SCOTLAND'S SOIL RESOURCE –

current state and threats

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SCOTLAND’S SOIL RESOURCE – CURRENT STATE AND THREATS

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SCOTLAND'S SOIL RESOURCE – CURRENT STATE AND THREATS

Executive Summary

Objectives

The overall aim of this report is to collate information about the state of Scottish soils and the pressures that affect their ability to support the range of vital functions upon which we rely. These include:

- Providing the basis for biomass production from our agricultural and forestry industries.
- Present and future existence of nationally and internationally valued habitats.
- Regulating our water supply and protecting it from contamination.
- Storing carbon.
- Sustaining biodiversity.
- Providing a foundation for buildings and roads.

The review is a critical assessment of the current evidence. The report sets out to identify important information gaps and make suggestions and recommendations as to how these might be addressed.

Scotland's Soil Resource

Soil is essentially a non-renewable resource and is fundamentally one of Scotland's most important assets. Its most widely recognised function is in supporting plant growth but sitting as it does at the interface between the atmosphere, biosphere and underlying rocks it is increasingly recognised for other environmental and ecosystem benefits. It is against this background that the concept of **soil quality** has been developed. Here soil quality is viewed in the wider context of 'fitness for purpose' for the range of functions that we expect soils to perform.

Scotland's soils are diverse and differ markedly from those in the remainder of the UK. The majority have acidic and organic-rich surface layers including large areas of blanket bog up to 8 metres thick. Such soils are often not managed intensively and play important roles in nature conservation, biodiversity and carbon storage and make a highly significant contribution to landscape value. In contrast, soils suitable for arable cropping are limited largely to eastern Scotland. Although relatively small in extent this land has produced some of the highest yields of wheat and barley in the world. Lowland soils in the west of Scotland support very productive pastures and a successful dairy industry.

Based on existing information, Scottish soils are generally of good quality. Only a few soils have high levels of contamination and levels in the remainder are generally low. There is little evidence to suggest that serious soil erosion, compaction or other problems related to land management are occurring widely. Some soils are particularly sensitive to acid inputs, but there is some evidence that this problem is less now. The validity of these statements is however reliant on good, recent soils data, and many of the existing national datasets are around 20-30 years old. Work to determine whether key soil properties (or indicators) are changing with time has begun. A systematic resampling of Scottish soils will start in 2007 but will not be completed until 2009. This initiative together with existing data will give an indication of whether soil properties in Scotland are actually changing. These data are components of the soil information system recommended to augment the data and evidence base.

Key findings and recommendations

This report has systematically and objectively reviewed the available evidence of the current status of Scotland's soils and the threats to these soils. On the basis of this review we have identified both potential and actual threats to Scottish soils and issues pertaining to how we might collate information describing these. The key findings related to specific threats and on some wider issues are given below.

Loss of organic matter

There is some evidence that levels of organic matter in Scottish soils may be declining. If the findings of a large study in England and Wales are replicated here, this could represent a very significant reduction in the UK stock of terrestrial carbon.

Recommendation

The status and change in soil organic carbon content in Scottish soils should be determined as a priority. SEERAD have already committed funding to achieve this within their research programme, but opportunities to expand this should be explored.

Climate change

It is very difficult to predict what might happen to our soils given the uncertainty attached to climate models. The effects might range from direct impacts on key soil properties, for example, soil organic matter content to indirect ones that affect soil management.

Recommendations

1. The status of and change in soil organic carbon in Scottish soils should be determined as a priority.
2. Any proposals for irreversible change of use to agricultural land should be carefully considered; where possible land of poorer quality should be substituted.

Loss of Biodiversity

The diversity of life (invertebrates and microorganisms) in soils is vast and un-explored. Soil biodiversity is therefore a true scientific frontier. The major impediment to evaluating any loss in biodiversity is the lack of systematic data that describes its current status, how it varies spatially and temporally as well as the key links between biodiversity and function. Work has already identified strong relationships between rare or valued habitats and rare and valued soils in Scotland and in the short term, this offers the best opportunities of filling this knowledge gap. There is evidence that contamination by heavy metals may alter and reduce specific components of the microbial community.

Recommendations

1. Further work is recommended to increase both our knowledge of soil biodiversity on designated sites and to increase our awareness and understanding of the role of soils in valued habitats.

2. Where there is evidence of biodiversity loss due to contamination or invasive species a full ecological risk analysis should be undertaken and a precautionary approach be adopted
3. Consideration should be to explicitly include soils in site designation criteria and in habitat action plans.

Structural degradation and compaction

Although compaction and structural degradation does occur on cultivated soils the incidence is localised and there is no clear evidence that these pose serious threats to soil quality nationally. In most circumstances the problem can be readily reversed.

Recommendation

Consideration should be given to the establishment of protocols to determine structure and compaction as part of the assessment procedures for farm monitoring of the GAEC requirements. The guidelines established for the Forestry sector provide a useful starting point. Such protocols would help fill the gaps in knowledge on the extent and impact of compaction.

Soil Erosion

Although soil erosion does occur on cultivated mineral soils and the impacts can be very visible and damaging, single events are confined to small areas. There is no clear evidence that it poses serious threats to soil quality and can be readily rectified. Erosion of organic soils is more evident and potentially could increase in frequency and severity under certain climate change scenarios.

Recommendations

1. Consideration should be given to the establishment of protocols to determine the threat and incidence of soil erosion as part of the assessment procedures required for farm monitoring of the GAEC requirements.
2. More research is required into the mechanisms that trigger peat erosion and into developing mitigation strategies to help reduce its impacts.

Soil Contamination

Based on current evidence most Scottish soils are not heavily contaminated, but there is some emerging evidence that sewage sludge application may be having a negative impact on the long term fertility of some soils. Some historic contamination of soil, for example from acid deposition is showing some signs of recovery.

Recommendation

Given the preliminary status of the evidence, a precautionary approach is recommended with reference to the application of sewage sludges relatively high in zinc to soils.

Soil sealing and mineral extraction

Based on the evidence available, agricultural land is being developed at twice the rate as in the mid 1990s. Soil sealing has a profound effect on the ability of soils to perform other functions and is effectively irreversible. Based on previous data, this development is likely to have occurred on some of our most versatile and productive soils.

Recommendation
In the context of sustainable development and use of our natural resources, it is recommended that information on the area of land developed, its location and the quality of the land be collected systematically.

Cultural Heritage

Cultural soils occur in small areas and archaeological sites, although large in number, are not extensive. The main threats are from erosion and sealing. Recent research indicates that cultural soils occur around a larger number of Scotland's settlements than first thought. There is also evidence that our archaeological record has been reduced in number and extent over the last 150 years. Such losses are irreversible.

Recommendation
The effectiveness of existing policies should be evaluated to provide guidance for the protection of cultural soils, particularly in areas subject to soil sealing. This needs to be supported by a better database for these soils.

Salinisation

The threat from salinisation, which has been identified as significant in a European context, does not currently represent a significant threat to soils in Scotland.

Relative significance of threats to Scottish soils

We used a simple scoring system to rank threats according to their relevance to all soil functions. Threats from **erosion**, **compaction** and **contamination** (other than acidification) were judged to be of localised significance, although they can lead to loss of important functions. They were also assessed as being relatively straightforward to rectify. **Sealing**, **loss of biodiversity** and **acidification** were scored more highly as threats nationally, with sealing affecting almost all soil functions. **Climate change** and **loss of organic matter** were identified as the most significant threats to soil functioning, although there is much uncertainty in the evidence here.

The data and evidence base

For a number of the identified threats, there is a lack or absence of data upon which to make robust conclusions. In particular there is a lack of trend data from which evidence of change in, and damage to, our soils might be determined.

Recommendations

1. A soil information and monitoring system should be established for Scotland. This would provide the platform for the integration of existing and new data and the information necessary for environmental reporting.
2. Consideration should also be given to the establishment of a system similar to the Representative Soil Sampling scheme in England and Wales to ensure that the level of soil nutrients in cultivated land is being maintained at levels suitable for crop growth without compromising the environment.

Overall conclusion

The soil resource of Scotland has developed over many millennia and continues to do so under both natural and human influences. Our soils are generally in good health and this, in large part, has resulted from the sustainable management systems employed by land managers over a prolonged period. A series of threats and pressures have been identified within this report and a number of recommendations made. Some of these relate to filling data gaps in our knowledge of the scale of these threats while others identify gaps in our fundamental understanding of processes that contribute to certain threats. Our analysis of the significance of the threats to Scottish soils has identified two linked threats, climate change and loss of organic matter, as the most significant. Notwithstanding the uncertainties associated with this judgement, there is increasing evidence of the need to safeguard our soil resource for future generations.

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Chapter 1 Introduction

1.1 Why are soils important for Scotland?

Soil is the natural and semi-natural material which forms the uppermost layer of the earth's crust, and covers the land surface. Its most widely recognised function is as the medium in which plants grow. Fertile soil therefore underpins food production for almost all societies. A former president of the United States, Franklin Delano Roosevelt, has said "The nation that destroys its soil, destroys itself."

Soil sits at the interface between the atmosphere, biosphere and the underlying geology and it is increasingly recognised that soil provides a range of environmental "services" well beyond crop growth. The range of environmental, economic and social benefits which soils provide for a country such as Scotland therefore includes:

- **providing the basis of the agricultural and forestry industries**. These industries produce the most tangible economic outputs from our soil resource through the production of crops, livestock and timber and sustain thousands of jobs in rural Scotland. Scotland's agricultural industry is rightly proud of its quality image and branding and a healthy soil resource is vital for this industry.
- **underpinning nationally and internationally valued and rare habitats**. These include blanket peatlands, montane habitats, native pine woodlands and machair grasslands. Such habitats attract thousands of visitors annually and contribute to Scotland's biggest industry, tourism. Again, many of these jobs are in rural Scotland.
- **protecting water from the effects of many pollutants**. Most of the water that we drink will have passed through our soils. In the soil, the acidity of rainfall can be neutralised and contaminants such as trace metals removed by adsorption to soil solids. We need to ensure that we do not exceed the capacity of some soils to treat such pollutants.
- **storing carbon.** Scotland's soils account for some 70% of the terrestrial storage of carbon in Great Britain (Milne and Brown, 1997). Warmer climates and more intensive land use can increase loss of carbon from the soil to the atmosphere. We need to ensure that our soils do not become net emitters of greenhouse gases and further accelerate climate change and manage our soils to maximise this 'environmental service'.
- **contributing to biodiversity**. Many of the organisms that live below ground have biotechnological and pharmaceutical potential.
- **providing a foundation for buildings and roads.** Soil is essentially a non renewable resource and building development is often considered to be irreversible.

1.2 Scotland’s soils

Because of its diverse geology and climate, Scotland possesses a wide variety of different soil types. The diverse topography gives rise to much further local-scale variation in soils and therefore mapping units shown on the 1:50 000 or 1:250 000 encompass a range of soil types with varying properties linked to local variations in slope and landform. A summary of soil classification and mapping procedures used in Scotland is provided in Appendix B and further details can be found in published maps and handbooks (MISR, 1981).

The distribution of the principal soil groups in Scotland is shown in Figure 1.1. Because of the strongly maritime climate with cool temperatures and rocks which are generally resistant to weathering and base cation deficient, Scottish soils are in general more organic, more leached and wetter than those of most other European countries. Scotland contains greater proportions of podzols (23.7% of the land area), peat soils (histosols, 22.5%) and gleys (20.6%) than Europe as a whole. The map also reveals the contrast between soil types in the Midland Valley and those in the Highlands and Southern Uplands. The Midland Valley is dominated by mineral soils whereas the Highlands and Southern Uplands are dominated by peaty soils (peat, peaty gleys and peaty podzols) especially in the west.

Figure 1.1. Principal Soil Types in Scotland.

