15 and 30 soil samples were taken at each site.

In addition to the profile bulk samples taken during NSIS_1, topsoil samples were taken from set distances from the profile pit, composite auger samples (0–15cm) were taken on a 20 by 20 metre grid, core samples (15 cm x 5 cm) were taken from the surface, and additional samples were taken from within each horizon to measure bulk density, moisture release characteristics and soil structural strength. A range of additional biological parameters are being measured in addition to the attributes described under the NSIS scheme.

- Lilly, A. et al. (2010). World Congress of Soil Science: Soil Solutions for a Changing World, 19thWCSS, Brisbane Australia, 1-6 August 2010. [online] http://www.iuss.org/19th%20WCSS/.%5Csymposium/pdf/0118.pdf (checked 28 February 2011).

Scheme 3 **RSPS**

Representative Soil Profiles of Scotland

This is a stratified surveillance scheme whose purpose is to characterise the soils shown on the 1:63 360 and 1:50 000 scale soil maps and was collected during field work for the 1:63 360 and 1:50 000 scale soil survey of Scotland. These profiles were selected at the time of mapping by soil surveyors to characterise the soils currently being mapped. The data comprise morphological descriptions of soil profiles and constituent horizons and systematic analytical data from soil horizon samples. There are around 6000 soil profiles characterised under this scheme.

It comprises primarily soil chemical attributes with limited soil physical data and soil morphological descriptions (although these are available in hard copy). A sub-set (30) was used for an intensive monitoring of soil water levels from May 1984 to August 1992.

Information collected: depth to top of sample; depth to base of sample; loss on ignition; percentage international sand; percentage international silt; percentage international clay; percentages of USDA or BSTC sand and silt; calcium; magnesium; sodium; potassium; exchangeable acidity; sum of cations; base saturation; pH in water; pH in calcium chloride; carbon; nitrogen; C/N ratio; organic matter; total phosphate; sample batch identification; and visual assessment of soil moisture at 1m. Spectrochemical analysis for limited numbers of profiles (mineralogy). Water-levels recorded ~ 30 profiles.

Schemes 1 and 3 provide much of the data that has been summarised into the Scottish Soils Knowledge and Information Base (SSKIB). This contains summary information (means, medians, maximum and minimum values) for a range of soil properties for the principal soil series in Scotland and underpins the Soil Indicators for Scottish Soils website online facility:

- MLURI - http://sifss.macaulay.ac.uk/.

Scheme 4 **SSMUTS**

Scottish soil map unit transect study

The aim was to characterise and quantify spatial and compositional variability of soil horizons and properties at high resolution (minimum 5 m distance apart) over a 1 km transect in the Balrownie, Corby and Winton soil series map units.

This was set up as a trial scheme, with the original intention of informing approaches to a systematic study of other map units of the 1:63 630 soil maps.

Information collected: depth to top of sample; depth to base of sample; loss on ignition; percentage international sand; percentage international silt; percentage international clay; percentages of USDA or BSTC sand and silt; calcium; magnesium; sodium; potassium; exchangeable acidity; sum of cations; base saturation; pH in water; pH in calcium chloride; carbon; nitrogen; C/N ratio; organic matter; total phosphate; sample batch identification; visual assessment of soil moisture at 1 m; and soil moisture release for 1 transect.

Scheme 5

Grid Surveys in Scotland

This was a purposive sampling of a limited number of locations in Scotland to establish spatial variability in a range of soil attributes and to quantify soil variability within estates, farms or fields. Soil samples were collected per horizon.

Information collected: depth to top of sample; depth to base of sample; loss on ignition; percentage international sand; percentage international silt; percentage international clay; percentages of USDA or BSTC sand and silt; calcium; magnesium; sodium; potassium; exchangeable acidity; sum of cations; base saturation; pH in water; pH in calcium chloride; carbon; nitrogen; C/N ratio; organic matter; total phosphate; and visual assessment of soil moisture at 1 m.

Scheme 6 **TIPSS**

Trends in pollution of Scottish Soils

To assess the pollution caused by atmospheric deposition by providing a 'snapshot in time' of the pollution loadings in upland organic soils in Scotland. The data demonstrate clear contrasting spatial trends from north to south and provide what may be considered the background levels in more pristine environments.

Sampled in 1990 and 1999: 30 Scottish sampling locations, 8 samples on each of 3 transects and 6 on 1 transect, designed to allow effect of atmospheric pollution loadings to be assessed on upland soils with highly organic surface horizons. The most southerly transect was resampled and analysed in 2010.

Information collected: Loss on ignition; total carbon and nitrogen; radiocaesium; total and 16 individual PAHs; total and 13 PCB congeners; cadmium; copper; zinc; lead; nickel; chromium; iron; and manganese.

- MLURI - http://www.macaulay.ac.uk/tipss/

Scheme 7 **CS + year**

Countryside Survey

The Countryside Survey is a stratified random monitoring scheme that provides a national network of sites across Great Britain, representing the main types of landscape, land cover and soil groups. The surveys aim to provide good quality data about chemical and biological properties of soil for the development of national databases.

The soil surveys in 1978, 2000 and 2007 have provided a sequence of good quality soil data. It aims to improve the understanding of links between soil biology, chemistry and the wider environment to support the development of suitable, effective strategies and policies relating to soil protection. The number of contextual parameters became larger for each subsequent survey. The survey does not cover urban areas and samples the topsoil only.

Samples are collected on a stratified random grid originally at 15 km intersects. For the 1978 soil sample about 200g was collected. For the 2000 and 2007 surveys, three cores were taken (one 15 cm deep by 8 cm; and two 8 cm deep by 4 cm).

Information collected by the Countryside Survery 1978: pH, loss on ignition, total carbon and nitrogen, Olsen-P, total cadmium, chromium, copper, nickel, lead, vanadium, zinc, mercury, arsenic, bacterial counts, BIOLOG, invertebrate taxa, collembola species, Oribatid species, functional groups. Range of PAHs and PCBs on 201 samples taken from 109 squares.

Information collected by the Countryside Survey 2000: see Monitoring and Assessing Soil Quality (MASQ) below.

Information collected by the Countryside Survey 2007: pH; soil organic matter; soil organic carbon; bulk density; hand texture; total-N; soil C:N (by calculation); Olsen-P; potential mineralisable N; invertebrate diversity by main taxa; and metals.

- CS 2007: Soils Report from 2007
  http://www.countrysidesurvey.org.uk/sites/default/files/pdfs/reports2007/CS_UK_2007_TR9-revised.pdf

Scheme 8 **MASQ**

Monitoring and Assessing Soil Quality

This is part of Countryside Survey 2000 and aims to provide good quality datasets for soil invertebrate and microbial communities, soil pH and organic matter and selected heavy metals and persistent organic pollutants.

The sampling strategy was designed to provide a restricted, stratified random sample of 1 km grid squares across Great Britain. The sample strata were derived from multi-variate analysis of relief, climate, geology and settlement which yielded 32 classes. Eight sample squares were randomly selected within each of the classes for the 1978 sample. Further land classes and more sample squares were added over the intervening years and for the Countryside Survey 2000 there were 40 land classes having 569 sample squares in Great Britain with 203 in Scotland. Soil sampling was restricted to the 256 squares visited during the 1978 campaign.

Sample locations within each 1 km square were selected according to protocols in the unpublished Countryside Survey 2000 field handbook. Topsoil samples were taken with corers.

Information collected: soil pH in water; loss on ignition; heavy metals by inductively coupled plasma-optical emission spectrometers (ICP- OES): cadmium; copper; chromium; lead; nickel; vanadium; and zinc. A novel analytical method was developed using gas chromatography-mass spectrometry (GC- MS) for the analysis of PAHs, PCBs and organochlorine pesticides (OCPs). Soil invertebrates were extracted and identified. Numbers and functional diversity of heterotrophic bacteria were identified.

- Black, H.I.J. et al. (2000) MASQ: Monitoring And Assessing Soil Quality in Great Britain. Countryside Survey Module 6: Soils and Pollution. Bristol Environment Agency (R & D Technical Report E1-063/TR) ISBN 1857056949. [online] http://nora.nerc.ac.uk/4297/2/SE1-063-TR-e-p.pdf (checked 28 February 2011).

Scheme 9 **ECN**

Environmental Change Network

The Environmental Change Network is a UK scheme set up to:

- establish and maintain a selected network of sites within the UK from which to obtain comparable long-term datasets through the monitoring of a range of variables identified as being of major environmental importance;
- provide for the integration and analysis of these data, so as to identify natural and man-induced environmental changes and improve understanding of the causes of change;
- distinguish short-term fluctuations from long-term trends, and predict future changes.