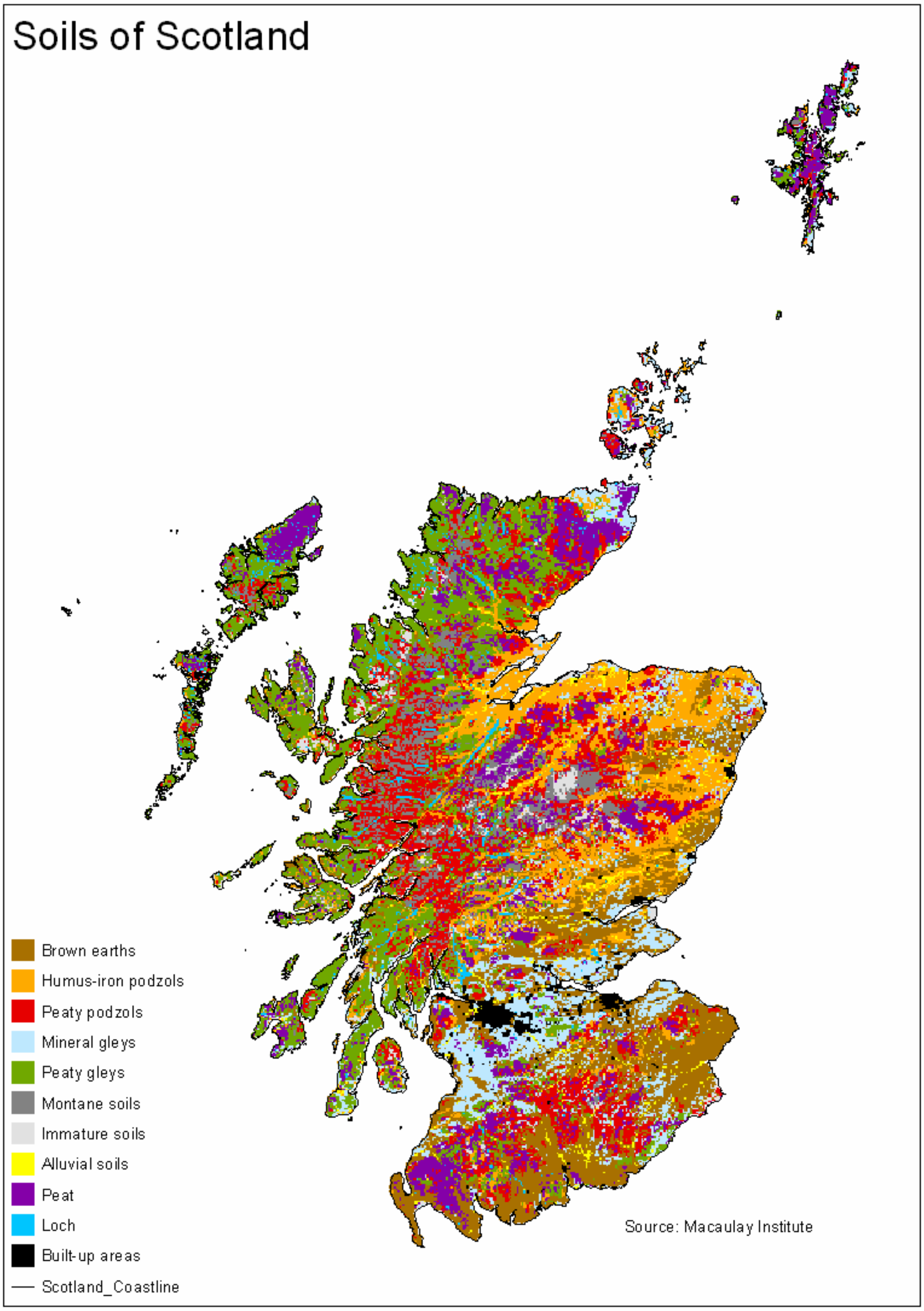
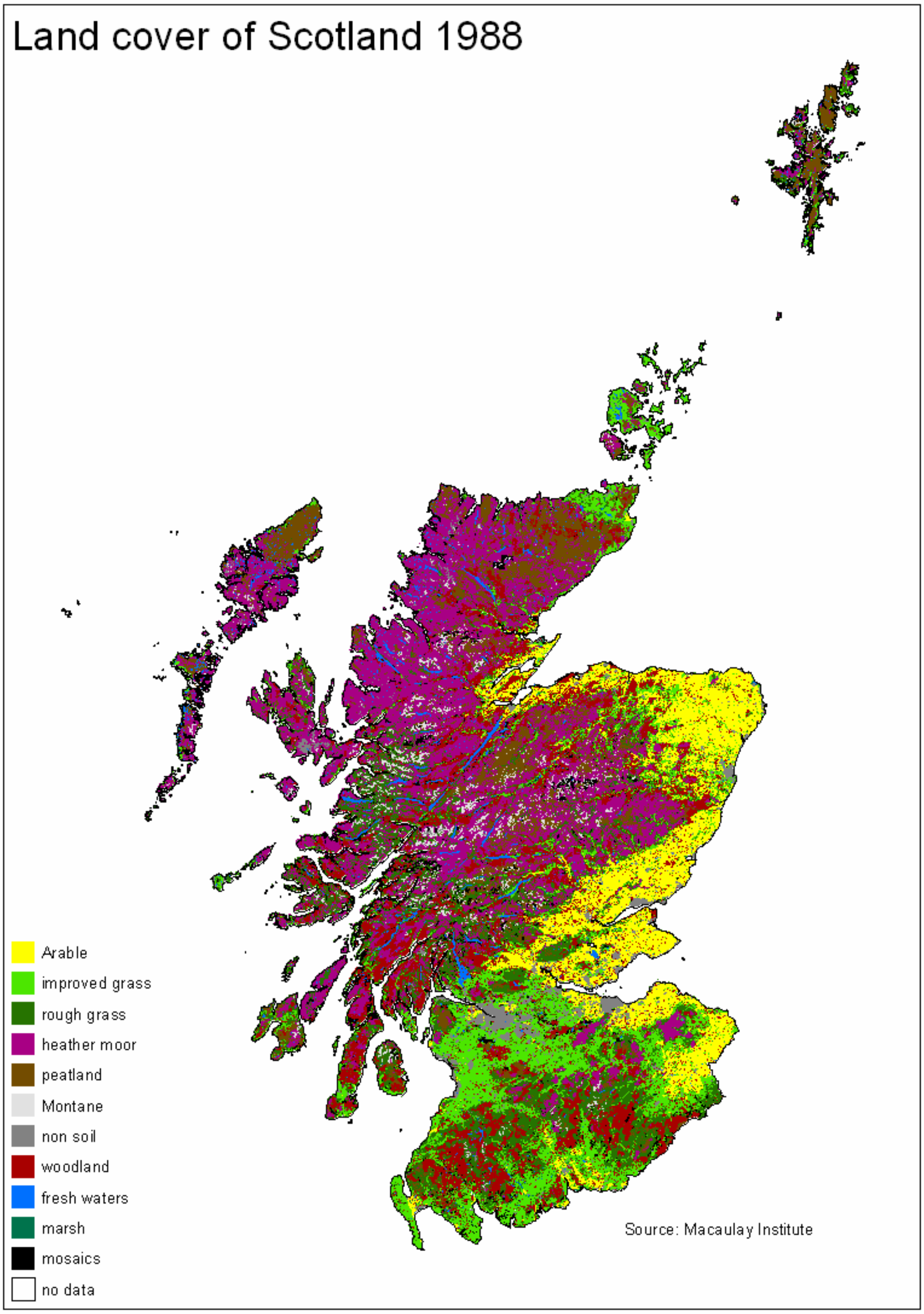


Figure 1.2. Land Cover of Scotland 1988 (LCS88).



This diversity of soil types underlies the wide range of functions associated with Scottish soils. Although almost all soils produce above-ground biomass, the land cover map of Scotland (Figure 1.2) shows that only around 25% of the area of Scotland is used for arable crops and improved grassland, with a further 17% under woodland. Arable crops are primarily located in the eastern half of the country and improved grassland in the south west. The remainder of the country is under semi-natural vegetation such as heather moorland, blanket bog and montane habitats, land covers which are dominant in upland Scotland. Many of these habitats of high conservation value are unique to Scotland and the soils that underpin them are rare in a UK, European and on occasion a global context. Scotland's peat soils account for 46% of the terrestrial carbon storage in Great Britain (Milne and Brown, 1997). The area of semi-natural communities and their underlying soils in Scotland provides an indication of the high importance of Scottish soils for wider environmental functions such as carbon storage, biodiversity or water filtration rather than agricultural crops or forestry production.

1.3 Project aims

The overall aim of this report is to collate information about the state of Scottish soils, the pressures on them and the major risks to them, and to evaluate how current policies protect soils in Scotland. The review is based on the evidence which is available, although it is recognised that there might be a lack of evidence on state of (and trends in) soils. The report will therefore also provide a critical assessment of the quality of the evidence which is available, point out information gaps and suggest how these might be filled.

Soil quality and protection in European countries has been the subject of many reports since the late 1990's. The European Union thematic strategy for soil protection (European Commission, 2002) identified the key soil functions as food and other biomass production, storing, filtering and transforming, habitat and gene pool, physical and cultural environment and a source of raw materials. Although there is no explicit EU soil protection policy, several policy areas impinge on soil protection, including the Water Framework Directive, Common Agricultural Policy and various waste and biocide directives.

In the UK, SEPA (SEPA, 2002) stressed the importance of Scottish soils as a non-renewable resource essential for a sustainable environment and identified the main pressures on soils arising from industry, agriculture and forestry and waste applications to land. It was also noted that 'the lack of data on trends in soil properties make it impossible to assess whether current land use practices and pollutant inputs are sustainable'. A CEH report (CEH, 2002) identified similar threats to Welsh soils and also drew attention to likely pressures from development and from climate change. A later report on the state of the soil resource in England and Wales (Environment Agency, 2004) concluded that there was insufficient good quality information, and that such information was essential for the development of effective policies to protect the resource. This report further highlighted the importance of the water retaining function of soils in lessening flooding problems.

Concerns over the state of the soil resource highlighted in such reports have been followed by moves towards the development of explicit policies such as the Soil

Action Plan for England (2004-2006) (DEFRA, 2004), the development of quality objectives within a soil protection strategy for Ireland (Environmental Protection Agency, 2002) and current development of a soil action plan for Wales as agreed in the Environment Strategy action plan (Welsh Assembly, 2006). The Irish strategy is based on identifying and reviewing existing information, developing key soil quality indicators and a monitoring network for these and developing codes of good practice for soil management (Environmental Protection Agency-Ireland, 2002). Priorities in DEFRA's action plan for England include soil quality indicators and monitoring, education and embedding soil protection within strategy and policy, but the plan places little emphasis on the information base other than a commitment to providing better access to soils information (DEFRA, 2004). The emerging Welsh action plan focuses on soil management, integration of soil protection into land use planning policy guidance, developing appropriate soil indicators, dealing with current and historic pollutants and promoting education and access to information on soil (Welsh Assembly, 2006).

1.4 Objectives

This project had six primary objectives. These were not all of equal importance and as the project developed different weightings were applied to each original objective. The specific objectives are:

1. To pull together existing evidence on the state, extent and diversity of Scottish soils and on land use, through using land use mapping and soil inventories and other relevant published studies (e.g. isolated case studies on soil erosion in addition to national or regional scale information – this could be derived from other studies e.g. sediment loads, greenhouse gas emissions inventory, countryside survey data).
2. To assess the quality of this status information, to identify information gaps and to advise how these might be filled. Objectives 1 and 2, the collation and critical appraisal of the evidence, were considered to be the most important objectives.
3. To identify and quantify the main current and likely future pressures on Scottish soils.
4. To assess gaps in the existing information on pressures on Scottish soils and advise how these might be filled with some justification as to why this needs to be acquired. Objectives 3 and 4, the identification and assessment of pressures, were the next most important objective.
5. To outline existing policies and guidelines which explicitly and implicitly relate to soil, to assess how they impinge on Scottish soils, and to set out where and how Scottish policies differ from elsewhere in the United Kingdom. This was the third most important objective.
6. On the basis of the above evidence, if applicable, to suggest options for a more sustainable use of Scottish soils. Objective 6 is not considered in the present report, but will be the subject of discussion among stakeholders following the launch of the report.

1.5 Approach

The project will use the soil functional approach as a framework for assessing both the status of, and threats to, the soil resource. As indicated earlier, soil is increasingly recognised as having multiple functions. These have been grouped under six key functions in the developing EU soil framework directive (European Commission, 2002) and they also form the basis of the English Soils Plan (DEFRA, 2004). The six key soil functions and their relevance to Scotland are, in brief:

<u>Food and other biomass production:</u>

This is most obvious and tangible of all the soil functions and the one that is easiest on which to put an economic value. A number of threats to the productive capacity of soils are anticipated, including for example damage to soil structure by machinery, application of wastes to land, maintenance of nutrient levels and as direct loss of agricultural land to building development. Although only approximately 25% of Scotland's soils are cultivated, it is important that they are not being irreversibly damaged or unnecessarily lost through sealing for future generations.

<u>Storing, filtering and transforming:</u>

This includes the filtering, buffering and adsorption potential of soils which helps protect water and air quality. River basin management is a requirement under the Water Framework Directive and the maintenance of key soil filtering and transforming functions are fundamental components of this. Scotland is a major sink and potential source of Greenhouse Gases and contains the majority of the UK's reservoir of terrestrial carbon because of the large areas of peaty and organic soils. These soils merit special consideration in the context of the UK's commitments to the Kyoto Protocol.

<u>Habitat and gene pool:</u>

Soils are a reservoir of huge biological diversity, but the contribution of many soil organisms to ecosystem services is largely unknown. Given its scale, the key to conserving soil biodiversity is to manage or protect soils so as to conserve their functions (nutrient supply, water retention and filtration etc.). Soils also support a number of terrestrial habitats of international significance and indeed should be viewed as being an integral part of those habitats. Given the recent completion of the NERC Thematic Research Programme on "Biological diversity and ecosystem function in soil" based at the Sourhope Research Station in the Borders, it is also timely to reflect on the wider implications of the programme's findings for Scottish soils.

<u>Physical & cultural environment:</u>

Soils provide a record of previous cultural influence or environmental change or past environments and also provide a protective cover for subsurface archaeological remains. Scotland has a distinctive range of soils as a result of both specific environmental influences and a long tradition of soil use. In some circumstances soils such as machair soils form an important element of the cultural landscape. In addition, many Scottish soils are rare within a UK and European context and this project will evaluate these, building on past and current work with SNH. The extent to which these soils are at risk will be assessed on the basis of 'group expert judgement' and then the effectiveness of conservation designations (e.g. SSSIs, scheduling by Historic Scotland) will be evaluated.

Source of raw materials:

Peat has a long history of use as a fuel in both Highland Scotland and Ireland, and in past decades there has also been intensive harvesting for horticultural use. The threat to key soil functions such as water retention and storage, filtration and carbon sink from large-scale exploitation of peat and other Scottish soils as sources of raw materials will be reviewed and assessed.

As a platform for built infrastructure:

This function is different from the remainder as once soil is asked to fulfil its 'platform role', it loses, to a large extent, its capacity to fulfil its multi-functional role in the environment. Soil is essentially a non-renewable resource and the consequences of sealing are long term.

1.6 Report structure

Subsequent chapters of the report will present and appraise the evidence relating to major threats to soil functioning in Scotland. These are:

- Loss of organic matter
- Climate change
- Loss of biodiversity
- Compaction and structural degradation
- Soil erosion
- Contamination from heavy metals, pesticides, atmospheric deposition of sulphur and nitrogen ("acid deposition"), past industrial activity and organic contaminants
- Loss of land to building development.
- Loss of cultural heritage such as rare soils or buried archaeological features.

Each chapter will define the threat briefly, indicate the range of soil functions affected, present and assess the evidence and likely future trends, indicate any important gaps in the evidence, and conclude with a statement based on the evidence and the expert judgement of the authors. The concluding chapter will summarise the main findings and identify significant gaps in our knowledge and how these might be addressed.

1.7 Key References

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Chapter 2 Loss of soil organic matter

This chapter describes the importance of soil organic matter in Scottish soils, how Scottish soils differ in this respect compared with some other parts of the UK and a discussion of the status of organic matter and organic carbon in Scottish soils.

2.1 Summary

- Scotland's soils are relatively rich in soil organic matter, particularly in the hills and uplands but also in arable and grassland soils compared with some other parts of the UK. Scotland contains a much higher proportion of organic soils than the rest of the UK.
- Soil organic matter is a key property of soil and helps soils fulfil a large number of functions including mediating climatic conditions through carbon storage (Chapter 3).
- There is some evidence that losses of dissolved organic carbon in streams draining peaty soils have increased in the last two decades implying a possible increase in losses of organic matter from these soils.
- Soil organic matter is being lost through peat erosion and better information on peat erosion processes, how to monitor it, and if possible how to mitigate it are required (Chapter 6).
- Large decreases in organic carbon concentrations of soils in England and Wales, particularly in soils of greater initial organic carbon concentration, have been reported recently; this trend, if also occurring in Scotland, would have serious implications for Scottish soils as a carbon store and in the climate change debate (Chapter 3).
- Maintenance of soil organic matter in soils is a GAEC requirement within the Single Farm Payment.