Soil samples were collected by depth and horizon every 5 years for soil chemistry and every 20 years for bulk density and water release characteristics and a wider range of chemical determinand. Soil water is collected on a fortnightly basis on A and B Horizons at 10 cm and 50 cm.

Information collected: site specific metadata; land management history; slope; parent material; and biodiversity measurements [tree diameter at breast height (DBH), dead wood assessment, vegetation survey (species list only)]. Initial survey: particle size analysis and soil mineralogy. For 5- and 20-yearly soil samples: moisture, pH. Exchangeable: acidity, sodium, potassium, calcium, magnesium, manganese and aluminium. Total: nitrogen, phosphorus, organic carbon, inorganic carbonate, lead, zinc, cadmium, copper, mercury, cobalt, molybdenum, arsenic, chromium and nickel. Extractable: iron, aluminium and phosphorus. Bulk density and water release characteristics (initial and 20-yearly samples). pH and conductivity on unfiltered water. After filtering: sodium, calcium, magnesium, iron, aluminium, ammonium- nitrogen, chlorine, nitrate-nitrogen, sulphate, sulphur, phosphate, phosphorus, alkalinity and dissolved organic carbon

- Centre for Ecology and Hydrology – The UK Environmental change network. [online] http://www.ecn.ac.uk/ (checked 10 November 2010).

Scheme 10 **BIOSOIL**

BioSoil

The purpose of the Biosoil project is to test the applicability of a soil sampling protocol across almost all EU member states. Protocol was developed by a 'Soil Expert Panel' of national forest soil scientists. Baseline data collected 2006.

Soil samples are collected from afforested sites on a 16 x 16 km square grid at depths of 0–5, 5–10, 10–20, 20–40 and 40–80 cm and also by sampling per horizon.

Information collected: depth of horizon, pH in water and calcium chloride, organic carbon, calcium carbonate, moisture content, bulk density, stone content, total carbon and nitrogen, aqua reqia extractable cations and metals, Oxalate extractable aluminium and iron, barium chloride extractable cations and acidity, and particle size analysis. For further information please see the Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests published by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests.

- Hiederer, R. and Durrant, T. (2010). Evaluation of BioSoil Demonstration Project Preliminary Data Analysis, IES EUR 24258. [online] http://eusoils.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/EUR24258.pdf (checked 10 November 2010).

Scheme 11

Level I Forest Conditions survey

The Level I Forest Condition Survey is a Europe-wide assessment of spatial and temporal variation in forest condition using crown density or transparency as the principal indicator. Surveys of crown density have been carried out on an annual basis since 1986 at between 1700 plots (in 1988) and 6000 plots (in 2000) across Europe. In the UK, there are approximately 90 Level 1 plots covering five tree species (oak, beech, Scots pine, Sitka spruce, Norway spruce). The protocol requires a minimum plot size of 0.25 ha (although this is not always realised), with the crown density of 24 'internal' plot trees assessed across the four aspects (north, south, east and west). The plots have been established on a 16 × 16 km transnational grid across Europe, enabling pan-European assessments of forest condition to be made. Level I plots have been moved from the 16 x 16 km grid in order to cover the main and most important tree species for the UK. Sixty-seven of these 90 plots were assessed for soil.

Soil samples are collected using core auger by depth, 0–5, 5–10, 10–20 cm plus sample of litter layer.

Information collected: depth of horizon, pH in calcium chloride, organic carbon, calcium carbonate, moisture content, bulk density, total carbon and nitrogen, aqua reqia extractable cations and metals.

- Forest Research - Forest condition monitoring - Level I network [online] http://www.forestry.gov.uk/fr/INFD-62VASW (checked 10 November 2010).

Scheme 12

Level II Intensive Monitoring of Forest Ecosystems

In 1995, 10 permanent intensive monitoring Level II plots have been installed in Great Britain in accordance with EU protocols. These represent three important forest species: Sitka spruce (*Picea sitchensis* (Bong.) Carr), Scots pine (*Pinus sylvestris* L.) and oak (*Quercus* spp.). An additional 10 plots were added in 2002; including a further two important forest species: beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*). There are six sites in Scotland. The locations of Level II plots were chosen to represent a range of soils, climatic and pollution conditions and different tree species. The 10 plots added in 2002 have not yet been characterised for soil.

Samples are collected using a core auger per horizon every 12 years, but the intention was every 10 years. Soil water sample are collected every two weeks.

Information collected: depth of horizon, pH in water and calcium chloride, organic carbon, calcium carbonate, moisture content, bulk density, stone content, total carbon and ntirogen, aqua reqia extractable cations and metals, barium chloride extractable cations and acidity, particle size analysis, for further information please see the Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests published by the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests. For soil solution - pH and conductivity, potassium, calcium, magnesium, sodium, aluminium, iron, manganese, total phosphorus, total sulphur, barium, silicon, strontium and zinc, chlorine, nitrate, sulphate, dissolved organic carbon, total carbon and total inorganic carbon, total nitrogen and alkalinity.

- Forestry research - Intensive long term monitoring of forest ecosystems. [online] http://www.forestry.gov.uk/fr/INFD-67MEVC (checked 10 November 2010).

Scheme 13

ITE/NCC 'Bunce 1971' woodland survey

The purpose of the scheme is to explore and measure changes in woodland soils, tree and shrub layers and the ground flora through a re-survey of woods first studied 30 years ago in 1971. It is a national scheme with a long (30-year) period between sampling cycles.

In this 1971 survey, 103 woods across Great Britain were selected as representative of a wider sample of 2,453 woods (> 4 ha) surveyed in the late 1960s.

Data available for the following potential drivers of change: phenological change;1976 drought and other drought years; 1987 storm and other wind-events; warmer winters; nitrogen oxide and ammonia deposition; reduced acidification; Dutch Elm disease; changes in grazing by deer and sheep; management for game; increased damage by grey squirrels; inappropriate woodland management; and stand development

Soil sampled from 0–15 cm were analysed for soil organic matter content (%), pH, total carbon and total nitrogen.

- Kirby, K.J., Smart, S.M., Black, H.I.J., Bunce, R.G.H., Corney,P.M. and Smithers, R.J. (2005). Long term ecological change in British woodland (1971–2001). Peterborough: English Nature (Research Report 653).

Scheme 14 **UKSHS**

UK Soil and Herbage Survey

To provide robust estimates of contaminant concentrations in soil and herbage at background (rural), urban and industrial locations. These can be used with earlier surveys to determine trends and as a reference dataset against which more detailed local surveys can be assessed. The data are not suitable for interrogation at individual sites; their real power is to provide a national picture.

Three levels of stratification: rural, urban and industrial sites. Rural sites samples on a 50 km grid. Urban and industrial sites sampled using local Environment Agency knowledge.

Samples collected between 2001 and 2002.

Information collected: soil pH, bulk density, soil organic carbon, soil texture (by hand),17 dioxins: total tetra, penta, hexa, hepta & octachloro dibenzodioxins & dibenzofurans, 2,3,7,8 TCDD and 1,2,3,7,8 PeCDD; PCB 18, PCB 28, PCB 31, PCB 47, PCB 49, PCB 51, PCB 52, PCB 77, PCB 81, PCB 99, PCB 101, PCB 105, PCB 114, PCB 118, PCB 123, PCB 126, PCB 138, PCB 153, PCB 156, PCB 157, PCB 167, PCB 169, PCB 170, PCB 180, PCB 189, 20 PAHs, benzo(a)pyrene; benzo(a)anthracene; dibenzo(ah)anthracene/ dibenzo(ac) anthracene; benzo(b)fluoranthene/benzo(j)fluoranthene; benzo(k)fluoranthene; indeno(1,2,3-cd)pyrene; chrysene; acenaphthene; acenaphthylene; benzo(ghi)perylene; coronene; fluoroanthene; fluorene; 1-methylphenanthrene; 2-methylphenanthrene; phenanthrene; pyrene; total concentrations of arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, platinum, tin, titanium, vanadium and zinc.

- Environment Agency. (2007). UK Soil & Herbage Pollutant Survey: project summary Science summary: SC000027. [online] http://publications.environment-agency.gov.uk/pdf/SCHO0607BMTE-e-e.pdf?lang=_w (checked 10 November 2010).

Scheme 15 **Sludge Exp**

Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long term soil fertility.