2.2 Introduction and Description of Threat

Soil organic matter (SOM) is a vital component in soils and helps soils fulfil a large number of functions. Brief outlines of its contributions to the range of soil functions are given below. In addition to these, SOM also has a major role to play in mediating climatic conditions, at a global level, as it is a significant carbon store; any loss of soil organic matter from soils would effectively increase carbon dioxide emissions to the atmosphere.

Organic carbon is measured as a percentage of dried soil or calculated from loss on ignition (LOI) assuming a standard % C in organic matter. Although there is some doubt about the use of the conversion factor of 1.72 between soil organic carbon and soil organic matter, we have taken the view that they can be viewed as synonymous for the purposes of this study. There are known limitations about the LOI method in that soil carbonates can also be burnt off in addition to the soil organic matter and is particularly relevant to some soils in Central Scotland where coal fragments are found. Concern has been expressed about its use in policy formulation, but it does have the distinct advantage that large sample numbers can be handled quickly and it is relatively inexpensive. Other methods do exist but they tend to be slower and more expensive. There is also a need for measurements of bulk density and horizon depths if the absolute amount of C is to be determined as g m^{-2}.

There is growing concern that soil organic matter levels, even within temperate regions such as Scotland, may be at risk due to soil management and global environmental change. Cultivation has been shown to increase accessibility of organic matter stored within natural soil aggregates to decomposer organisms and thereby decreases organic matter concentrations. In general terms, soil organic matter will decompose more rapidly under warmer conditions and if the Scottish climate is on a slowly warming trend (Scottish Executive 2006) then there may be implications for soil organic matter levels. Periodic drought conditions, which themselves are a function of temperature/rainfall interactions, may also be a cause of carbon loss from peaty soils and could be more serious than a temperature increase alone.

Biomass, food and fibre production

There is little hard evidence that a decline in soil organic matter content will adversely affect crop yield in mineral soils (Loveland and Webb, 2003) and there does not appear to be a critical threshold of organic matter in the agricultural soils of temperate regions. However, how much of this is down to continued high fertiliser inputs is unclear. Soil organic matter does increase aggregate stability (Chapter 5) and the water storage capacity of the soil, hence directly influencing plant growth. There is a gradual increase in the uptake of organic farming in Scotland and this will have a beneficial effect on the organic matter status on these soils.

Environmental Interactions

Organic matter contributes to a number of the environmental interaction functions of soil:

- As a carbon store. If soil organic matter levels decline either by emission of carbon dioxide or methane to the air or by physical movement to water courses, this function has clearly diminished. This has clear implications for issues covered in Chapter 3 (Climate change)
- It contributes to aggregate stability with clear evidence that as organic matter levels increase, the mean weight diameter of water-stable aggregates decrease. This reduces the potential for soil compaction and erosion and this effect is particularly marked on sandy soils. Clear differences between arable and pasture soils of the same soil series in organic matter content and aggregate stability have been shown to occur (Chaney and Swift, 1984). These issues are covered in Chapters 5 and 6.
- Contributes to the water holding capacity of the soil and therefore contributes to the potential amelioration or enhancement of flood risk (Chapter 6)
- Contributes to the ability of soil to adsorb and degrade pollutants (Chapter 7).

Support of ecosystems, habitats and biodiversity

The absolute content, type and age of soil organic matter is inextricably linked to soil macro- and mesofauna as well as micrororganisms. However other factors such as soil acidity, soil moisture content and texture also influence biodiversity. Changes in soil organic matter status will change both the soil organism community as well as the ability of the soil to act as the base for semi-natural habitats. There is not a simple relationship between SOM content and biodiversity, but there is some emerging evidence from the Netherlands suggesting that diversity is reduced in soils with low organic matter content which themselves are related to intensity of management (Chapter 4).

Provision of raw materials

Loss of organic matter from soils does not affect its ability to provide sand, clay or topsoil. Some of the decreases reported by Bellamy et al (2005) would suggest that the nature of highly organic horizons are changing radically and may influence the ability of the soil to be used a peat source.

Protection of cultural heritage.

The main potential impact is the increased erosion risk that might occur should soil organic matter levels decline, particularly on sandy soils, thereby providing less protection to the underlying heritage site of interest.

Provision of a platform

Declining soil organic matter levels do not affect this function.

Soil organic matter influences a number of processes across the range of soil functions and is a key soil property. This is particularly the case in Scotland in relation to climate change (Chapter 3) and greenhouse gas (GHG) emissions. Reliable evidence that its current status may be under threat should be taken very seriously; firstly to establish the whether the threat exists and secondly, to identify the processes that are contributing to its decline.

2.3 Policy

Soil organic matter is recognised as a vital component of soils and a number of advisory documents such as the PEPFAA code and the Farm Soils Plan provide practical measures to help maintain soil organic matter levels in cultivated agricultural soils. Until the arrival of the GAEC requirements within the cross-compliance measures that form part of the reform of the Common Agricultural Policy, there was no formal or legislative requirement on farmers to manage their soils with the specific objective of maintaining organic carbon levels. This development represents a significant shift in policy; in addition to maintaining soils in good condition for biomass production, farmers are also required to maintain the carbon stocks within the soil for environmental functions.

Woodland soils generally contain higher levels of organic matter than agricultural soils and it is important that forest management recognises this and seeks to minimise damage to soils and losses of organic matter through ground disturbance. Some preparation techniques can be very intrusive. These issues are addressed at a high level within the UK Forestry Standard. In addition, the recently revised Forest and Soils Guidelines suggest a number of management options, for example cultivation, drainage and thinning regimes, that are aimed at maintaining and enhancing soil organic matter levels. The Scottish Forestry Strategy is currently being revised and amongst the many aims is one to establish new woodlands on soils with low current levels of organic matter to enhance carbon sequestration.

Peat is protected under the Habitats Directive and SSSI legislation for its biodiversity benefits whilst some other SSSIs are designated for their geodiversity and protection of key features of the quaternary period.

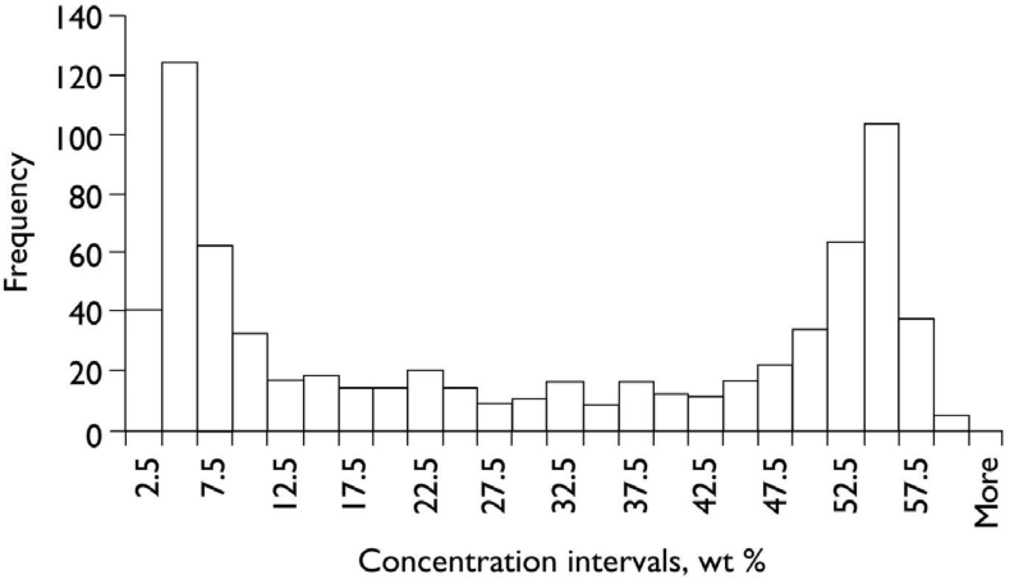
2.4 Evidence

2.4.1 Current status

Virtually all organic matter in Scottish soils is derived from litter fall, subsurface degradation of plant roots, rhizodeposition and exudation and soil organisms. In agricultural areas, some soil organic matter is derived from farmyard manures and slurries. Very little organic matter in soil originates from non-agricultural wastes such as exempt industrial wastes, composts and sewage sludges. although this proportion may be expected to grow in the future (Scottish Water 2006). Some overdeepened, plaggen soils (Chapter 9) have been enriched in organic matter through the addition of seaweed and other turf translocation techniques.

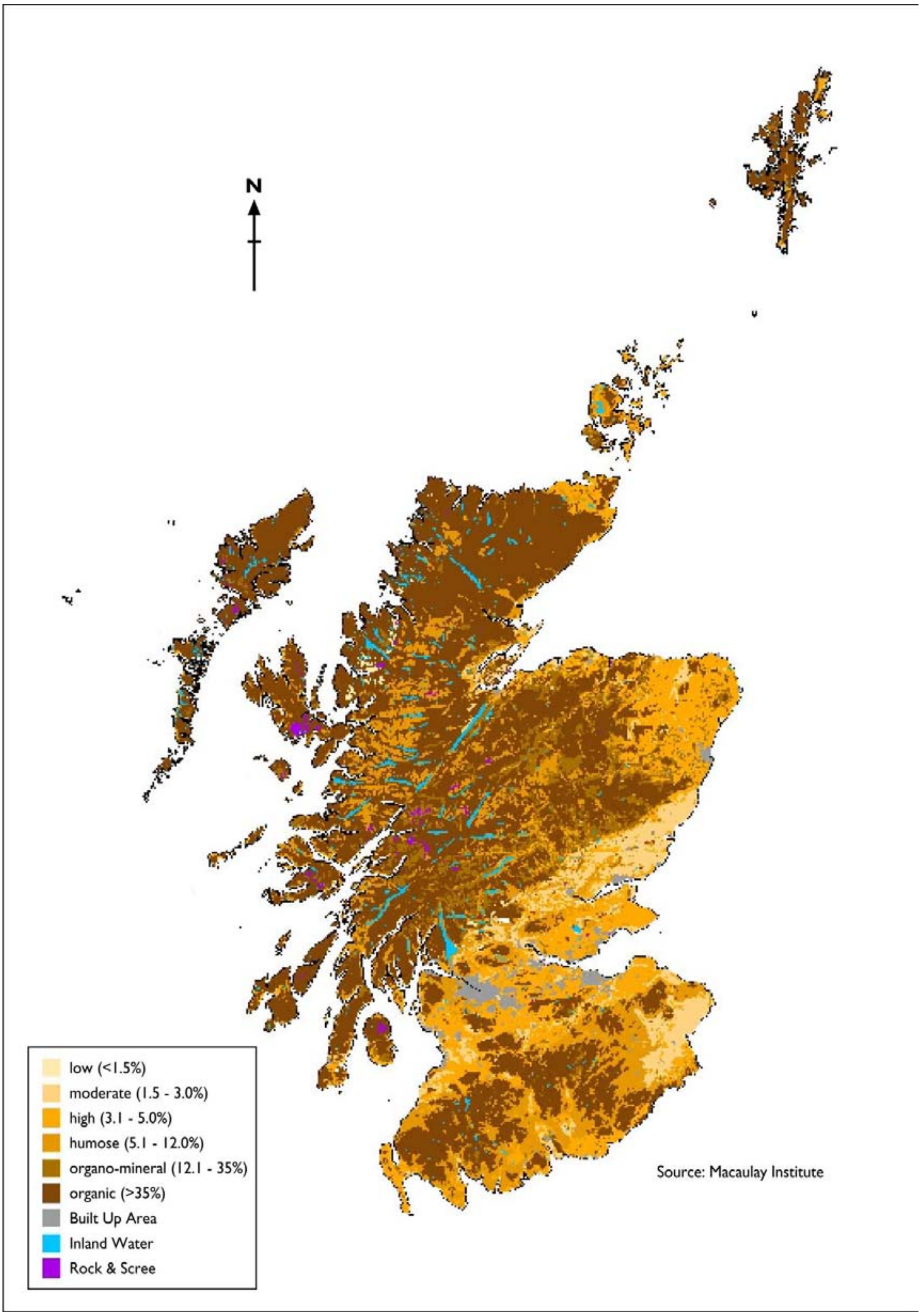
Compared with many other soil properties, the current status of soil organic matter can be characterised relatively well although there are significant limitations due to heterogeneity of soils and lack of measurements of bulk density needed to calculate absolute masses of C in the soil. Soil organic matter and soil organic carbon are two attributes within the Macaulay Institute (MI) soil database and they can be used to give a broad picture of the soil organic matter status of Scottish soils. Figure 2.1 illustrates the distribution of SOM content in the uppermost horizon of the 10 km NSIS datapoints. These data refer to the time period between 1978 and 1987 and a subset of these will be revisited to identify whether these values are still current. A bimodal distribution is apparent. The peak at around 5% organic carbon represents the bulk of the agricultural soils in Scotland whilst the peak at around 55% represents many of the blanket peat sites and other organo-mineral soils such as peaty podzols and peaty gleys. Compared with soils in England and Wales, even the mineral soils have higher levels of organic carbon than their counterparts south of the border (Bradley et al., 2005).

Figure 2.1 The frequency distribution of carbon content in the uppermost horizon of the soils sampled at 721 sites on the10 km grid National Soils Inventory Scotland



Additional information in the database has been linked to the 1: 250,000 scale soil map to produce an indicative map of soil organic matter content within the uppermost soil horizon across the country (Figure 2.2). This map provides a summary of data that was captured over a prolonged time period from the 1950s until the 1980s and this must be borne in mind when it is interpreted.

Figure 2.2 Topsoil organic carbon content



Source: Macaulay Institute

There is a clear separation between the highly organic soils throughout much of the Highlands and the Southern Uplands and those on the predominantly cultivated soils of the Central Valley and NE Scotland where much lower levels are present. Most of the cultivated land in Scotland has moderate or high levels (5-10%) of organic matter. High soil organic matter levels exist in the Highlands and Southern Uplands where the cooler and wetter climate conditions inhibit the decomposition of organic matter in plant material deposited on the soil surface. In such areas, the accumulation of organic matter is often more rapid than decomposition and an organic surface horizon forms. On level or gently sloping sites the total accumulation can be as much as 7-8 metres.

Although data on the C content of Scottish soils is relatively good, it must be remembered that these cannot be translated directly into carbon stocks; bulk density of each soil horizon must also be considered. Bradley et al. (2005) have reported on the development of a database of soil carbon and land use and have estimated that Scotland contains 48% of the carbon stocks in soils in the UK down to a depth of 100 cm. The carbon stock in the top 30 cm in organic soils under semi-natural vegetation is similar to that contained in the same depth of mineral grassland soil. In both it is estimated to be 16 kg m^{-3}. This is despite the fact that soils under semi-natural vegetation having approximately ten times the amount of carbon (as a % weight) than the soils under pasture. The much lower bulk density of organic horizons negates its higher % C content. This paper also indicates that the total stock of carbon in Scottish soils to one metre depth (2,187 Tg C) is split approximately equally between 0-30 cm depth and 30-100 cm depth. Estimates of C stocks below 100 cm depth are currently being determined as part of the ECOSSE project funded by the Scottish Executive, but it is inevitable that this addition will bring Scotland's total contribution well above 50%. Previous estimates have put this figure at 71% (Milne and Brown, 1997) and it will be interesting to compare the new estimate to this. It is impossible to get a truly definitive estimate of SOM, but the importance of soil as a carbon stock is emphasised by the fact that in the whole of Great Britain, it holds between 80 and 90 times more carbon than the vegetation.

2.4.2 Data availability

Organic matter is reasonably well characterised for the period 1978-1987 in the NSIS. The other data held within the MI soils database comprise data with an inherent bias as the soils were selected subjectively in order to characterise soil series, but some very detailed grid and transect data (between 10 and 50 m spacing) also exist and give detailed estimates of spatial variability.

There are also monitoring data from the Countryside Survey and a limited number of Scottish Water and FC data. Data will also be available within the UK Soil and Herbage study (pending) although this is at a much wider sampling density than the NSI. A number of very detailed surveys of peat bogs exist throughout Scotland where depths were measured along transects and a number of attributes measured including degree of decomposition (the Van Post Humification index), moisture and ash content. The peat surveys were largely carried out between 1949 and 1961 and as such provide a unique record of the depth and state of Scottish bogs at that time. There will also be data coming on stream from the EU BioSoil survey and monitoring project. More information on these datasets can be found in Appendix A.

2.5 Gaps in data / evidence

There has been no systematic investigation into reductions in soil C levels, although data are being collected from heathland sites where birch has been planted as part of the SEERAD funded ECOSSE project. Indirect evidence exists in the form of increased concentrations of dissolved organic carbon (DOC) in stream waters draining upland catchments where soils are dominantly peaty. Data published by McCartney et al. (2003) show a clear rising trend in DOC concentrations in a stream draining a mature forest catchment near Loch Ard in west-central Scotland from around 5 mg l^{-1} in the early 1980s to around 16 mg l^{-1} in 2003 (Fig. 2.3). There also appears to be a trend towards higher values in extreme events from 1995 onwards. A similar although less dramatic trend is seen at the Glensaugh Environmental Change Network (ECN) site (Fig. 2.4).

Worrall et al (2003) summarised data from 198 streams within the UK (155 in Scotland). These showed a statistically significant increase in DOC concentrations at 77% of the 198 sites. The remaining 23% showed no trend and no sites showed a decrease. The trends were independent of regional effects of rainfall, acid and nitrogen deposition and land use change. The mean annual increase was 0.17 mg l^{-1}, which is similar to the increase seen at the Glensaugh ECN site.

Further work has investigated whether these changes can be linked to climate change (Worrall et al., 2004; Freeman et al., 2004) but both have cast doubt on whether climate warming on its own offers satisfactory explanations. Recovery from acidification (Chapter 7) may be the trigger for these increases in DOC levels.

Figure 2.3 DOC losses from a site near Loch Ard, Central Scotland, over a 16 year period.

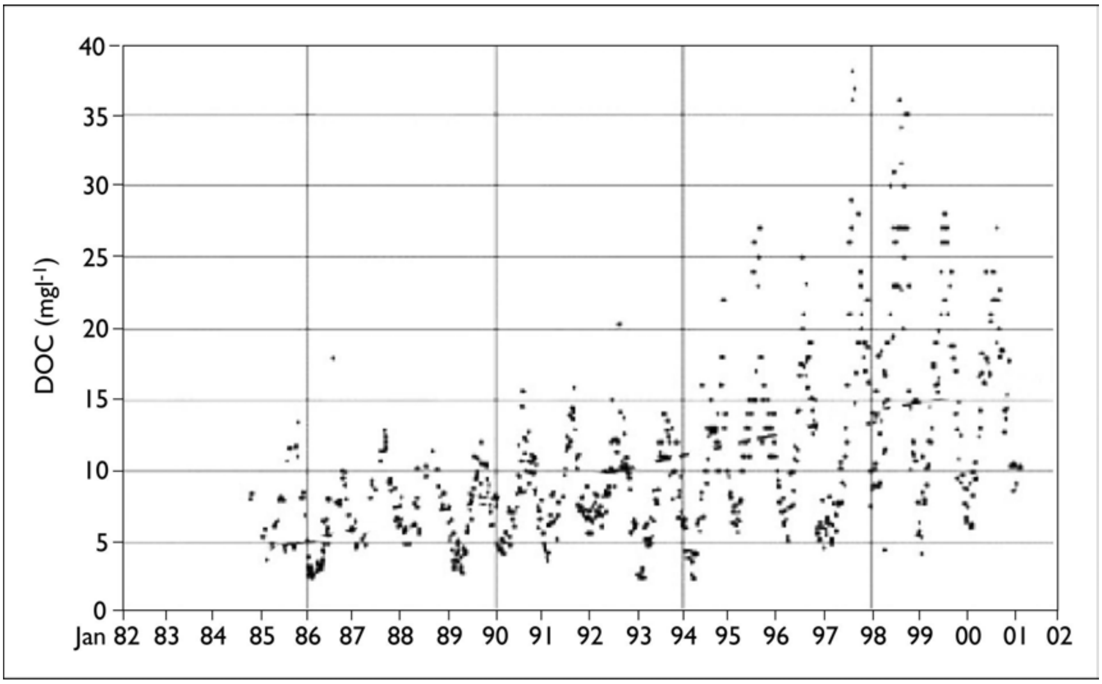
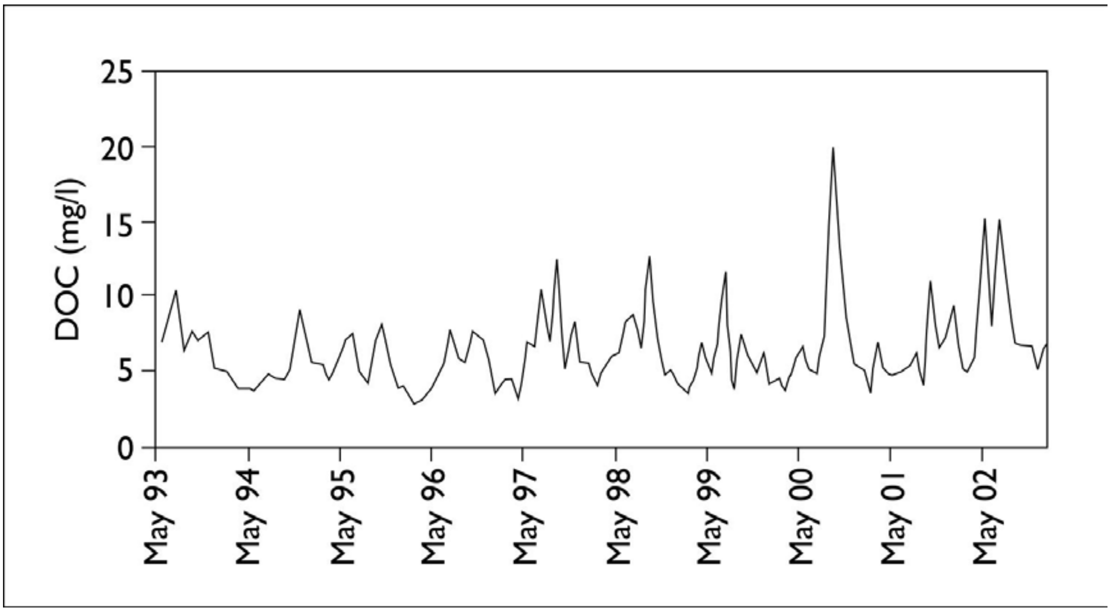


Figure 2.4 DOC concentrations from the Glensaugh ECN site.



There is direct evidence of decreases in soil carbon concentrations from England and Wales with the largest changes found in soils with the largest initial carbon concentrations (Bellamy et al., 2005). This study was based on a comprehensive phased and partial resampling of the NSI in England and Wales which achieved a 40% revisiting of the original sample sites. The details are:

- 1994-95 (arable and rotational grassland sites n = 853, 33% of the original)
- 1995-96 (permanent grassland sites n = 771, 49% of the original)
- 2003 (non-agricultural sites n = 555, 37% of the original)

Overall a 40% revisiting of the original sample population was achieved.

Soils with low (<3%) original soil organic carbon values showed very small increases in soil carbon but for the remainder of the soils, all showed decreases in soil organic carbon. These decreases increased in proportion to the original organic carbon content and were greatest for upland soils with organic surface horizons. For soils with carbon contents of greater than 10% (100 g kg^{-1}), the rate of decrease was 2% per year. Reference to Figure 4.1 indicates that this is very relevant in the context of Scottish soils although no comparable data are available for Scotland. Without additional data (bulk density and soil depths) they do not prove that there has been any decline in the absolute amounts of C in the soil. What it does say is that there has been a decline in organic carbon within the upper 15 cm of the soil compared with the initial sampling period. Whether these declines are similar in scale to the increases in DOC observed requires more detailed examination.

The paper does not attempt to identify the mechanism that has caused this decline or where the carbon has gone. It is fair to say that the findings have surprised the soil science community and that more work is required to identify the causes. Defra have carried out an independent analysis of the raw data and found that the C loss that they calculate is similar to that reported by Bellamy et al (2005). The report also outlines the importance of bulk density (which was not measured) in any calculation of carbon stocks and the absence of any information on management changes that might have been partly responsible for C increase or decrease.

Soils are traditionally thought of as sinks for carbon, primarily peats and other soils with highly organic surface horizons and Chapman et al. (2001) summarized carbon accumulation rates on a range of soils and land use systems. These varied from around 20 up to 200 g C m^{-2} a^{-1} on different types of peatland although it was acknowledged that these rates are very difficult to measure. However, these figures estimate the rate at which organic carbon accumulates at the soil surface suggesting that organic matter (and therefore carbon) depth is increasing, whereas the results produced by Bellamy et al (2005). suggest a reduction in the C concentration (rather than depth). Chapman *et al.* (2001) also indicate that podzols and other organo-mineral soils have reached equilibrium. It is not clear from the work of Bellamy et al (2005). precisely what type of soil is contributing to the biggest losses, but there do appear to be conflicting messages between C accumulation in peats in their 'building' phase and the reported reduction in C concentration in these soils.

Although we have information on the extent and location of peat erosion (Chapter 6), we do not have any data on whether erosion events are becoming more common, more intense or both? This is clearly another potential source of carbon loss from soil. Climate change may trigger more of these events (Chapter 3) and it is important that we develop a better understanding of peat erosion processes, how to monitor it and if possible to develop mitigation strategies.

Since soil organic matter supports a number of soil functions and the agriculture and land use and forestry sectors account for 20% of GHG emissions in Scotland (Scottish Executive 2006) it is important that work is undertaken to confirm (or otherwise) the extent of C loss from soils across Scotland. A partial resampling of the NSI in Scotland has been commissioned by SEERAD and the results from this will indicate whether similar reductions are found here. A key difference in the approach will be that the soils will be sampled based on a pedological horizon by horizon basis rather than by coring or auguring down from the soil surface. The method of soil sampling has been highlighted within the DEFRA report as an area where potential uncertainty might be introduced.

2.6 Conclusions

- Scotland contains well over half the total carbon contained in British soils and it is one of the principal soil attributes that distinguishes Scottish soils from the rest of the United Kingdom.

- Soil organic matter profoundly influences a whole range of soil functions and can influence a number of the other threats such as erosion risk, compaction and loss of biodiversity

- The importance of organic matter in soils has already been recognized within the GAEC requirements and the Scottish Executive's climate change programme.

- There is emerging evidence that soil organic matter content in Scottish soils may be decreasing but more data are required to confirm this. Increased DOC levels in streams draining catchments containing predominantly peaty soils provides the best indirect evidence of losses. Large reductions in soil organic carbon have been found in similar soils in England and Wales, based on direct measurement of soil organic matter content.

- Better information on peat erosion processes, how to monitor it, and if possible how to mitigate it are required.

- Soil organic matter is a key attribute of Scottish soils and cuts across a number of areas of policy interest to the Scottish Executive; sustainable farming and forestry, climate change, biodiversity for example. It could be argued that it also indirectly affects the tourist industry as it sustains the above ground habitats that many visitors come to Scotland to enjoy.

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Chapter 3 Climate change

This chapter examines how Scottish soils might change in response to potential changes in our climate, some of the implications of those changes for soil functions and land management and on feedbacks through GHG emissions.

3.1 Summary

- Although there are large uncertainties, it is expected that Scotland's climate will get warmer, drier in summer, wetter in winter and with an increased risk of storm events.
- The soil property most likely to be impacted is organic matter content but it is very difficult to be certain in which way and to what extent.
- Climate change may affect soil carbon turnover in a number of different ways and in different soils.
- Yields of agricultural and forestry products may be adversely affected, particularly if summer rainfall decreases and temperature increases thereby causing reductions in soil moisture content.
- The focus of this chapter is the impact of climate change on soils, but it is recognised that there are feedback loops e.g. increased emissions of N_2O from wetter soils, but also potential for mitigation through adoption of specific land management practices.
- Land management, for example trafficability and soil workability may be impacted at crucial times of the year, leading to a potentially increased risk of compaction.
- Erosion risk, dependent on other factors such as crop cover and soil type, may increase if storm events occur more regularly. This in turn would lead to more serious downstream effects such as increased siltation and/or eutrophication.
- Some valued soils and habitats may be disproportionately at risk, for example machair (from increased flooding) and montane soils (from warming).

3.2 Introduction and Description of Threat

There is an increasing consensus that human activities are causing considerable changes to the world's climate. This is largely through the emission of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrogen oxides that contribute to overall warming. Climatic conditions are factors which influence soil forming processes and also partly determine the extent to which soils can perform individual functions.

3.3 Policy

A report commissioned by Scottish Executive (Kerr and Allen, 2001) to review climate policy in countries with similar socio-economic and environmental characteristics to Scotland concluded that agricultural policy should be developed to encourage biomass production as an energy resource and to reduce nitrous oxide and methane emissions. Policies of this nature were found at that time in Ireland, Sweden and Denmark.

In 2006, the Scottish Executive set out its Climate Change Programme within which progress to date was described and further adaptation strategies outlined. The contribution that the agriculture and the land use change and forestry sector make to Scottish GHG emissions is significant and the role that soils play within it is highlighted.