To determine the effect of zinc, copper and cadmium additions in sewage sludge on soil microbial processes (biomass carbon, soil respiration, *Rhizobium leguminosarum* biovar *trifolii*), selected soil chemical properties and metal bioavailability to crops, agricultural productivity and long-term soil fertility. To compare the effects of zinc, copper and cadmium additions in metal-amended liquid sludges with additions via contaminated sludge cakes on metal bioavailability for micro-organisms and crops, agricultural productivity and long-term soil fertility.

Two fixed sites in Scotland - Hartwood, Auchincruive.

Soils were sampled to fixed depth (25 cm) using screw auger every year from 1994–1998, and then every two years (1999, 2001, 2003 and 2005, 2007, 2009).

Information collected: total soil zinc, copper and cadmium, ammonium nitrate extractable zinc, copper and cadmium, pH, extractable phosphorus, potassium and magnesium, cation exchange capacity, total nitrogen, organic carbon, conductivity, biomass carbon, respiration rate and Rhizobium most probable numbers.

- CSA 6222 Long-term Sludge Experiments Phase III (2007) http://randd.defra.gov.uk/Document.aspx?Document=SP0130_6505_FRP.pdf (checked 28 February 2011).
- Campbell, C. D. et al. (2009). Impact of long-term sewage sludge additions to biological functions in Scottish soils, report to Scottish Government. [online] http://www.scotland.gov.uk/Publications/2009/11/10091545/9 (checked 10 November 2010).

Scheme 16 **SEPA SCM**

SEPA soil compliance monitoring

SEPA carries out soil monitoring to check compliance against the Sludge (Use in Agriculture) Regulations 1989 and the Waste Management Licensing Regulations 1994 (as amended). Sampling began in 2007. Between 2007 and 2010 around 80 fields per year were sampled following SEPA's soil sampling procedure – i.e. 25 auger samples are taken per field to a depth of 20 cm in a W pattern and bulked to give one soil sample per field. Soil samples are analysed for pH; total carbon and nitrogen, extractable phosphorus, potassium and magnesium, total cadmium, chromium, copper, mercury, nickel, lead and zinc, and microbial biomass. Earthworms are also sampled at a subset of the fields. In addition, land use and land management information is obtained from talking to the land manager / farmer and recorded.

- SEPA soil compliance monitoring annual report 2007 and 2008. [online] http://www.sepa.org.uk/land/land_publications.aspx (checked 10 November 2010).

Scheme 17 **HMS**

SEPA Harmonised Monitoring Scheme

The Harmonised Monitoring Scheme (HMS) is a national water quality archive dating back to 1974. SEPA monitors 56 Scottish rivers under the HMS. The rivers are sampled at a location as far downstream as possible (i.e. as close as possible to the tidal limit) so that samples reflect inputs from the entire catchment feeding each river. Samples are collected monthly, and water temperature and flow are recorded. These samples are analysed for a range of natural and synthetic substances. Daily mean river flows at sites near the water sampling locations are used to estimate fluxes of materials from the rivers to the sea.

The following parameters are measured: alkalinity; arsenic; average flow; biochemical oxygen demand; calcium; chemical oxygen demand; chloride; dissolved oxygen (% saturation); lead; magnesium; mercury; nitrogen (ammoniacal); nitrogen (nitrate); pH; phosphorus (Ortho-P); phosphorus (total); potassium; silicate; sodium; sulphate; suspended solids; temperature; total organic carbon; and turbidity.

- Further information can be found at:http://www.sepa.org.uk/science_and_research/data_and_reports/water/scottish_river_water_quality.aspx (checked 28 February 2011).

Scheme 18 **SSFIS1996**

Scottish Soil Fertility Information System pre-1996

This includes samples collected by Scottish Agricultural College (SAC) staff or by the landowner/user where a soil fertility problem has been identified. The scheme was discontinued in 1996 and replaced by SSFIS1996+ from 1996 onwards.

Soil sampling was carried out on a 'W' pattern within a field or unit of 5 ha, whichever was smaller. The samples are thus accurate to an area of approximately 5 ha.

Information collected: pH in water; acetic acid extractable phosphorous (to end of March 1992); ammonium acetate/acetic acid extractable phosphorous (from May 1992 onwards)

Scheme 19 **SSFIS1996+**

Scottish Soil Fertility Information System post-1996

This includes samples collected by SAC staff or by the landowner/user where a soil fertility problem has been identified. Soil sampling is carried out on a 'W' pattern within a field or unit of 5 ha, whichever is smaller. The samples are thus accurate to an area of approximately 5 ha.

Information collected (not necessarily all determinands for all samples): fresh pH; pH, total nitrogen; total carbon; derived organic matter; organic matter by loss on ignition; organic matter (wet oxidation); mineralisable ammonium; mineralisable nitrate; nitrate-nitrogen (calcium sulphate), acid soluble fluoride; water extractable sulphate; cation exchange capacity; ADAS pH; ADAS extractable potassium; ADAS extractable magnesium; ADAS extractable sodium; ADAS extractable phosphorus, conductivity; conductivity (saturated calcium sulphate $CaSO_4$). Aqua regia digest: aluminium; arsenic; boron; barium; calcium; cadmium; cobalt; chromium; copper; iron; mercury; potassium; magnesium; manganese; molybdenum; sodium; nickel; phosphorus; lead; sulphur; selenium; tin; zinc. Extractable: aluminium; boron; calcium; cobalt; chromium; copper; iron; potassium; magnesium; manganese; molybdenum; sodium; ammonium; nickel; nitrate; phosphorus; lead; sulphur; zinc.

Scheme 20 **G-BASE**

Geochemical Baseline Survey of the Environment

G-BASE is the national geochemical survey of the UK surface environment funded by the British Geological Survey (BGS) via the NERC Science Budget. The aim of the survey is to provide systematic data on the geochemistry of the rural surface environment in Great Britain based on samples of stream sediments, stream water and soils for resource management and environmental purposes.

Soil samples are collected with an auger at fixed depth of 5–20 and 35–50 cm on a systematic grid of 1 per 2 km^2. Every second UK national 1 km grid square is sampled as indicated on Ordnance Survey 1:50 000 topographic maps. Samples are collected from the least disturbed area of land as close as possible to the centre of each grid square

Information collected: total concentrations of sodium oxide, magnesium oxide, aluminium oxide, silicon dioxide, phosphorus pentoxide, potassium oxide, calcium oxide, titanium dioxide, manganese oxide, iron oxide, scandium, vanadium, chromium, cobalt, barium, nickel, copper, zinc, gallium, germanium, arsenic, selenium, bromine, rubidium, strontium, yttrium, zirconium, niobium, molybdenum, hafnium, tantalum, tungsten, thallium, lead, bismuth, thorium, uranium, silver, cadmium, tin, antimony, tellurium, iodine, caesium, lanthanum, cerium, soil pH and loss on ignition (as an indicator of organic matter).

- British Geological Survey - Geochemical Baseline Survey of the Environment (G-BASE). [online] http://www.bgs.ac.uk/gbase/home.html (checked 10 November 2010).

Scheme 21 **G-BASE urban**

Geochemical Survey of Urban Environments

The geochemical survey of urban environments is part of the G-BASE project and focuses on surveying cities. The aim of the survey is to provide systematic data on the geochemistry of urban environments in Great Britain for planning and environmental purposes.

Soil samples are collected with auger at fixed depth of 5–20 and 35–50 cm on a systematic grid of 4 per one km square of the OS 1:25,000 OS topographic map.

Information collected: total concentrations of sodium oxide, magnesium oxide, aluminium oxide, silicon dioxide, phosphorous oxide, potassium oxide, calcium oxide, titanium dioxide, manganese oxide, iron oxide, scandium, vanadium, chromium, cobalt, barium, nickel, copper, zinc, gallium, germanium, arsenic, selenium, bromine, rubidium, strontium, yttrium, zirconium, niobium, molybdenum, hafnium, tantalum, tungsten, thallium, lead, bismuth, thorium, uranium, silver, cadmium, tin, antimony, tellurium, iodine, caesium, lanthanum, cerium, soil pH and loss on ignition (as an indicator of organic matter).

- British Geological Survey – urban geochemistry [online] http://www.bgs.ac.uk/gbase/urban.html (checked 10 November 2010).

Scheme 22

Forum of European Geological Surveys European Geochemical Survey (FOREGS)

The FOREGS geochemical survey aims to provide systematic data on the geochemistry of the European rural surface environment based on samples of stream sediments, stream water, soil, humus and floodplain sediment, for resource management and environmental purposes. Although it has European scope, the sampling density is relatively low for covering the UK (five randomly generated sampling points within each 160 x 160 km grid cell). Soil samples were collected from pits, one 5–25 cm sample and a 25 cm section from within 50–200 cm (the C horizon) and a humus sample was sampled in the upper 3 cm removing any mineral material.