3.4 Evidence

There is some evidence that Scotland's climate has warmed up marginally over the last century (Scottish Executive 2006). Since 1961, temperatures have increased in every season and in every part of Scotland. This has been the fastest period of warming identified in the period from 1914-2004. Rainfall in winter is almost 60% higher in northern and western Scotland over the last forty years although there have been no significant changes in summer rainfall. There are also shorter frosty periods and less incidences of frost and the growing season is approximately one month longer than 100 years ago. More information on climate trends can be found in a recent publication produced by Barnett *et al* (2006). On a global scale, the 1990s was the warmest decade in the last century. Extreme events and seasons are also occurring on a more regular basis and there is a body of evidence developing that is indicating some serious climate shifts have actually started.

Analysis of extreme rainfall data for the period 1961 to 2000 indicate that event magnitudes have significantly increased particularly for Scotland. For example the 50 year rainfall event in Scotland has become an 8 year event for eastern Scotland and an 11 year event for southern Scotland during the analysis period (Fowler and Kilsby, 2003). Black and Burns (2002) recently reassessed the flood risk for Scottish rivers using long-term flood records. They found that the frequency of peak over threshold events increased during the 1980s and 1990s especially in the west of Scotland. Recent frequencies may be the greatest within the last 100 years. However they found no similar evidence of increases in flood magnitude, although 8 out of 16 of Scotland's largest catchments have exceeded their previous flow maxima in the period since 1989 (Black and Burns, 2002). Another recent analysis predicts that for the UK as a whole, event magnitudes at a given return period will increase by 10% for short-duration (1-2 day) events and by up to 30% for longer frequency (5-10 day) events (Ekstrom et al., 2004).

We cannot be certain on the scale or indeed the direction of the climatic shift that might occur in Scotland but current models suggest a possible warming of up to 3.5 °C in summer and 2.5 °C in winter by the 2080s (Hulme *et al* 2002 quoted in Scottish Executive 2006) in a high emissions scenario. This would mean that Edinburgh might have a climate somewhat similar to that of London in the present day. More extreme events, both in frequency and magnitude, such as storm force winds and rainfall are also likely. Current predictions from the UK Climate Impacts Programme (Hulme *et al* 2002) suggest smaller changes in a low emissions scenario but with still a 1-2 °C increase in mean annual temperature. An alternative scenario is one where melting of the Greenland icecap and increased rainfall in Russia might lead to a dilution of the salt water in the North Atlantic leading to the Gulf Stream taking a more southerly route and in effect being 'switched off'. This would create much cooler conditions in Scotland, particularly in winter.

This short chapter will discuss some of the broader implications of a warming climate, with more extreme rainfall events, for Scotland's soils and for the ways that they might be managed. Clearly these must be seen as being speculative and cannot be viewed as evidence of change or threat, but should form a focus for further debate and to identify research and monitoring requirements.

3.5 Potential impacts of climate change on Scottish soils

A changing climate might impact on soils in two ways. Firstly there are the direct effects of changes to soil properties and secondly the indirect effects resulting from soil/climate interactions of for example soils becoming wetter or drier for longer or shorter periods of the year.

3.5.1 Direct effects

The soil property that is most vulnerable to climate change is soil organic matter content. As already discussed (Chapter 2), this property has an enormous influence on all soil functions so any changes to its status will have a profound impact. In cultivated soils, organic matter content is fundamental to soil structural stability, and moisture and nutrient holding capacity. Increased organic matter turnover caused by increased temperatures may therefore have a detrimental effect on such properties, and problems such as erosion and surface capping which are more common in southern England at the present time may become more common in Scotland. Any decline in soil organic matter levels in arable soils will also reduce the carbon storage function, increase their sensitivity to added pollutants such as heavy metals through waste recycling and the risk of leaching of soluble pollutants may be enhanced. Soil biodiversity may also decrease given the relationship between SOM and microbial biomass. From the NSI resampling exercises in England and Wales, there is some evidence for arable of small decreases in carbon content over recent years. However for arable soils, these are not at a level or scale that need cause undue alarm (Loveland and Webb 2003). It is also unclear whether the small declines have been caused by changes in organic matter turnover rates or by land management practices, a combination of the two or neither.

Scotland has extensive areas (over half the land area), of semi-natural soils with highly organic surface horizons. Warmer temperatures may lead to these becoming sources of greenhouse gases rather than the sinks that they are currently considered to be. Organic carbon concentrations have declined dramatically in the limited sample of such soils in England and Wales (Bellamy et al., 2005). Although no clear trigger for this decline has been identified, a warming climate has been speculated as a significant contributor. If this is indeed the case and if the climate change scenarios for Scotland do actually happen, then the consequences for Scotland's soils and the implications for our greenhouse gas emissions inventory are profound. The declines seen in England and Wales have occurred under a marginal shift of around 0.5 °C, small compared with those that might occur over the next century. **We urgently require some data from Scotland to quantify any similar changes in organic carbon concentrations in our organic rich semi-natural soils (see also Chapter 2).** Here, in addition, the development of the ECOSSE model will increase our understanding of C (and N) cycling in these organic soils and can be used to predict C losses under a number of climate change scenarios. For future monitoring and modelling, we require data on the depth of individual soil horizons, the C content of these horizons and the bulk density of a representative sample of soils. The current data contain the first two attributes but the third (bulk density) is estimated from a relatively small sample set.

3.5.2 Indirect effects

Soil can usually recover quickly from a ‘bad year’. For example, if soil structural degradation during harvesting operations occurs during a particularly wet year, there is frequently significant recovery of structure during the next growing season under appropriate management. Similarly, adverse impacts can be remediated on grassland soils. However if climate change impacts in such a way that ‘bad years’ become more frequent, there would be implications for the long term health and use of certain soils for example those that prone to structural degradation. There is less information on the ease and rate of recovery of semi-natural soils, but these soils are much less trafficked than those under agricultural use.

Climatic factors interact with soils and can have a profound influence on their functional capacity. Soils with similar properties respond differently to different climatic inputs. An example of this is the decreased workability and trafficability of soils in west central Scotland compared with the east. Rainfall in lowland Ayrshire is approximately 50% higher than in East Lothian and this has a marked influence on the potential and actual farming systems in the two areas. If winter rainfall does increase as predicted then the risk of soil compaction (see Chapter 5) could also increase as the window of opportunity for land work narrows and farmers may be forced to access land in less than optimal conditions.

Threats from the greater occurrence of wet soils induced by climate change have been assessed in a limited number of case studies. Weather constrains the time available during the winter half year for carrying out operations with heavy machinery and also limits the time available for spreading slurry and other wastes. Modelling indicates that the number of available working days at sites in Scotland will decrease because of expected increases in winter rainfall (Cooper et al., 1997). This same study also indicated that higher winter temperatures would reduce the number of days when the soil is frozen, thereby further reducing workdays for machinery. Other studies point to the effect of rainfall changes on the net emissions of N_2O from wet soils (Flynn et al., 2005). They demonstrate that N_2O emissions will increase, assuming fertiliser applications and land use remain the same, as a result of climate change.

Another indirect effect of increased rainfall might be an increased risk of flooding (see Chapter 6). Soils are likely to be saturated for longer periods in winter and coupled with the fact that saturated soils have a reduced capacity to receive more water, the risk of direct run-off will be increased. This risk will be greater after heavy rainfall, events that are predicted with increased regularity under climate change scenarios.

The risk of soil erosion (see Chapter 6) may increase if the pattern, duration, intensity and location of rainfall events were to change. If more and/or heavier rain falls when the soil is bare or partially bare, soil erosion will increase. This is particularly the case with autumn sown crops when the soil is bare for a number of months and the soil is much more likely to be at field capacity. Soils are bare for a much shorter time in spring and are going through a process of drying out after winter.

If, as is predicted, Scotland's climate becomes drier in summer, there is a risk that some soils may experience drought more frequently leading to lower crop yields. Again the soil itself is not changing *per se* – the moisture storage capacity of the soil is not changing – but there will be lower direct inputs from rainfall. Although winter rainfall may be higher than at present, lower rainfall and higher temperatures during summer is likely to increase the risk of drought. Irrigation may increase as a management response but this option might not always be available given the predicted decreased rainfall during the growing season.

The indirect effects of climate change on semi-natural soils are likely to be seen through changes in the pattern and range of semi-natural habitats and species, rather than by evidence of soil compaction or poorer crop yields. Soil biodiversity may be vulnerable to specific stresses such as moisture deficit in the soil.

There is potential for an increased likelihood of peat erosion (see also chapters 2 and 6). There is uncertainty about what the primary trigger for peat erosion actually is and given that most extensive areas of eroded peat are on high-level plateaux, climate is considered to be at in least in part responsible for the erosion process. The climate has changed from the time when the peat was actively building to that of the present day when the building phase has changed or slowed down. Eroded peat contains many bare peat surfaces in hags and gullies. If these bare peat soils are exposed to warmer conditions than at present they will dry out and a crust will form at the surface - this process occurs after dry periods at present. If a high intensity rainfall event or strong wind occurs immediately after a prolonged warm dry period then there is huge potential for the surface crust to be removed and washed into the drainage system. There may also be more potential for larger scale events such as bog bursts and peat slides.

3.5.3 Soils and habitats at highest risk.

Some valued soils and habitats (see Chapter 4) are at risk of damage or reduction in size should climate warm up and/or sea levels rise. There may also an increased risk of invasion by non-native species as described in Chapter 4. Many of the calcareous soils of the machair in the Western Isles are near sea level, and although their complete disappearance is highly unlikely, they are likely to be increasingly subjected to inundation both as a result of higher sea levels and increased storminess causing more wind erosion and flooding events. If this were to happen, the environment, the economy and even the social and infra-structure of the Western Isles would be damaged. Such sea incursion may also lead to salinisation of the soils.

Our highest mountains sustain soils and habitats more commonly found in the Arctic at much lower altitudes than in Scotland. The relatively maritime nature of our climate and our relatively southerly latitude also makes the presence of these soils a valuable and unique outlier from the vast majority of their extent. Any warming of Scotland's climate will affect this habitat although the rate of change is open to speculation. In terms of soil processes, these soils are influenced much more by physical processes such as cryoturbation caused by periodic freezing and thawing rather than chemical or biological processes compared with soils at lower altitudes. These effects will be diminished and the very nature of the soils will change. Nevertheless, this environment is likely to remain extreme in nature and one where exposure to very windy conditions will have a profound influence on the above and below ground environment.

Our blanket peatlands are internationally recognized and, again because of the extreme maritime nature of our climate, are rare in global terms. The cool wet climatic conditions result in low evapotranspiration rates and accumulation of organic matter at the soil surface. Accumulation rates of organic matter that exceed that decay rates over several millennia has resulted in peat depths of up to 7-8 metres in the most extreme cases. Any change to the climatic regime affecting Scotland will alter this process although precisely how is open to question.

3.6 Conclusions

Given the uncertain nature of this threat, we cannot be clear about its scale or impact. Nevertheless we can make some judgements on potential changes to soil properties and whether soils might become more or less vulnerable to other threats. Climate change may:

- Change soil organic matter content, with a reduction more probable. Given the role that soil organic matter has on a number of soil functions, this is a key issue that affects the soil resource of Scotland and on our terrestrial carbon budget.
- Lead to a requirement for new soil management strategies on some soils. The risk of soil compaction on agricultural soils may increase and some soils might become more sensitive to these risks.
- Have a potential effect on biomass production through increased intensity and duration of soil drought.
- Increase the potential for soil erosion with possibly peaty soils most at risk and therefore increased loss of terrestrial carbon

The pattern of soils and land use in the Scottish countryside is the result of soil forming factors interacting with social and human influences over a number of millennia. Scotland may be facing environmental change at a rate hitherto not experienced and this poses questions about how our land resource might respond. Is it resilient enough to adapt to these changes gradually or are there unforeseen responses that are too difficult to predict? Given this uncertainty, there is a case for adopting the precautionary principle and where possible, ensuring that our soils retain as wide a range of potential functions as possible. In addition and as importantly, climate change will affect the whole world and may result in quite dramatic climate shifts to the extent that food production in some areas may become seriously compromised. We need to view our soils in the widest possible perspective; our soils might be quite resilient but those in other parts of the world may not be.

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Chapter 4 Loss of Soil Biodiversity

This chapter describes the importance of soil biodiversity in Scottish soils, how and if Scottish soils differ in this respect compared with other parts of the UK and a discussion of the status of biodiversity in Scottish soils.

4.1 Summary

- The greatest value of our soil biodiversity is the ecological services the organisms perform which underpin all of soil's ecological functions.

- Soil biodiversity is at a true scientific frontier. The major impediment to evaluating any loss in biodiversity is the lack of systematic data that describes its current status, how it varies spatially and temporally as well as the key links between soil biodiversity and soil function

- There are already soil organisms on Biodiversity Action Plans (BAP) group species lists which include fungi and ephemeral soil dwellers and these are protected by habitat BAPs.

- There is evidence that contamination of soil and invasive species, such as the New Zealand flatworm, threaten soil biodiversity and in the longer term could impair soil functioning.

- While there is no *a priori* reason or evidence that Scotland has unique soil organisms we do have unique habitats that have not been fully investigated. Habitats such as native pine woodland do have unique soil biodiversity assemblages as a component.

- Consideration for the protecting soil biodiversity as a component of habitats under conservation protection is for the moment the only practical way of ensuring that such biodiversity is not lost. Soil biodiversity management should be explicitly considered in habitat action plans when appropriate.

- Where there is evidence of biodiversity loss due to contamination or invasive species a full ecological risk analysis should be undertaken and precautionary approach be adopted.

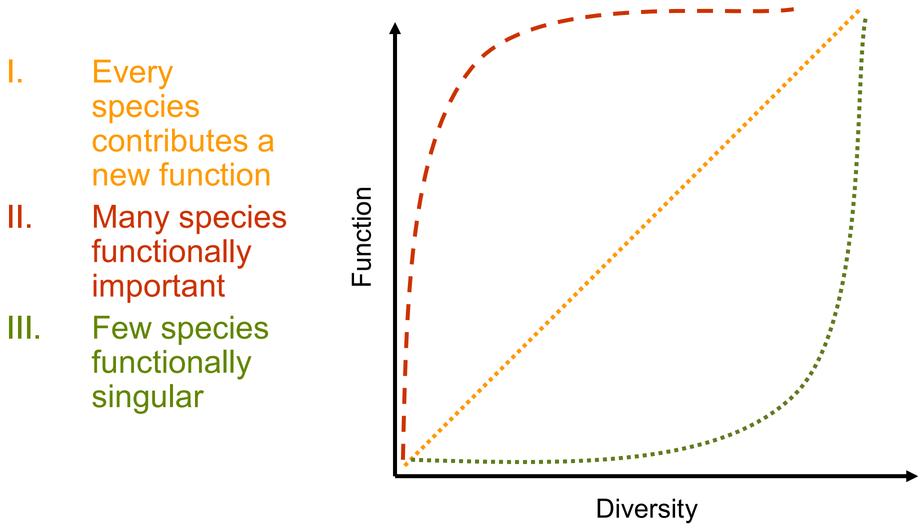
4.2 Introduction and Description of Threat

In its broadest sense biodiversity means the variety of life on Earth and all the interactions that take place between species and community assemblages. It encompasses a range of scales from the size of individual genes up to entire ecosystems.

Organisms that live in soil include not just the true plants everyone is familiar with, but also animals that use soil as a habitat and breeding ground (e.g. badgers, moles, various small herbivores) as well as lower plants (mosses), invertebrates such as beetles, spiders, mites and worms as well as the ‘hidden’ microscopic life forms of the fungi, bacteria and protozoa. In this chapter soil biodiversity will be restricted to the invertebrate and microscopic organisms that live in soil. The hidden diversity in soil is vast and largely unexplored comprising several thousand to possibly millions of species in single gram of soil.

Biodiversity represents the complex interplay between these inter-related trophic levels thus combinations of individual taxa or species in different communities can result in many different communities with different characteristics. It is often assumed that diversity is a pre-requisite for the maintenance of soil stability, resistance and resilience of ecosystems (Wall, 2004). While the impact of the loss of biodiversity on soil functions seems to be intuitive it may depend on whether the function is dependent on a few ‘specialist’ organisms or is performed by many different ‘generalist’ species. In the latter case loss of biodiversity may not result in any significant loss of function as much of the diversity is considered to be redundant. Several hypothetical relationships between diversity and function have therefore been proposed (Fig 4.1, Naeem and Wright, 2003). Given the enormous diversity of soil organisms, and wide range of metabolic processes and functions they are capable of, generalisations are not yet possible. However, it is clear that as the ecological functions of soil depend fundamentally on the soil’s biodiversity, loss of biodiversity will potentially undermine one or many inter-related functions.

Figure 4.1 – Theoretical relationship between diversity and function (After Naeem & Wright, 2003).



There are many potential causes of the loss of biodiversity. The Millennium Ecosystem Assessment (2003) listed the key threats to biodiversity worldwide as loss and damage of habitats, climate change, invasive non-native species and overexploitation of species. These apply equally to soil biodiversity. Any physical loss of soil can inevitably lead to loss of biodiversity and any change in land use or vegetation is likely to alter soil biodiversity. Several potential causes of the loss of biodiversity are related to the other soil threats e.g.:-

- Loss of organic matter (Chapter 2)
- Climate change (Chapter 3)
- Erosion/loss of structure (Chapter 6)
- Contamination (Chapter 7a-c)

Impacts on soil functions

Loss of biodiversity is unlikely to affect the provision of a platform for building and raw materials but may have a role protecting cultural artefacts and evidence due to their degradation capacity. In contrast, biodiversity in soil underpins all of soil's ecological functions and either drives or contributes to many of the ecosystem processes that determine local, regional and global responses, the recycling of organic materials, including waste, pollutants and contaminants, major nutrients, such as N and P, the development and maintenance of soil structure and its contribution to resistance from erosion and effective drainage. Loss of biodiversity could therefore affect all of these ecosystem services.

Biomass, food and fibre production

Loss of soil biodiversity may reduce plant biomass production indirectly as it contributes to the maintenance of soil physical structure, nutrient cycling, plant-microbe symbiotic nutrient uptake, plant growth promotion and protection from pathogens by antagonistic organisms. However, as soil biodiversity is influenced by aboveground productivity, reductions in plant productivity caused by some abiotic factor are more likely to affect soil biodiversity.

Environmental Interactions

Loss of biodiversity and biological functions may alter the balance of carbon stored in soil and the exchange of greenhouse gases. However, plant production is again more likely to have a larger influence on these functions than soil biodiversity per se, an observation which serves to emphasise the importance of management or protection of the ecosystem as a whole, rather than soils as an isolated component. The metabolism or transformation of pollutants coupled with effects on soil structure also have consequences for the transport and movement of pollutants to waters and the atmosphere so affecting the buffering, filtering and transformation function.

Support of ecosystems, habitats and biodiversity

Soil biodiversity has an inherent value as a component of our ecosystems and any loss detracts from this function. Loss of soil biodiversity and specific protected soil fauna can be not only detrimental to soil quality but also the maintenance of favourable conservation status of protected habitats. Soil biodiversity is part of a food web which directly links to higher organism food webs e.g. soil invertebrates are a vital food resource for birds. The large and unexplored diversity of organisms in soil also represents a potential gene bank for the discovery of new biotechnological enzymes, pharmaceutical compounds and molecules as well as organisms that might be useful for biological control, plant growth promotion and bioremediation. Soil biodiversity also has value as a potentially very sensitive indicator of environmental change and several biological indicators have been deployed in national-scale monitoring schemes in Europe (e.g. Breure et al., 2005; Winding et al., 2005) and elsewhere (Sparling and Schipper, 2002).

4.3 Policy

The UK government has signed up to the Convention on Biological Diversity (CBD) and to the European Union target to halt the loss of biodiversity by 2010. Latterly further international initiatives explicitly considering soil biodiversity have been established under the auspices of the UNEP CBD (http://www.fao.org/ag/AGL/agll/soilbiod/initiative.stm) which in part recognises the role soil biodiversity can play in more environmentally friendly agriculture. In Scotland the Nature Conservation (Scotland) Act 2004 makes it a duty on all public bodies to further the conservation of biodiversity. The Scottish Biodiversity Strategy (2005) sets out what we need to do to conserve and enhance biodiversity over the next 25 years. Most of the diversity in soil is to be found in soil microbial communities. The Convention on Biological Diversity does not protect microorganisms explicitly and they were omitted from any sovereignty rights or claims. However soil biodiversity is explicitly protected in the "ecosystem approach" adopted as a framework in this and subsequent conventions and has been recognized as crucial to the global sustainability of our ecosystems and welfare of mankind in the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2003). It is interesting to note that the Dutch Soil Monitoring Network which has used biodiversity indicators extensively in their national soil monitoring programmes was justified in the Netherlands to meet their obligations following the Rio Earth summit in 1992 (Breure et al., 2003).

4.4 Evidence

4.4.1 Current status

There are several ways of looking at the status of Scotland's soil biodiversity. For higher plants, animals and most invertebrates taxonomic identification is relatively more complete and straightforward. The taxonomic approach is, however, far more limited for identifying microorganisms in soil and consequently different approaches have been used to describe and quantify diversity in functional, genetic and taxonomic terms. Lastly given the complexity and unknown nature of the biodiversity it is also useful to consider soil biodiversity in terms of the diversity of soil types and distinct habitats that these support.

Taxonomic diversity

Threats to biodiversity of higher plants and animals have been long recognised and are covered by the Rio convention on biodiversity and the biodiversity action plans (BAPs) for habitats and species. However, these plans do not explicitly cover the soil component and yet the existence of such species cannot be divorced from the underlying soil properties. The underlying assumption is that any species or habitat that is rare has inherent value and requires protection and this is embodied in the habitat support function of soil. The BAPs and Red Book lists (compilations of rare species) are therefore good evidence of a threat to soil biodiversity.

Data used to construct or inform either BAPs or Red Book lists are gathered by taxonomic specialist groups using the best available information to assess each species against objective criteria and specific thresholds such as, *international responsibility and evidence of decline*. However, the coverage of soil organisms is very patchy because most are inconspicuous and uncharismatic and the number of committed experts is small.

Rare fungi in the hydnoid group found in woodlands and the grassland wax cap fungi have species group BAPs (Table 4.1). The evidence that these species are under threat is primarily based on observations of the presence of the fruiting body which appears aboveground as sporocarps (mushrooms). Much of the data on fungi are gathered through survey by experts and members of the British Mycological Society and is of good quality (see example in Appendix B). The majority of the biomass of these fungi is actually found in the belowground mycelium and so evidence based on sporocarps may not be a good indicator of their extent and abundance (Gardes and Bruns, 1996).

The stipitate hydnoid fungi (*Hydnum, Hydnellum, Bankera, Phellodon, Sarcodon*) are the largest group of soil organisms on BAPs. Commonly known as 'tooth fungi' most are known to form symbiotic associations (mycorrhiza) with trees. Scots pine is the most common host and although some species have been recorded in Wales and Northern Ireland, the majority of hydnoid fungi in the UK are supported by pine in the native pine woodlands of Scotland. Sporocarp records suggest that populations have been declining in recent years more so than other groups of fungi and this has lead to a grouped Priority Species Action Plan for 14 species of hydnoid fungi (Anon, 1994). These species represent 52% of all the fungi included in UK BAPs and given their association with native pine woodlands of Scotland they are worthy of special consideration as some are critically endangered (Table 4.1). The major threats contributing to the decline of these species are associated with the historic loss and fragmentation of native pinewood habitats and changing forest management practices (Anon, 1999).

Table 4.1 - Soil-dependent fungal species (excluding plant pathogens without a soil stage and species not recorded in Scotland). All information from http://www.ukbap.org.uk/ and subsequent web pages http://www.ukbap.org.uk/UKPlans.aspx?ID=338 viewed on 30th March 2006 as well as Anon, 1999.

Fungi	**Status (GB Red list)**	**Threats**
Grouped plan for tooth fungi (hydnoid)		Loss of habitat, Changing forest management
Bankera fuligineoalba (Drab Tooth)	Endangered	
Hydnellum aurantiacum (Orange Tooth)	Critically Endangered	
Hydnellum caeruleum (Blue Tooth)	Endangered	
Hydnellum concrescens (Zoned Tooth)	Vulnerable	
Hydnellum ferrugineum (Mealy Tooth)	Endangered	
Hydnellum peckii (Devil's Tooth)	Vulnerable	
Hydnellum scrobiculatum (Ridged Tooth)	Vulnerable	
Hydnellum spongiospies (Velvet Tooth)	Vulnerable	
Phellodon confluens (Fused Tooth)	Vulnerable	
Phellodon melaleucus (Grey Tooth)	Vulnerable	
Phellodon tomentosus (Woolly Tooth)	Vulnerable	
Poronia punctata (Nail Fungus)	Vulnerable	
Sarcodon glaucopus (Greenfoot Tooth)	Vulnerable	
Sarcodon imbricatus (Scaly Tooth)	Vulnerable	
Sarcodon scabrosus (Bitter tooth)	Endangered	
Waxcaps		Reduced grazing, increased ploughing, fertiliser
Hygrocybe calyptriformis (Pink Waxcap)	*Low Risk*	
Hygrocybe spadicea (Date Waxcap)	Vulnerable	
Earthtongue		
Microglossum olivaceum (Olive Earthtongue)	Vulnerable	Agricultural improvement of grasslands

Wax cap fungi are found primarily on unimproved grassland, montane or sub-alpine habitats and are brightly coloured with a waxy cap. As with the hydnoid group population trends in these species are poorly understood and fruit body counts may also under or over estimate belowground distribution and biomass. Potential threats to these fungi include improvement of its grassland habitat through ploughing, fertilisation and reduced grazing/cutting. Studies in Scotland suggest that the unimproved grasslands of Scotland are of 'exceptional' importance for their conservation compared with other Northern European countries (Newton et al., 2003). Such habitats are relatively old and can be characterized not only by particular plant assemblages and sward conditions but also with associated soil characteristics e.g. low available nutrients. Consequently land improvement and use of fertilizers may be detrimental to the abundance and diversity of wax caps.

The threats to both groups of fungi are primarily habitat loss and in fact their presence/absence is often used as an indictor of the extent of restoration/degradation of habitat value (Anon, 1994). Both groups of fungi have functional roles in symbiosis and decomposition processes that support biomass production in these habitats and environmental interactions functions but the impact of their loss on these or other ecosystem functions have not been explicitly studied. Consequently, their loss is currently considered primarily in terms of their inherent value related to the habitat support function.

There are also several species of invertebrates on BAP that are ephemeral soil dwellers (Table 4.2). The wood ants are main species of importance for Scotland. Their relationship to soil is primarily with respect to their nests which are usually built on well-drained slopes or small ridges and they are threatened primarily by the loss of suitable habitat and inappropriate woodland management (Appendix Table 5.1). *Formica exsecta* is the most endangered and another possible cause with relevance to soil is the possible role of nutrient enrichment leading to grassland invasion of their preferred habitats. There are also several moths and beetles (http://www.ukbap.org.uk/SpeciesGroup.aspx?ID=23*)* that descend from vegetation (e.g. pine) to pupate and have a life stage in soil and are similarly threatened by habitat loss and disturbance. These species are not unique to Scotland.

Table 4.2 Species lists of invertebrates with life stage in soil that are identified on BAPs and Red Book lists and are recorded in Scotland. (http://www.ukbap.org.uk/ and subsequent pages ~/SpeciesGroup.aspx?ID=4 and ~SpeciesGroup.aspx?ID=23) viewed on 30th March 2006).

Ephemeral soil dwellers	**Status (GB Red list)**	**Threats**
Ants - nests on and partially underground:		
Formica aquilonia (Scottish wood ant)	*Nationally scarce*	*Loss of habitat* *Inappropriate management*
Formica exsecta (Narrow-headed ant)	*Endangered*	*Habitat loss and fragmentation; nutrient enrichment of soils and development of grass*
Formica lugubris (Hairy wood ant (Northern))	GB – *Local* Globally *Near Threatened.*	*Loss of habitat* *Inappropriate management*

Earthworms are also relatively easily identified and pay a key role in soil as ecosystem engineers and they can have a disproportionate influence on soil ecosystem functioning being vital to the supply and turnover of nutrients and the physical structure of aggregates and pores that aid drainage and gas transfer. A survey by SCRI in 1995 identified 13 different species of earthworms in Scotland in agricultural fields. While earthworms can be sensitive to pollution the main threat to their existence is the invasive species the New Zealand flatworm which predates on certain species. As the New Zealand flatworm is increasing in numbers and extent it may potentially pose a threat to earthworm diversity. As earthworms are keystone species in soil there may be cascading effects on other aspects of soil biodiversity that have hitherto not been investigated. A 12% reduction in earthworm populations in some field sites in Scotland was reported by Boag (1999) and changes in community structure have been also recorded (Jones et al., 2001).