Information collected: initial survey: particle size analysis, soil mineralogy. For 5- and 20- yearly soil samples: Moisture, pH, exchangeable: acidity, sodium, potassium, calcium, magnesium, manganese and aluminium. Total: nitrogen, phosphorus, organic carbon, inorganic carbonate, lead, zinc, cadmium, copper, mercury, cobalt, molybdenum, arsenic, chromium and nickel. Extractable: iron, aluminium, and phosphorous. Bulk density and water release characteristics (initial and 20-yearly samples).

- FOREGS – Geochemical Baseline Mapping Programme. [online] http://www.gtk.fi/foregs/geochem/index.htm (checked 10 November 2010).

Scheme 23

Land Use/Cover Area Frame Statistical Survey (LUCAS)

LUCAS is a regular, harmonised survey across all Member States to gather information on land cover and land use in response to a decision of the European Parliament, the European Statistical Office (EUROSTAT) in close cooperation with the Directorate General responsible for Agriculture.

Estimates of the area occupied by different land use or land cover types are computed on the basis of observations taken at more than 250,000 sample points throughout the EU rather than mapping the entire area under investigation. By repeating the survey every few years, changes to land use can be identified.

During the 2009 survey, soil samples were collected from the surface horizon using a spade in 1350 locations in the UK (around 400 in Scotland) and sent for analysis to Joint Research Centre at Ispra in Italy where the samples are analysed to assess key parameters (e.g. texture, organic matter content, pH, heavy metals) in order to assess the state of the soil across Europe.

Information collected:_ coarse fragments, particle size distribution (Food and Agriculture Organisation), pH in calcium chloride, pH in water, organic carbon, carbonate content, phosphorus content, total nitrogen content, extractable potassium content, MULTISPECTRAL properties (with diffuse reflectance measurements saturation), cation exchange capacity.

- Joint Research Centre – LUCAS: Land Use/Cover Area frame Statistical Survey. [online] http://eusoils.jrc.ec.europa.eu/projects/Lucas/ (checked 10 November 2010).

Scheme 24

National Countryside Monitoring Scheme

This is a case study of change in land cover and land use in Scotland based on 1947, 1973 and 1988 aerial photographs. It does not include any soil sampling or analysis but provides information on vegetation and habitats.

- Mackey E.C, Shewry M.,C. and Tudor,G.J. (eds). (1988) Land cover change: Scotland from the 1940s to the 1980s. pp. 263. Edinburgh: The Stationary Office.

Scheme 25 — SQUID

SQuID

In Phase 1 the project considered the suitability of 13 biological indicators of soil quality for deployment in a national-scale soil monitoring scheme. Biological indicators tested include: eight soil microbial groups (ammonia oxidisers, denitrifiers, fungi, bacteria, Archaea, methanogens, methanotrophs and actinomycetes) identified from TRFLP fingerprinting; Soil microbial community structure and biomass characterised from PLFA profiles; multiple substrate induced respiration (MSIR) derived by gas chromatography or Microresp^{TM} ; multi-enzyme profiling via microplate fluorometric assay; nematode community structure from Baermann extractions, and Microarthropod community structure from Tullgren dry extractions.

- Black, H.I.J et al. (2008). SQID: Prioritising biological indicators of soil quality for deployment in a national-scale soil monitoring scheme. Summary report. NERC/Centre for Ecology & Hydrology, 22pp. (CEH Project Number: C03061, Defra Project No. SP0529) [online] http://nora.nerc.ac.uk/8108/2/N008108CR.pdf (checked 10 November 2010).

Scheme 26 — NERC SoilBio

NERC Soil Biodiversity Programme

The NERC 'Soil Biodiversity Programme' was an integrated programme of research on the biological diversity of soil biota and the functional roles played by soil organisms in key ecological processes. The programme ran from 1997–2004.

This focus on research activities in an upland grassland ecosystem in the Scottish Borders provided an extensive qualitative assessment of soil biodiversity and its response to a range of manipulation stresses.

- NERC – Soil biodiversity programme. [online] http://soilbio.nerc.ac.uk/ (checked 10 November 2010).

Scheme 27 — MICRONET

SEERAD - MICRONET programme on soil microbial ecology

The MICRONET programme was a nine-year SEERAD funded programme, that initially developed and applied molecular and community scale techniques to quantify the diversity of microbial populations. This work has shown significant differences in microbial populations in soils under different land uses. The research within the programme was set up to investigate the relationship between plants and microbial communities, and will contribute to the development of strategies for sustainable land use.

- http://www.scotland.gov.uk/Publications/2002/11/15716/12536 (checked 25 February 2011).

Scheme 28

UK Biodiversity Action Plan (UKBAP)

The UKBAP (http://www.ukbap.org.uk/) describes the biological resources of the UK and provides detailed plans for conservation of these resources, at national and devolved levels. The 2008 report contains the fourth update on the progress to conserve the species and habitats identified as requiring priority action under UKBAP. The report examines 45 habitats in detail and 475 species (covered by 391 Species Action Plans).

- http://www.jncc.gov.uk/pdf/pub2010_UKBAPHighlightsReport2008.pdf (checked 28 February 2011)

Scheme 29 **SCM**

Site condition monitoring

The site condition monitoring dataset held by SNH, recorded information collected during phase 1 and 2 of the Common Standards Monitoring for Special Areas of Conservation, Special Protection Areas, Ramsar sites and Sites of Special Scientific Interest. The condition of interest features for which the protected site has been notified or designated is monitored. Each interest feature will have one or more measurable attributes that will be assessed against targets, thus provide a pass or fail result. Additional information may also be recorded as narrative relating observed changes in the condition of the interest features to the reasons for such changes.

SNH provided data for peatland Common Standards Monitoring sites: 259 upland habitats (includes blanket bog), 237 lowland wetlands, 30 lowland dry heath sites, 7 bog woodland sites and 19 Quaternary features. SNH also provided data for protected soil biodiversity species and soil dwelling species – fungus, invertebrates.

- Scottish Natural Heritage – Site condition monitoring. [online] http://www.snh.gov.uk/protecting-scotlands-nature/protected-areas/site-condition-monitoring/ (checked 10 November 2010).

Scheme 30 **SEWS**

Scottish Earthworm Survey

In early 1990 and 2009, SCRI conducted a national earthworm survey of Scotland across 100 farms sites in Scotland. The aim is to compare and contrast both databases to determine whether changing environmental conditions, e.g. changing land management, have impacted upon earthworm communities over an approximate 20-year period.

- Findings from the original work are published in: Boag, B., Palmer, L. F., Neilson, R., Legg, R and Chambers S. J. (1997). Distribution, prevalence and intensity of earthworm populations in arable land and grassland in Scotland. *Annals of Applied Biology*, **130**, 153–165.

Scheme 31 **MOORCO**

Moorland colonisation by birch and pine, and the consequences for biodiversity

MOORCO aims to understand the role biodiversity plays, and how it provides resistance and resilience to change at different stages in succession. It will also help underpin land use management and planning policies, and will form an essential part of understanding and predicting the impacts of long-term environmental change.

Sites studied include Invercauld Estate, Glensaugh and Ballogie.

- More information on this project can be found at: http://www.macaulay.ac.uk/moorco/ (checked 28 February 2011).

Annex 2 Description of the scoring methodologies used in the tables presented in Chapters 3–10

This annex must be read in conjunction with the main text as it refers to several tables in Chapters 3–10.

2.1 Introduction

The purpose of this annex is to describe the methodology adopted in this report to assess the relative importance of the various pressures causing soil degradation and of their impacts. We also provide an overview of the socio-economic evaluation in Glenk et al. (2010) and explain how we have used this to describe how we combine socio-economic impacts with environmental impacts to get a wider understanding of the state of Scotland's soils.

In Chapter 2.6, 'Reporting and assessing the threats to soils', we present details of the conceptual model that has been used to describe the environmental and socio-economic issues that relate to Scotland's soils and define key terms used such as drivers, pressures, threats and impacts.

The evaluation of the environmental impacts on soil is based on expert judgment and considers the following issues:

- the relative importance of different pressures leading to threats to soils over a 25-year timescale based on the magnitude of the pressure, the potential reversibility of the pressure, the spatial extent of the pressure, how well the pressure is characterised (i.e. uncertainty) and the trend in its intensity;
- the cumulative environmental impact of each threat on each of the soil functions based on the magnitude of the impact on soil functions, how difficult it would be to reverse the effects of the threat on each function, the spatial extent over which the threat acts, how well the threat is understood (i.e. uncertainty) and the trend in its impact.

Common assessment criteria and a scoring system were developed for this report and used accordingly by the authors of the relevant chapters. The authors individually provide different perspectives in their area of expertise and, therefore, collectively represent the best available grouping to make the judgements represented in the tables.

The socio-economic impacts of each threat on each of the soil functions (considering different types of socio-economic costs, their magnitude, and the level of uncertainty attached to the costs) were also derived from information published in Glenk et al. (2010). This is combined with environmental information produced in this report to provide a wider understanding of the state of soil and of the impacts associated with degradation.

2.2 Methodology for scoring and assessing the pressures leading to soil threats

Each of the report sections dealing with specific threats (Chapters 3–9) includes an assessment of the relative importance of pressures leading to the threat (see, for example, Table 3.1). These tables review a range of pressures that were identified by the authors as relevant to the threat. This includes climate change[6], agricultural and forestry land use and land management practices, land use change, development and transport, waste management, resource extraction, transboundary pressures and recreational use of land.

The criteria for the expert-judgment assessment of these pressures are presented below.

- Magnitude of pressure on threat: this considers the current magnitude of the pressures, with three scoring options:
  - 1 low: not a significant pressure;
  - 2 moderate: a significant pressure;
  - 3 high: a very significant pressure.

- Reversibility of pressure on threat: this considers if the pressure is reversible and over what time scale, with three scoring options:
  - 1 pressure potentially short term and reversible;
  - 2 pressure potentially medium term and reversible;
  - 3 pressure effectively irreversible.

- Spatial extent of the pressure: this considers the scale at which the pressure is applied, with four scoring options:
  - 0 limited: very limited extent;
  - 1 local: confined to field or small catchment scale;
  - 2 regional: confined to one or more major region(s) or primary land use within Scotland (e.g. arable soils, forestry);
  - 3 national: extends across Scotland.

- Uncertainty: this considers both the level of understanding and data quality, with three scoring options:
  - 1 pressure well characterised and quantified where possible;
  - 2 pressure moderately well characterised but data primarily qualitative in nature;
  - 3 pressure poorly characterised.

- Trend in pressure: this considers the predicted change in pressure intensity (not the impact of pressures on threats) over the next 25 years, and with three scoring options:
  - +1 pressure predicted to increase in intensity;
  - 0 pressure predicted to be stable in intensity;
  - -1 pressure predicted to decrease in intensity.

These criteria are summarised in series of footnotes under each table in the text.

[6] Climate change was considered as a threat in Towers et al. (2006)

The scores for magnitude, reversibility, spatial extent and trend for each threat were added together to provide an 'aggregated pressure value' as shown below:

	Magnitude of impact	Reversibility	Spatial extent	Trend	Aggregated pressure value
Pressure X	Score for pressure X	Score for pressure X	Score for pressure X	Score for pressure X	Total score for pressure X

It is then possible to rank both the cumulative score for each separate aggregated pressure (i.e. cumulative significance of pressure) and the cumulative score of pressures on a single soil function (i.e. cumulative response of threat) as shown in table below:

	Threat A	Threat B	⋮	Threat N	Cumulative significance of pressure
Pressure a	Aggregate pressure (a) on threat A	Aggregate pressure (a) on threat B	...	Aggregate pressure (a) on threat N	Total aggregate pressure (a) on threat A to N
⋮	⋮	⋮	⋮	⋮	⋮
Pressure n	Aggregate pressure (n) on threat A	Aggregate pressure (n) on threat B	...	Aggregate pressure (n) on threat N	Total aggregate pressure (n) on threat A to N
Cumulative response of threat	Total for threat A of aggregate pressure a to n	Total for threat B of aggregate pressure a to n	...	Total for threat N of aggregate pressure a to n	

The ranked totals in the last column therefore enable the identification of those pressures that provide the biggest overall contribution to threats. The totals in the bottom row of the table give an indication of which threats are driven by the largest number of pressures. See Table 10.1.

2.3 Methodology for scoring the environmental impacts caused by the threats

Each of the report sections dealing with specific threats (Chapters 3–8) also include an assessment of the environmental impact of the threat on each of the principal soil functions (see, for example, Table 3.2). Each table considers how soil function responds to that specific threat. All seven soil functions described in Chapter 2.2 were considered. Where a threat has no known impact on the function this was noted as being not applicable. Five criteria were considered and scored as described below.

- Magnitude of impact: this scores how the threat impacts the soil function where it is know to be expressed with four scoring options:
  - 0 no impact;
  - 1 low: unlikely to have any significant impact on that function;
  - 2 moderate: impacts on the function are significant, but not threatening the operation of the function itself;
  - 3 high: likely to lead to serious impairment or the loss of that function.
- Reversibility: this considers if reversibility is theoretically possible and over what timescale, with three scoring options:
  - 1 effects of the threat can be easily reversed by simple modifications to management practices or natural attenuation, reversal possible within a season;
  - 2 effects can be reversed but only by significant changes to management practices, technical intervention or by new guidelines or policy, reversal possible within a few years;
  - 3 effectively irreversible. No economic or technical/management solution, effects can only be reversed by major changes in policy at a national or international level and/or are likely to take many decades.
- Spatial extent: this considers the scale at which the pressure is applied, with four scoring options:
  - 0 limited: very limited extent;
  - 1 local: confined to field or small catchment scale;
  - 2 regional: confined to one or more major region(s) or primary land use within Scotland (e.g. arable soils, forestry);
  - 3 national: extends across Scotland.
- Uncertainty: this considers both level of understanding and data, with three scoring options
  - 1 low: threat is well characterised, causal factors well understood and quantified where possible, good quantitative data on the soils affected;
  - 2 moderate: causal factors not fully understood, some gaps in our data on soils affected (e.g. evidence based on more limited research studies rather than on national sample sets or on qualitative information);
  - 3 high: poor understanding of the causal factors with no quantification of the effects of these, few data on which to assess current status of soils affected.

- Trend in impact: this assesses pressures (not impact of pressures on threats) over the next 25 years, and includes three scoring options:

  +1 impact predicted to increase over timescale;

  0 impact predicted to be stable over timescale;

  -1 impact predicted to decrease over timescale.

The scores for magnitude, reversibility, spatial extent and trend for each soil function were added to provide an 'aggregated function value' reflecting the impact of threats on a given soil function.

	Magnitude of impact	**Reversibility**	**Spatial extent**	**Trend**	**Aggregated function value**
Soil function A	Score for function A	Score for function A	Score for function A	Score for function A	Total score for function A

The 'cumulative function value' of a given threat on all soil functions was assessed as the total of individual criteria for magnitude, reversibility, spatial extent and trends.

	Magnitude of impact	**Reversibility**	**Spatial extent**	**Trend**	**Uncertainty**
Soil function A	Score for function A	Score for function A	Score for function A	Score for function A	Score for function A
⋮	⋮	⋮	⋮	⋮	⋮
Soil function N	Score for function N	Score for function N	Score for function N	Score for function N	Score for function N
Cumulative function value	Total score for function A to N	Total score for function A to N	Total score for function A to N	Total score for function A to N	Total score for function A to N

The threat posed by newly emerging issues is not included in this analysis, as it is difficult to produce meaningful scores at this stage due to lack of evidence. Contamination (excluding contaminated land) represents an average of scores for contamination by acidification and eutrophication, metals, pathogens, radioactive substances and organic chemicals.

2.4 Methodology for analysis of the environmental impacts caused by the threats

The 'cumulative function value' described in section 2.3 are added together to provide an assessment of the overall impact of each threat across all the soil functions. The total environmental score for each threat on all of the seven soil functions provides a means to rank threats in order to ascertain their relative significance. See Table 10.2 for the results of the implementation of this method.

	Cumulative magnitude	Cumulative reversibility	Cumulative extent	Cumulative trend	Total environmental score
Threat X	Total score for function A to N	Total score for function A to N	Total score for function A to N	Total score for function A to N	**Total of cumulative functions value for threat X**
⋮	⋮	⋮	⋮	⋮	⋮
Threat Z	Total score for function A to N	Total score for function A to N	Total score for function A to N	Total score for function A to N	**Total of cumulative functions value for threat Z**

Table 10.3 in Chapter 10 presents summary information on the number of soil functions that are affected at differing spatial scales by each individual threat.