Functional diversity

Soil biodiversity would be underestimated in terms of its value if we were only to use the taxonomic approach. The numbers and diversity of organisms in soil are both vast and as an intense area of research such numbers are often being revised, usually upwards. In functional terms there are perhaps no traits that are likely to be unique to Scottish soils, and the collective activities and interactions of component species that make up the soil communities has yet to be proven to be distinctive in Scottish soils. There have been several studies of biodiversity in Scottish soils e.g. through the SEERAD funded MicroNet project and the NERC funded UK Soil Biodiversity Programme (SBP) both centred on a grassland site at Sourhope in the Scottish Borders. These studies have confirmed the large diversity of organisms that can be found in soil and that for some of the rapid steps in C cycling through plants and in the rhizosphere there is probably considerable inherent functional redundancy (Fitter et al., 2005). This may also be true in general, for the slower, more difficult to detect, processes in the C cycle which may regulate the turnover of the large reservoir of recalcitrant C in soils. While such studies aid our understanding of such aspects of soil biodiversity they do not provide evidence of threats or loss in soil biodiversity on a wider scale.

The loss of organic matter is a potential threat to soil biodiversity as there is clear evidence that biological activity, and microbial biomass (Wardle, 1992) as well as the diversity of some species (Breure et al., 2003) is positively correlated with inputs and levels of soil organic matter across a range of soil types. Climate change and the multiplicative direct and indirect effects that result will also likely have implications for soil biodiversity. For example elevated carbon dioxide and UV-B radiation can result in shifts in the microbial community structure but this is probably due to the direct effects of these stresses on plant growth and C and N cycling (Johnson et al., 2002). The direct effects of climate change are most likely to be related to warming and changes in the water status of soils. Changes in these parameters are most likely to affect the rates of growth and activity of organisms and so soil processes rather than diversity per se as short term fluctuations in temperature and water are frequent normal stresses on soil organisms. Soil erosion will also likely result in the loss of biodiversity, especially as a large proportion of the biodiversity and biomass is retained in the surface layers of soil. A decline in organic C and/or loss of biodiversity will also reduce aggregate stability and impair physical soil properties, reducing infiltration and potentially exacerbating erosion risk.

There are many published studies that demonstrate soil processes mediated by soil organisms can be impaired in the presence of high levels of heavy metals and organic contaminants, although there have been few field-based case studies on Scottish soils. Most contamination issues are not unique to Scotland, and overall Scottish soils have low levels of contamination (Chapter 7) with most threats being localised due to point source contamination. Scotland's preponderance of low pH soils may, however, make them more vulnerable to certain types of contaminants e.g. metals or atmospheric inputs of nitrogen or sulphur. Such interactions with soil pH may be a partial explanation of why Rhizobia bacteria at Hartwood in Scotland were more sensitive to Zn-rich sewage sludge than at other sites in England and Wales (Chapter 7c).

While the wider ecological impacts of GMOs has been studied in the farm scale trials (http://www.Defra.gov.uk/environment/gm/fse/) the use of GM plants and microbes on soil functions has not been fully evaluated and there have been no field trials in Scotland. Field studies elsewhere e.g. on insecticide expressing maize have shown there is no evidence of a threat to soil biodiversity (Griffiths et al., 2005) and similarly laboratory studies using Scottish soils to evaluate GM bacteria showed no effect on the diversity of bacteria or selected soil processes studied (White et al., 1994). A further threat specific to biodiversity is the impact of invading alien species. Invasive plants may alter soil biodiversity but this remains an understudied area. The invasive New Zealand flatworm is also a specific threat to earthworms on which it is predatory, with possible knock-on effects for soil structure and hydrology (Haria et al., 1998).

Land use, incorporating changes in vegetation and management, have been shown to alter soil biodiversity in many situations both for soil invertebrates and microbial communities. Soil management such as tillage, fertiliser and pesticide use have all been documented to alter biodiversity and this can also affect the balance of soil functions (Stockdale et al., 2006). There is evidence from case studies that agricultural practices, such as fertiliser use and ploughing, that create more homogenous selective conditions may reduce the diversity of important soil microorganisms such as *Rhizobium* (Martinez-Romero and Cabellero, 1996) and arbuscular mycorrhizal (AM) fungi (Helgason et al., 1998). These organisms live in symbiosis with plants and facilitate nutrient uptake and support crop growth. In many respects soil management actually compensates and replaces the functions we would otherwise rely on the various components of biodiversity to perform. There is an opportunity with new knowledge of the role and functions of soil biodiversity to re-visit the balance and reliance on biodiversity versus management inputs.

Changes in vegetation will also alter soil biodiversity. For example, birch colonisation of heather moorland may decrease the number of enchytraeid worms and increase earthworms due to a change in organic matter quality and an increase in soil pH. Such changes can result in significant changes in soil processes and have implications for soil and ecosystem function e.g. C sequestration potential. This change in biodiversity *per se* represents a qualitative shift in community structure and does not necessarily represent a net loss of species diversity or function. Consideration of such changes can therefore be value laden and subjective. Consequently land use change cannot necessarily be considered a threat to biodiversity. Changes in land use are also relatively easily reversible and consequently have lower risk but there is little information on how long they take to respond. A recent review did not identify any particular loss or impairment to soil functions due to biodiversity loss per se, nor any specific Scottish issues (Stockdale et al., 2006).

The greatest value of our soil biodiversity is in the diversity of functions it performs that underpin all soils ecological services. Estimates of the extant diversity of microorganisms in soil are under continued revision with estimates of thousands to millions of species per gramme of soil (Gans et al., 2005). While there is no *a priori* reason why Scotland should have unique soil biodiversity our knowledge of soil biodiversity is only just beginning. Scotland does have unique habitats, such as native pine woodland, which do have unique soil biodiversity assemblages as a component. Global programmes of bio-prospecting and discovery using DNA probes are underway in which sovereignty and intellectual property rights are considered (http://www.sorcerer2expedition.org/version1/HTML/main.htm and http://www.unep.org/Documents.multilingual/Default.asp?DocumentID=270&ArticleID=3180). Consequently, there are perhaps economic reasons to investigate and protect Scotland's soil biodiversity.

Soil diversity and the valued habitat approach

Scotland's soil clearly supports some distinctive, valued habitats and communities such as native pine woodland, machair and deep peats of the Flow Country that are protected under Natura 2000. It is the soil and climate that predominantly determines their present and future existence. At this level it is the distribution of under-pinning lithology, soil type, topography and its location in the landscape that determines the natural boundaries to these habitats. For example, machair habitats are founded on shelly sands which have soil pH close to neutral and are predominantly very freely draining. Machair wetland is also an important habitat. They support species rich plant communities but their distribution is entirely limited to the extent of this particular soil resource. We can perhaps estimate loss of soil biodiversity of machair therefore by estimating loss of the soil resource which may occur by wind and sea erosion. Other soil types that support valued habitats are more dynamic in geological terms. For example over thousands of years, peat bogs have replaced native pine woodland and possibly vice-versa but both are possibilities due to climate changes and the soil lithology of Scotland that favours acid loving plants in these areas. In contrast, we have a very low present extent of native pine woodland but given the extent of the soil resource appropriate for this habitat there is scope to expand this habitat enormously. The ability of different soil types to support such habitats is therefore a valuable way to assess the current status and future potential. This is the basis of the approach adopted in the Native Woodland Model developed by the Macaulay Institute and SNH (SNH, 2004).

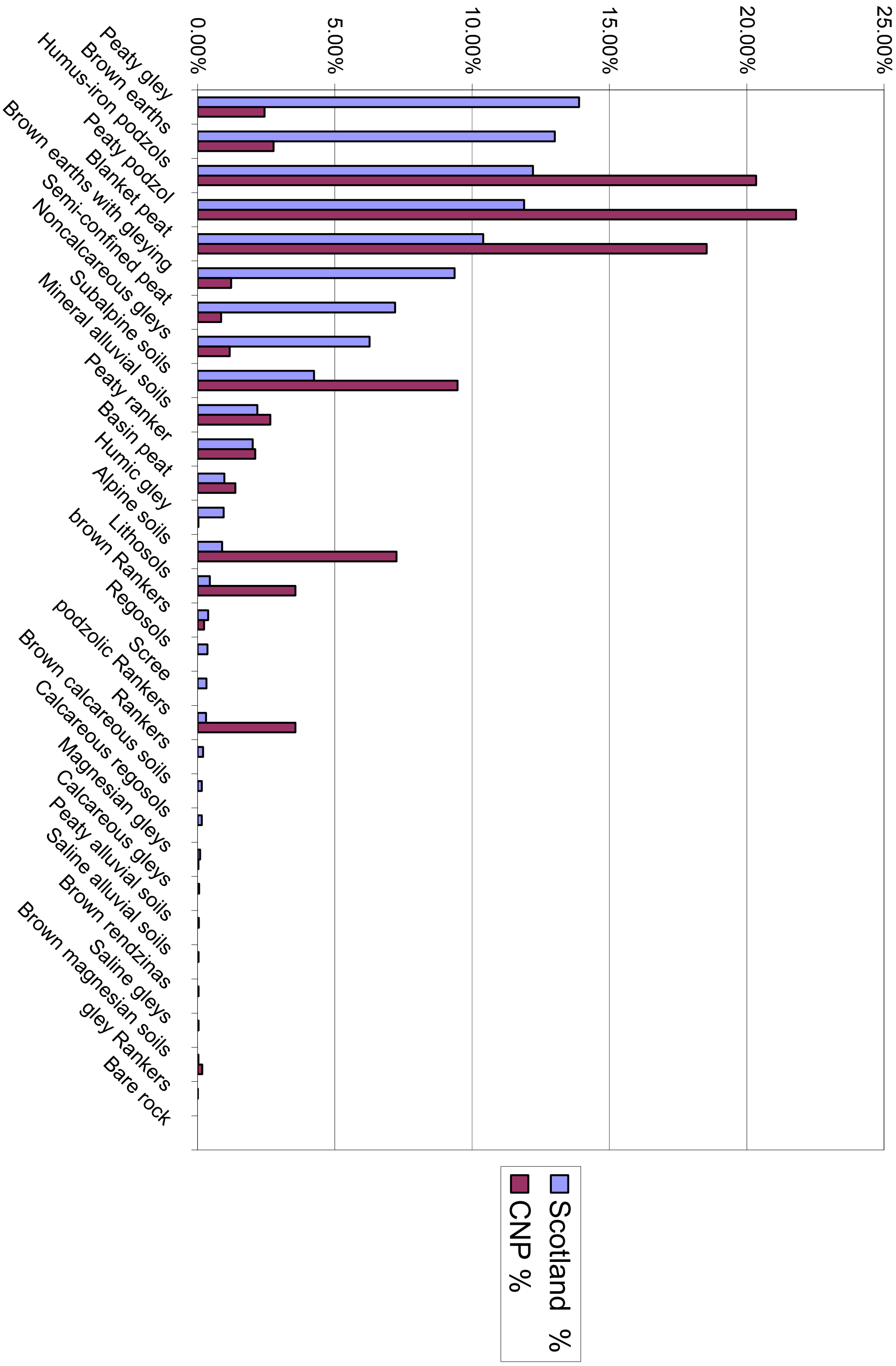
The contribution of soil to biodiversity of habitats can be determined by examining the distribution and diversity of soils in Scotland. Threats at this scale can be evaluated by considering how land management/restoration or large scale events (changing rainfall patterns, sea/wind erosion) are likely to influence this distribution in the long term.

Although 26% of Scotland's land area has at least one nature conservation designation, and many areas have several, soil is not one of the features or reasons for the designation e.g. peat is designated because of the habitat it supports. Sites of Special Scientific Interest (SSSIs) form the backbone of conservation sites in the UK. These have been designated on biological, geological and mixed criteria with no explicit consideration of pedological features. Many of these are also designated as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) under the EU Habitat and Birds Directives respectively.

Although there is no provision in UK law for the conservation of particular soils through site designation, it can be argued that soils within SSSIs are protected from potentially damaging operations and that management agreements will implicitly conserve soil functionality. A number of studies have taken place (Gauld and Bell, 1997; Gauld et al., 2000; Gauld et al., 2003) that examine the relationship between soils, designated sites and Natural Heritage Futures areas and this has been taken further into the development of a soil conservation index (Towers et al., 2005). The approach to date is primarily driven by the criteria currently used to designate sites namely rarity, representativeness and diversity. This has been developed and tested in the Cairngorms National Park (CNP) which has a similar % of SSSIs within it to the national average. It has been established that, by contrast with other designated features, the value of a soil cannot be assessed by the presence or absence of specific features or the mean value of certain properties. A spatial approach is required that examines the interactions between soil and other aspects of the environment and addresses the functionality of the soil within a given context.

Figure 4.2 shows the percentage cover of different soils within the CNP and in Scotland. It is clear that the CNP differs radically from the rest of the country. Rare soils, for example brown magnesian soils, magnesian gleys, saline alluvial soils, saline gleys, brown calcareous soils, calcareous gleys, calcareous regosols, calcareous gleys and brown rendzinas are all of very limited extent, but occur on a range of designated sites, including national nature reserves (NNRs), with valued aboveground habitats and species throughout Scotland. They also all have some very distinctive soil properties, such as high base status, high sand content or an unusual chemistry. These result primarily from the nature of the soil parent material, but can also be a function of their geographical context e.g. proximity to the sea. This rarity and their distinctive properties may well be related to unique or rare below ground biological assemblages so existing designations may provide a useful starting point for further work if this can be established.

Figure 4.2 Assessed percentage cover of soils in Scotland and the Cairngorms National Park



Other soils like the montane soils and peats in the CNP are relatively common – indeed peat is among the most extensive soils in Scotland – but their value is their rarity within the UK and Europe, particularly when coupled with the oceanic and maritime nature of our climate.

Some soils from a purely pedological and classification perspective are very common, for example brown forest soils and humus-iron podzols but they do form the base for a number of valued and rare habitats such as the Atlantic oakwoods in western Scotland and Scots pine woodlands. In this context, any assessment of soil rarity must be treated with some caution unless there is added information about the type of vegetation with which it is associated and supports.

The concept of biological diversity is well established and can be quantified in terms of richness, object abundance and proportional abundance as summarized by Ibanez et al. (1995); these authors applied such measures to the quantification of soil diversity (pedodiversity), for example the proportional abundance of soil types within particular areas. A case study of soil diversity at for the US using the Shannon diversity index suggested that ‘the clear regional distribution of soil types calls for integrated planning in order to maintain undisturbed segments of soils for a variety of future uses and purposes’ (Guo et al., 2003; op cit. p. 113-4). No similar study on soil diversity has been carried out in Scotland but clearly such an analysis would be complementary to the assessment of biodiversity. Indeed, as discussed above in relation to protecting habitats, Ibanez et al. (2005) proposed that soil diversity could also be used as a surrogate for biodiversity and there is to use existing soil maps to investigate this to assist in the evaluation and management of landscapes.