2.5 Methodology for analysis of the socio-economic impacts caused by the threats

This report builds on work published in Glenk et al. (2010) which identified the socio-economic impacts of soil degradation for all the soil functions as used in this report. The Glenk et al. (2010) report provides semi-quantitative assessments on the following threats to soil:

- loss of soil organic matter;
- sealing;
- contamination (contaminated land);
- atmospheric deposition;
- changes in soil biodiversity;
- erosion and landslides;
- compaction.

Because the socio-economic tables produced in Glenk et al. (2010) are semi-quantitative, we have translated them into a scoring system comparable to the one used for the environmental impacts in this report. For each threat leading to soil degradation, the Glenk et al. (2010) report considers how individual soil functions are impacted according to the nature of the cost to society, whether it is an off- or on-site impact, the impact status and the data status that reflect the level of information available to support the assessment.

The terms for impact status (that range from low to high) were converted into numerical values in order to produce cumulative totals that are used in the summary analysis as presented in Chapter 10. Numerical values were attached to the terms as follows:

- low =1;
- low-to-medium = 2;
- medium or variable (low-to-high) = 3;
- medium-to-high = 4;
- high = 5.

Using this numerical transformation of the impact status scores, the socio-economic impact of threats was assessed using two methods. The sum of these two methods produced a final socio-economic value (see Table 10.4).

	For each threat	Impacts	Impact status numerical values (1 to 5)	**Interim value for scoring method 1**
	Soil function A	Impact a	Value for impact a function A	Maximum value for soil function A for threat a
		⋮	⋮	
		Impact z	Value for impact z function A	
	⋮	⋮	⋮	⋮
	Soil function N	Impact a	Value for impact a function N	Maximum value for soil function N for threat a
		⋮	⋮	
		Impact z	Value for impact z function N	
Value for scoring method 2	Number of function impacted	**X**	Average score	Total socio-economic score = Method 1 score + Method 2 score

Method 1

Worst-case scenario scoring—cumulative total of highest score for each soil function

This aims to present a 'worst case' scenario by only considering the highest scoring socio-economic impact for each soil function. For each threat the maximum impact value for each soil function is retained. For example, in Table 3.3, the 'storing carbon' function is subject to two impacts, one marked as high status and the other as variable. The high status impact scores 5 and the variable status impact scores 3, so only the impact scoring 5 is added to the cumulative total that is presented in the first column of Table 10.4. If this logic is followed for each of the functions listed in Table 3.3 (where there are a total of five functions affected by eight impacts) then a cumulative score of 16 is generated for loss of soil organic matter.

Method 2

Mean scoring—weighting system according to number of impact per threats, their average status and the total number of functions that are impacted

There are two steps to this scoring approach.

- **Average score for each socio-economic impact:** in Table 3.3, for example there are eight impacts with scores ranging from 2–5, and the average score for these is 3.
- **Average impact multiplied by the number of functions impacted:** this multiplies the average score for each socio-economic impact by the number of soil functions affected by the threat. Looking at Table 3.3 once more, it can be seen that a total of 5 functions are listed, which when multiplied by the average score of 3 gives a total of 15.

Total socio-economic score = Method 1 score + Method 2 score

A simple aggregate score (total socio-economic score) is then generated by adding the results in the Method 1 score column of Table 10.4 to those in the Method 2 weighted score column.

These aggregate scores are placed in the total socio-economic score column of Table 10.4 and ranked in order to illustrate the relative socio-economic significance of impacts caused by the threats to soil functions. For example, in the case of loss of soil organic matter, the total of 16 in the Method 1 score column is added to the total of 15 in the Method 2 weighted score column in order to generate a total socio-economic score of 31.

The data status column in the socio-economic tables in Chapters 3-8 can also be used as an overall measure of uncertainty, by calculating the percentage of impacts applied to each threat for which economic estimates are not available (marked 'N' in the column). These measures of uncertainty are provided for illustrative purposes only, and are therefore not ranked.

2.6 Combining the environmental and socio-economic impact summaries for threats

The harmonisation of the environmental and socio-economic assessment scorings enable us to produce an overall assessment of threats to soil functions by adding together the environmental scores from Table 10.2 and the socio-economic scores from Table 10.4. The combined scores shown in table 10.5 can then be ranked to provide a final overall assessment of the threats.

	Environmental assessment						
	Cumulative magnitude	**Cumulative reversibility**	**Cumulative extent**	**Cumulative trend**	**Total environmental score**	**Total socio – economic score**	**Combined score**
Threat X	Total score for function A to N	Total score for function A to N	Total score for function A to N	Total score for function A to N	**Total of cumulative functions value for threat X**	**Method 1 + Method 2**	+
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
Threat Z	Total score for function A to N	Total score for function A to N	Total score for function A to N	Total score for function A to N	**Total of cumulative functions value for threat Z**	**Method 1 + Method 2**	+

Using loss of soil organic matter as an example from Table 10.5, the total score of 58 for environmental impacts is added to the total score of 31 for socio-economic impacts in order to generate a combined score of 89 that is ranked against the combined scores for all the other threats.

Table 10.5 can therefore be used to ascertain the relative significance of threats to soil functions, taking into account both environmental and socio-economic factors.

As indicated in the footnotes to Tables 10.4 and 10.5, socio-economic impact assessments for contamination are only available for 'contamination' (i.e. contaminated land) or atmospheric deposition. Unfortunately, the socio-economic impacts of atmospheric deposition cannot be allocated with any sufficient degree of certainty to any general or specific type of diffuse contamination. For example, atmospheric deposition does not equate to acidification and eutrophication specifically, as eutrophication can also result from the application of fertilisers and manures to agricultural land. Similarly, it does not equate to diffuse pollution in general, as various types of diffuse contamination can arise from the application of fertilisers, sewage sludge and industrial waste materials to agricultural land. For these reasons it was not possible to use the figures for atmospheric deposition in Table 10.4 against any type of threat listed in Table 10.5, and there are, therefore, no aggregate socio-economic scores available for any of the diffuse sources of contamination.

Annex 3 State of knowledge on pressures on soil biodiversity

This annex presents information on current understanding of pressures known to have, or likely to have an impact on soil biodiversity in Scotland. The quality of knowledge is characterised by one of the following five classes:

(√√) = where impacts have been detected in Scotland;

(√) = where impacts have been detected elsewhere and expected to be relevant to Scotland;

(O) = where impacts are expected in Scotland but no evidence yet available;

(#) = where no impact is expected in Scotland based on current understanding;

(?) = where we don't know.

Pressure	Example	Microbial[1]	Inverte-brates[2]	Higher animals[3]	Biologically driven processes[4]
Climate change	Elevated CO_2	√	√	O	√
	Temperature increases	√	√√	O	√√
	Drought	√	√	O	√
	Flooding	√	√	O	√
	Sea level rise	O	?	O	?
	Others, e.g. snow cover	O	O	O	√
	Migration of native species	O	√	O	?
Land use change	Agricultural expansion	√	√√	√	√√
	Forestry expansion	√	√√	√	√
	Habitat restoration	√√	√	√	√
Land management practises	Tillage	√√	√√	√	√
	Overgrazing	√√	√√	√	√√
	Agrochemicals	√√	√√	O	√√
	Organic amendments	√√	√√	O	√√
	Drainage	√√	√√	O	√√
	Genetically modified organisms/genetically modified microorganisms	#	#	O	√
	Change in crop/tree species	√√	√√	O	√√

Pressure	Example	Microbial[1]	Inverte-brates[2]	Higher animals[3]	Biologically driven processes[4]
Loss and damage of habitats	Successional vegetation change	√√	√√	O	√√
	Burning	√√	√√	√	√√
	Over harvesting/foraging	√√	O	O	?
	Soil loss	√√	√	O	√√
Development	Soil handling/storage and reuse	√	√	√	√
	Soil compaction	√	√	O	√
	Sealing	√√	O	O	O
Invasive non-native species	Invertebrates	O	√√	O	O
	Vascular/lower plant/fungus	√	√√	O	O
Contamination	Acidification/Eutrophication	√√	√√	O	√√
	Heavy metals	√√	√√	O	√√
	Organic pollutants	√	√	O	√

[1] e.g. bacteria, fungi, microbial community structure, protozoa, etc.

[2] e.g. those which have all or part of their life-cyle in the soil (collembola, earthworms, nematodes, community structure, bees, etc.).

[3] e.g. mammals, birds and reptiles.

[4] e.g. greenhouse gases, enzymes, decomposition, aggregation, etc.

Annex 4 List of soil biodiversity species

The soil biodiversity species list shown here is extracted from the Scottish Biodiversity List (2005) and the UK Biodiversity Action Plan species list. It was developed from expert judgment and available information on species, and is not an exhaustive list. The list will be updated with new evidence on soil fauna when it becomes available.

Most species derive from the Scottish Biodiversity List, which is a list of animals, plants and habitats that Scottish Ministers consider to be of principal importance for biodiversity conservation in Scotland. The purpose of the Scottish Biodiversity list is to help public bodies carry out their biodiversity duty by identifying the species and habitats that are the highest priority for biodiversity conservation in Scotland. See the following SNH web page for details:

- http://www.snh.gov.uk/protecting-scotlands-nature/biodiversity-scotland/scottish-biodiversity-list/

Soil biodiversity, for the purpose of this assessment, is described as including all organisms that spend part, or all, of their life cycle in the soil for feeding, nesting, hibernating, or foraging such as:

- microbial organisms;
- insects and other invertebrates;
- higher animals including mammals, birds and reptiles.

Plants, although important for soil biodiversity, are not considered here. Algae and slime mould are also not considered.

Group	Species name	Common name (if known)	Comment
Mammal	*Arvicola terrestris*	European Water Vole	Burrows excavated within the banks of rivers
Mammal	*Lepus europaeus*	Brown Hare	
Mammal	*Lepus timidus*	Mountain Hare	
Mammal	*Lutra lutra*	European Otter	Excavated burrow
Mammal	*Meles meles*	Eurasian Badger	
Mammal	*Microtus arvalis*	Common Vole	Excavated burrow
Herptile	*Bufo calamita*	Natterjack Toad	Hibernates in sandy soil in winter
Herptile	*Lacerta agilis*	Sand Lizard	Lays eggs in sand in spring/ summer and hibernates in sandy soil during winter
Bird	*Alcedo atthis*	Common Kingfisher	Burrows in sandy river banks
Bird	*Fratercula arctica*	Puffin	Nests in cliff soil burrows
BIrd	*Hydrobates pelagicus*	European Storm-petrel	
Bird	*Oceanodroma leucorhoa*	Leach's Storm-petrel	
Bird	*Puffinus puffinus*	Manx Shearwater	
Insect	*Ammophila sabulosa*	Red Banded Sand Wasp	
Insect	*Andrena cineraria*	Grey Mining Bee	

Group	Species name	Common name (if known)	Comment
Insect	*Andrena helvola*		
Insect	*Andrena marginata*		
Insect	*Andrena nitida*		
Insect	*Andrena ruficrus*		
Insect	*Anoplius concinnus*		
Insect	*Astata pinguis*		
Insect	*Bombus distinguendus*	Great Yellow Bumble Bee	
Insect	*Bombus monticola*	Mountain Bumble Bee	Nests within tunnels in the ground made by other mammals
Insect	*Bombus ruderarius*	Red-tailed carder bee	
Insect	*Colletes daviesanus*		
Insect	*Colletes floralis*	Northern colletes	
Insect	*Colletes fodiens*		
Insect	*Crabro peltarius*		Nests in dry soil burrows
Insect	*Crossocerus quadrimaculatus*	4-Spotted digger wasp	
Insect	*Dicranomyia omissinervis (=Limonia)*	A cranefly	
Insect	*Dictenidia bimaculata*	A cranefly	
Insect	*Diodontus tristis*	Melancholy black wasp	Nests in sandy soil
Insect	*Dysmachus trigonus*	Robber fly	Overwinters as larvae and pupates in the soil
Insect	*Formica exsecta*	Narrow-headed ant	
Insect	*Formica fusca*	Negro ant	
Insect	*Formicoxenus nitidulus*	Shining guest ant	
Insect	*Hedychridium ardens*		Parasitic of soil nesting species
Insect	*Lasioglossum fulvicorne*		
Insect	*Lasioglossum smeathmanellum*		
Insect	*Lasioglossum villosulum*		
Insect	*Lindenius albilabris*		
Insect	*Mycomya rosalba*	A fungus gnat	Larvae feed on soil root/fungi
Insect	*Nephrotoma aculeata*	A cranefly	Sandy river bank
Insect	*Nephrotoma analis*	A cranefly	Sandy river bank
Insect	*Nephrotoma cornicina*	A cranefly	Wide range of soil types
Insect	*Nephrotoma guestfalica*	A cranefly	Sandy river bank
Insect	*Nephrotoma lunulicornis*	A cranefly	Sandy river bank
Insect	*Nigrotipula nigra*	A cranefly	Peaty moist soil
Insect	*Nomada fabriciana*	Fabricius' nomad bee	Parasitic of soil nesting species
Insect	*Oxybelus uniglumis*	Common spiny digger wasp	

Group	Species name	Common name (if known)	Comment
Insect	*Priocnemis schioedtei*		
Insect	*Procas granulicollis*	Weevil	
Insect	*Phronia persimilis*	A fungus gnat	Larvae feed on soil root/fungi
Insect	*Phronia sylvatica*	A fungus gnat	Larvae feed on soil root/fungi
Insect	*Prionocera pubescens*	A cranefly	
Insect	*Rhadiurgus variabilis*	A cranefly	Larvae in sandy soil
Insect	*Rymosia speyae*	A fungus gnat	Larvae feed on soil root/fungi
Insect	*Spiriverpa lunulata*	A predatory fly	In sandy soils of river (banks)
Insect	*Tachysphex pompiliformis*		
Insect	*Tipula bistilata*	A cranefly	
Insect	*Tipula cava*	A cranefly	
Insect	*Tipula hortorum*	A cranefly	
Insect	*Tipula invenusta*	A cranefly	
Insect	*Tipula laetabilis*	A cranefly	
Insect	*Tipula limbata*	A cranefly	
Insect	*Tipula luridorostris*	A cranefly	
Insect	*Tipula marginella*	A cranefly	
Insect	*Tipula melanoceros*	A cranefly	
Insect	*Tipula pabulina*	A cranefly	
Mollusc	*Arion hortensis*	Slug	
Mollusc	*Cecilioides acicula*	Blind (or agate) snail	
Mollusc	*Truncatellina cylindrica*		
Fungus	*Abortiporus biennis*		Root pathogen
Fungus	*Amanita nivalis*		Ectomycorrhyizal
Fungus	*Armillaria ectypa*	Marsh honey fungus	Litter
Fungus	*Bankera fuligineoalba*	Drab tooth fungus	Ectomycorrhizal - pinus
Fungus	*Boletopsis leucomelaena*	Poroid fungus	Ectomycorrhyizal
Fungus	*Boletopsis perplexa*	Black falsebolete	Ectomycorrhizal - pinus
Fungus	*Calocybe onychina*	Lilac domeca	Saprotrophic
Fungus	*Camarophyllopsis atropuncta*		Saprotrophic
Fungus	*Camarophyllopsis foetens*		Saprotrophic
Fungus	*Camarophyllopsis micacea*		Saprotrophic
Fungus	*Camarophyllopsis schulzeri*		Saprotrophic
Fungus	*Cantharellus ferruginascens*	A chanterelle	Ectomycorrhyizal
Fungus	*Cantharellus friesii*	Orange chanterelle	Ectomycorrhyizal

Group	Species name	Common name (if known)	Comment
Fungus	*Cantharellus melanoxeros*	Blackening chanterelle	Ectomycorrhyizal
Fungus	*Chrysomphalina chrysophylla*		Saprotrophic
Fungus	*Clavaria incarnata*		Saprotrophic
Fungus	*Clavaria purpurea*		Saprotrophic
Fungus	*Collybia putilla*		Saprotrophic
Fungus	*Collybia racemosa*		Saprotrophic
Fungus	*Coprinus ammophilae*		Saprotrophic
Fungus	*Cordyceps sphecocephala*	Insect parsite	
Fungus	*Cortinarius cyanites*		Ectomycorrhyizal
Fungus	*Cortinarius laniger*		Ectomycorrhyizal
Fungus	*Cortinarius limonius*		Ectomycorrhyizal
Fungus	*Cortinarius orellanus*		Ectomycorrhyizal
Fungus	*Cortinarius porphyropus*		Ectomycorrhyizal
Fungus	*Cortinarius rubicundulus*		Ectomycorrhyizal
Fungus	*Cortinarius saginus = C. subtriumphans*		Ectomycorrhyizal
Fungus	*Cudonia circinans*		Saprotrophic
Fungus	*Cudonia confusa*		Saprotrophic
Fungus	*Cyathus stercoreus*	Dung Bird's Nest	Grow on dung or soil with dung
Fungus	*Cystoderma cinnabarinum* = C. terrei		Saprotrophic
Fungus	*Entoloma aethiops*		Saprotrophic
Fungus	*Entoloma bloxamii*	Big blue pinkgill	Saprotrophic on grass litter
Fungus	*Entoloma excentricum*		Saprotrophic
Fungus	*Entoloma griseorubidum*		Saprotrophic
Fungus	*Entoloma tjallingiorum*		Saprotrophic
Fungus	*Fayodia bisphaerigera* = F. gracilipes		Saprotrophic
Fungus	*Flammulaster limulatus* sl = *F. limulatus* var. limulatus / *F. limulatus* var. litus / *F. limulatus* var. novasilvensis		Saprotrophic
Fungus	*Galerina antheliae*		Saprotrophic
Fungus	*Geastrum fornicatus*	Arched Earthstar	Saprotrophic
Fungus	*Geastrum triplex*	Collared Earthstar	Saprotrophic
Fungus	*Geoglossum atropurpureum*	Dark purple earthtongue	Saprotrophic -indicators of old unfertilised grassland
Fungus	*Geoglossum elongatum*		Saprotrophic
Fungus	*Geoglossum starbaeckii*		Saprotrophic
Fungus	*Gloeoporus dichrous*		Saprotrophic

Group	Species name	Common name (if known)	Comment
Fungus	*Guepinia helvelloides*		Saprotrophic
Fungus	*Gyromitra leucoxantha*		Saprotrophic
Fungus	*Helvella leucomelaena*		Saprotrophic
Fungus	*Hohenbuehelia culmicola*		Litter
Fungus	*Hydnellum aurantiacum*	Orange tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Hydnellum caeruleum*	Blue tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Hydnellum concrescens*	Tooth fungus	Ectomycorrhyizal -pinus-quercus cataneas fagus
Fungus	*Hydnellum ferrugineum*	Mealy tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Hydnellum peckii*	Devil's tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Hydnellum scrobiculatum*	Ridge tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Hydnellum spongiosipes*	Velvet tooth fungus	Ectomycorrhyizal -quercus cataneas fagus
Fungus	*Hygrocybe calciphila*		Saprotrophic
Fungus	*Hygrocybe calyptriformis*	Pink meadow cap	Saprotrophic
Fungus	*Hygrocybe lilacina*		Saprotrophic
Fungus	*Hygrocybe spadicea*	Date-coloured waxcap	Saprotrophic
Fungus	*Hygrocybe xanthochroa*		Saprotrophic
Fungus	*Hygrophorus camarophyllus*		Saprotrophic
Fungus	*Hygrophorus nemoreus*		Saprotrophic
Fungus	*Laccaria maritima*		Ectomycorrhyizal
Fungus	*Lactarius musteus*		Ectomycorrhyizal
Fungus	*Lactarius resimus*		Ectomycorrhyizal
Fungus	*Leccinum salicola*	Willow bolete	Ectomycorrhyizal
Fungus	*Leccinum vulpinum*		Ectomycorrhyizal
Fungus	*Leucocortinarius bulbiger*		Ectomycorrhyizal
Fungus	*Lycoperdon caudatum*	Pedicelled puffball	Saprotrophic
Fungus	*Marasmius hudsonii*		Saprotrophic
Fungus	*Melanoleuca schumacheri*		Saprotrophic
Fungus	*Microglossum olivaceum*	Earth-tongue	Saprotrophic
Fungus	*Multiclavula vernalis*		Saprotrophic
Fungus	*Mycena aurantiomarginata*	Saprotrophic	
Fungus	*Mycena picta*		Saprotrophic
Fungus	*Mycena urania*		Saprotrophic
Fungus	*Octavianina asterosperma*	Ectomycorrhyizal	
Fungus	*Omphalina galericolor*		Saprotrophic
Fungus	*Otidea cantharella = Flavoscypha cantharella*		Saprotrophic

Group	Species name	Common name (if known)	Comment
Fungus	*Otidia phlebophora = Flavoscypha phlebophora*		Saprotrophic
Fungus	*Phellodon confluens*	Tooth fungus	Ectomycorrhyizal -betula quercus cataneas fagus
Fungus	*Phellodon melaleucus*	Tooth fungus	Ectomycorrhyizal -pinus quercus, betual, fagus,castanea
Fungus	*Phellodn niger*	Black tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Phellodon tomentosus*	Tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Phylloporus pelletieri*	Golden gilled bolete	Ectomycorrhyizal - alnus , betual, castanea
Fungus	*Plectania melastoma*		Saprotrophic
Fungus	*Pluteus pellitis*		Saprotrophic
Fungus	*Polyporus umbellatus*	Umbrella polypore	Wood parasite fruit form the ground near base of tree
Fungus	*Psathyrella caput-medusae*		Saprotrophic
Fungus	*Pseudoplectania nigrella*		Saprotrophic
Fungus	*Pterula caricis-pendulae*		Saprotrophic
Fungus	*Ramaria botrytis s.l.*		Ectomycorrhyizal
Fungus	*Rhodocybe gemina*		Saprotrophic
Fungus	*Ripartites tricholoma*		Saprotrophic
Fungus	*Russula aurantiaca*		Ectomycorrhyizal
Fungus	*Russula aurea = R. aurata*		Ectomycorrhyizal
Fungus	*Russula badia*		Ectomycorrhyizal
Fungus	*Russula intermedia = R. lundellii*		Ectomycorrhyizal
Fungus	*Russula laccata including R. norvegica*		ectomycorrhyizal
Fungus	*Russula lilacea*		Ectomycorrhyizal
Fungus	*Russula minutula*		Ectomycorrhyizal
Fungus	*Russula pelargonia*		Ectomycorrhyizal
Fungus	*Russula raoltii*		Ectomycorrhyizal
Fungus	*Russula rutila*		Ectomycorrhyizal
Fungus	*Russula solaris*		Ectomycorrhyizal
Fungus	*Sarcodon glaucopus*	Tooth fungus	Ectomycorrhyizal -pinus
Fungus	*Sarcodon scabrosus*	Tooth fungus	Ectomycorrhyizal - cataneas quercus
Fungus	*Sarcodon squamosus = S. imbricatus*	Scaly fungus	Ectomycorrhyizal -pinus
Fungus	*Sarcoscypha coccinea*	Scarlet elf cup	Saprotrophic
Fungus	*Squamanita paradoxa*		Mycoparasite
Fungus	*Squamanita pearsonii*		Mycoparasite
Fungus	*Stropharia hornemanii*		Saprotrophic

Group	Species name	Common name (if known)	Comment
Fungus	*Tricholoma aestuans*		Ectomycorrhyizal
Fungus	*Tricholoma apium*		Ectomycorrhyizal
Fungus	*Tricholoma colossus*	Giant knight	Ectomycorrhyizal -pinus
Fungus	*Tricholoma robustum*	Riobust Knight	Ectomycorrhyizal -pinus
Fungus	*Tricholoma stans*		Ectomycorrhyizal
Fungus	*Tulostoma niveum*	White stalk puffball	Saprotrophic

Annex 5 Scottish sites, regional and national survey and monitoring schemes recording data on soil biodiversity (see Annex 1 for details on schemes)

Group	Survey/site	NSIS_2	CS	SEWS	ECN	Native Pinewood survey	MOORCO	Micronet	NERC SoilBio	Sludge Exp
	Years	2007–2009	1998 (X) 2007 (+)	1995, 2010	1998 on				1997–2004	1995 on
	Habitat extent	All broad habitats and a few priority habitats	All broad habitats	Arable and improved grassland	Montane, managed acid grassland	Priority habitat	Moorland - birch succession	Managed acid grassland	Managed acid grassland	Improved grassland
Group	**Organism**									
Microbial	Bacteria	X	+					X	X	X
	Fungi	X						X	X	X
	Microbial community structure	X	+				X	X	X	X
	Protozoa							X	X	
Inverte-brate	Nematodes		+			X			X	
	Microarthropods		X			X	X		X	
	Earthworms			X					X	
	Others				X *(tipulid)*				X	
Functional	Microbial activity	X	+						X	X
	Greenhouse gas emissions								X	
	Enzyme activities		+						X	
	Carbon utilisation	X	X+						X	X
	Organic matter decomposition								X	

* Mammal surveys are not presented here.

NSIS_2, National Soil Inventory of Scotland-resampling; CS, Countryside Survey; SEWS, Scottish Earthworm Survey; ECN, Environmental Change Network; MOORCO, moorland colonisation by birch and pine, and the consequences for biodiversity; Micronet, SEERAD-funded programme on soil microbial ecology; NERC SoilBio, NERC soil biodiversity; Sludge Exp, long term sludge experiments.