4.4.2 Data availability and gaps

As methods for measuring soil biodiversity (especially microbial diversity) have been only recently developed **there is a lack of long term or systematic wide area data for either taxonomic or functional diversity**. There are no systematic surveys or information on the full nature and extent of soil biodiversity that covers the diverse range of soil types and land uses in Scotland. Most information is available for invertebrates that are more amenable to identification and there are no systematic wide area data on soil microbial diversity.

Data on nematode abundance and species occurrence exist for both Scottish and UK soils published as an Atlas of the UK (Heath et al., 1977) but limited and no systematic re-sampling has been undertaken. Countryside Survey 2000 represents the only systematic survey in which soil invertebrates (Acari, Collembola, Oribatid mites), Biolog (a physiological profiling method) and the number of heterotrophic bacteria were analysed in samples from the 1998 survey (Black et al., 2003). The Countryside Survey is due to be re-sampled in 2007 and the invertebrate analysis if repeated would provide some evidence of change for this group at least.

The SEERAD funded work-package on “Risk based methodologies to assess soil health”, started in April 2006, will measure a range of soil biodiversity components in both a subset of rare soils and soils from the re-sampled NSIS but this will be the first baseline set of values to be measured on this grid and evidence of change would require further re-sampling in the future. There are some data from the first NSIS samples for nematodes and the utility of these is also under investigation. New molecular methods as well as physiological techniques are proposed to study the fungal and bacterial diversity of Scottish soils in this study. In addition this work will encompass a re-survey of earthworm species found in Scotland, first undertaken by SCRI in 1995 (Boag et al., 1997) and will, starting in 2007, compare the current earthworm fauna with the baseline data for 100 arable farms and investigate possible correlations with climate/management over this period.

One of the difficulties for any monitoring scheme for soil biodiversity is to know what to measure. There are two Defra funded projects dealing with this topic (SQID I and SQID II) due to report in 2008/2009 and make recommendations to the UK-Soil Indicators Consortium. Furthermore while change may be monitored in future activities there will remain difficulties in interpreting what change means for soil functions until understanding of the biodiversity function relationships are more advanced. Lack of understanding this relationship has recently been highlighted by scientists and policy advisors (Sutherland et al., 2006) as one of the most important ecological questions of our time.

The provision of good baseline data is essential if ecological classification methods are to be used to assess soil quality, soil protection and to monitor change. The lack of such data limits the progression of such approaches as now being practised in the Netherlands (Breure et al., 2005) where biodiversity has been monitored in a 5 year rolling programme for over 20 different biological parameters.

4.5 Conclusions

- Soil biodiversity is a true scientific frontier.
- In a few cases there is evidence of loss or threats to certain soil organisms with intrinsic conservation value.
- The greatest value of our soil biodiversity is the diversity of functions that underpin all soils ecological services.
- There is evidence that contamination and invasive species such as the New Zealand flatworm threaten soil biodiversity, but any consequent loss of function may not be immediately obvious which is a source of concern because of the possible lack of an early warning for loss of function.
- There is evidence that contamination by heavy metals may alter and reduce specific components of the microbial community (Chapter 7).
- The major impediment to evaluating any loss in biodiversity is the lack of systematic data that describes the current status and how it varies spatially and temporally.
- Scotland does have unique habitats, such as native pine woodland, which have unique soil biodiversity assemblages as a component.
- Global programmes of bio-prospecting and discovery using DNA probes are underway so there are perhaps economic reasons to investigate and protect Scotland’s soil biodiversity.
- Protecting soil biodiversity as a component of rare habitats is probably the only practical way of ensuring this biodiversity is not lost in advance of obtaining a more informed opinion on its extent and importance. There is potential for using valued or rare habitats as surrogates for below ground biodiversity.

- Given there is evidence of loss and threat it is appropriate to recommend that soils are in future explicitly considered in habitat action plans and that effects on the ecology of soils are considered in risk assessments for contaminants and waste recycling practices.

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Chapter 5 Structural degradation and compaction

This chapter summarises the ways in which soil management affects soil structure in both agriculture and forestry and evaluates the evidence for whether the structure of Scotland's soils is being adversely affected by current land management practices.

5.1 Summary

- Soil structure refers to the size, shape and arrangement of aggregates and pore space within the soil and thus influences aeration, water retention and water movement within the root zone and the quality of the habitat for soil biota.
- The factors controlling soil structural properties are generally well understood. There are large variations in the structural quality of individual soils linked to soil management. However, there is no systematic monitoring of structural properties and therefore little hard evidence of structural degradation and compaction.
- There are anecdotal reports of damage through poaching by grazing animals and trafficking by farm machinery but this tends to be localized and related to management.
- Case studies indicate that reduced organic matter content in arable soils makes them more susceptible to structural damage.
- The forestry sector has devised a method for systematic assessment of soil physical damage following forestry operations; such data can provide evidence of the type and scale of damage and the types of soil that with which it is most frequently associated.
- Maintaining soil structure and minimizing compaction is a GAEC requirement within the SFP conditions. It therefore moves from being voluntary actions to compulsory.
- Monitoring of changes in soil structural condition is essential for ensuring the adequacy of policies to protect soils and assessing the impacts of changing climate.

5.2 Introduction and Description of the Threat

In most soils the primary particles (sand, silt and clay) are grouped into secondary aggregates or peds, separated by large pores. Soil structure refers to the size, shape and arrangement of these aggregates and pore space within the soil. Aggregates are not permanent but can be deformed under pressure as diverse as the impact of large raindrops, trampling by cattle or compaction under vehicle wheels. Structure is a fundamental property of the soil. Together with texture, it effectively controls aeration, water retention and water movement within the root zone. Structure has a major influence on plant growth and therefore on the food and other biomass production function of the soil. It also influences the environmental functions or filtering and transforming and biodiversity, particularly the habitat for larger soil fauna.

Soil structure is strongly influenced by land management. The most favourable structures are generally found in the uppermost 30 cm of soils under grassland and are comprised of crumb or granular aggregates, spheroidal in shape and generally between 2 and 5 mm in diameter. Total pore space in such soils exceeds 50% of the soil volume and a significant proportion of the pores are larger macro-pores, between the spheroidal aggregates. Aggregates in grassland soils are also generally more stable due to their greater concentration of organic matter which binds mineral particles into a network which is resistant to dispersion forces associated with wetting and/or mechanical disruption. Arable cultivation is generally linked to a decline in the quality of soil structure, with fewer granular aggregates and reductions in total pore space, in macro-pore volume and in aggregate stability. A reduction in the stability of aggregates is of concern as aggregates are less able to resist disruption forces in the field. In particular less stable aggregates at the surface of the soil are likely to collapse and disperse when exposed to intense rainfall, thereby leading to crust formation, loss of infiltration capacity and increased surface runoff. Increased surface runoff in turn may increase soil erosion and therefore the loss of fertile topsoil and the transfer of sediment to watercourses.

Soils with reduced organic matter are also more susceptible to plastic deformation and therefore more likely to be compacted when trafficked by heavy machinery. The combination of heavy machinery and wet soils is a major contributor to soil compaction, frequently increasing bulk density and reducing macro-porosity and air and water movement. Recent decades have seen an increase in the mass and power of machinery used in both agriculture and forestry. Although there are considerable uncertainties, predictions of future climate change suggest that the winter half year in Scotland will be generally wetter (Chapter 3). Both these trends suggest that structural damage to soils could increase in the future.

Impacts of compaction and structural damage on other soil functions

Food and other biomass production

Possible reductions in crop yields, although the evidence of these is somewhat equivocal and effects on crop yield in any situation appear to be heavily dependent on climatic conditions. Greater compaction has its greatest negative impact on crop yields in wet years, and may be advantageous in drier years (Ball et al., 1997; Ball and Ritchie, 1999). Water holding capacity will be reduced in compacted soils, which may be more at risk of drought in drier years.

Environmental interactions

Possible increases in the flux of greenhouse gases such as N_2O to the atmosphere from compacted soils. N_2O fluxes are more likely to be significant when water-filled pore space is high (Ball et al., 1999) and no other factors are limiting. N_2O fluxes are also strongly linked to nitrate availability (Flynn et al., 2005) and therefore increased N_2O fluxes in compacted soils at times of the year when nitrate concentrations are low.

Increased surface runoff from compacted soils may increase transport of sediment and adsorbed nutrients and pesticides leading to greater pollution of aquatic systems (Ball et al., 1997). Cultivation and traffic management systems which are designed to reduce or eliminate soil compaction may have unwanted side effects as the use of "tramlines" may concentrate runoff into channels leading to a greater threat from soil erosion.

Biodiversity
Compaction and loss of large pore space between aggregates leads to a significant loss of habitat for larger soil fauna such as earthworms. Disruption of aggregates and consequent loss of internal pores (for example by cultivation) increases the accessibility of carbon compounds to bacteria and fungi.

Other functions
Soil compaction is unlikely to have significant impacts on the other three major soil functions identified in Chapter 1. Decline in soil structural quality is closely linked to decline in organic matter. Conversely disruption of structural aggregates by cultivation increases the exposure of the organic matter within aggregates to the action of decomposers and thus overall rates of organic matter decomposition. These two threats are thus closely interlinked.

5.3 Policy

Farmers receiving direct payments are expected to maintain their land in Good Agricultural and Environmental Condition (GAEC) as described in The Cross Compliance Notes for Guidance (SEERAD 2006). The appropriate measures to maintain soil structure consist of "Do not carry out any cultivations if water is standing on the surface or the soil is saturated". These measures do not however cover compaction by traffic or livestock. The PEPFAA code and the Farm Soils Plan also offer practical advice to farmers on how to maintain soil structure.

It is unclear how the maintenance of structure might be monitored. The visual soil assessment (VSA) method developed in New Zealand provides some guidance and recent work by Batey and McKenzie (2006) and Spoor (2006) summarise current thinking on the identification and alleviation of soil compaction. It is possible that it is such visual assessment tools will form the basis of SEERAD's approach to monitoring the GAEC requirements.

Heavy machinery is used in the forestry industry at specific times in the crop rotation and these have the potential to damage soil structure. These issues are addressed at a high level within the UK Forestry Standard and the recently revised, but as yet unpublished, Forests and Soils Guidelines.

5.4 Evidence

The quality of soil structure is recorded when soil profiles are described during routine soil survey. Bulk density, the most basic measure of compaction, is less frequently measured, and other properties linked to soil structure, such as aggregate stability or shear strength, are only determined in specialist research investigations. The evidence base for assessing this threat to soils is therefore more limited and primarily derived from case studies which have demonstrated the link between soil management and soil structural properties.

5.4.1 Soil management, compaction and structural damage

Soil compaction is primarily assessed through increased bulk density. However, a range of other measures of structural properties such as cone penetrometer resistance, shear strength, macro-porosity, air permeability and gas diffusivity are also affected and these can also be used as indices of compaction. Ball et al. (2000) found that the liquid limit moisture content of the soil was the best predictor of susceptibility to compaction.

A substantial amount of research into the effects of soil management on soil structure and compaction has been carried out by SAC and the former Scottish station of the National Institute of Agricultural Engineering. Ball et al. (1997) has summarized and reviewed the major findings of this work. This paper highlighted increasing problems of soil management since the 1980's due to both soil management and climatic factors. The move from spring to winter cereals, increase in number of grass cuts for silage and increasing annual rainfall were all seen as contributing to the trend.

Cultivation and pressure of machinery both have significant effects on the structural properties of soil. In a comparison of zero, light and heavy compaction treatments, Ball and Ritchie (1999) found that in wet conditions, heavy compaction (equivalent to a loaded tractor) reduced air porosity, air permeability and gas diffusivity and increased cone penetrometer resistance and was linked to a near 20% reduction in barley yield. However, this study also showed that some light compaction was necessary during dry conditions to maintain crop productivity. Zero traffic systems have been linked to substantial increases in the volume of macro-pores and mean pore size when compared with both reduced pressure and conventional traffic systems. However, the benefits of reduced ground pressure systems are offset by the increased area of compaction damage within the field (Douglas and Koppi, 1997). Table 5.1 (Ball et al, 1997) summarises some data on the effects of three types of machinery on soil properties related to compaction in an arable field cultivated with winter barley.

Table 5.1: Effects of farm traffic type on soil compaction.

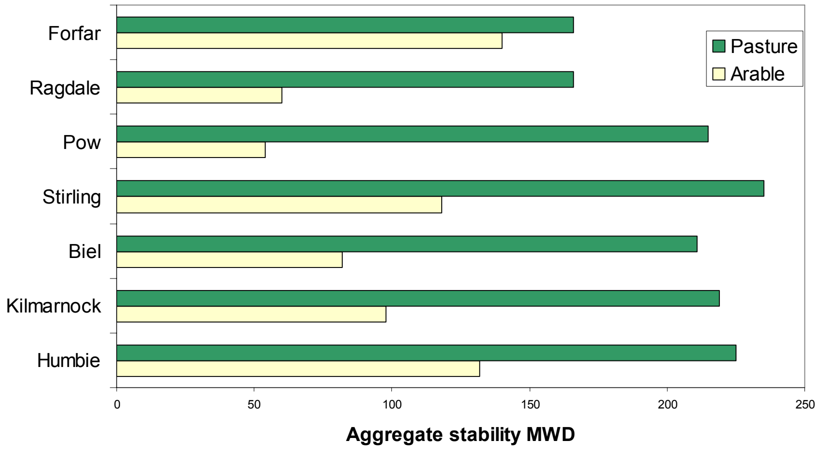
Farm traffic type	Bulk density (g cm^{-3})	Air porosity (v v^{-1})	Infiltration rate (mm min^{-1})	Yield (Mg ha^{-1})
Zero ground pressure	1.17	0.23	34.7	4.70
Reduced ground pressure	1.28	0.13	13.5	4.13
Conventional	1.31	0.13	9.2	4.08

Ball and Douglas (2003) developed and tested an index of physical soil quality based on structure, root growth and surface condition. Type and size of aggregates, rupture resistance, number and continuity of macropores, rooting, and the nature of the soil surface were all scored using simple ordinal scales. Composite scores for structure and rooting across all soil layers are then calculated and reported along with the surface condition score to provide an overall summary of soil physical quality. The index discriminated well between soils under arable and grass land uses, and increased with increasing time under ley and decreased with increasing time under arable.

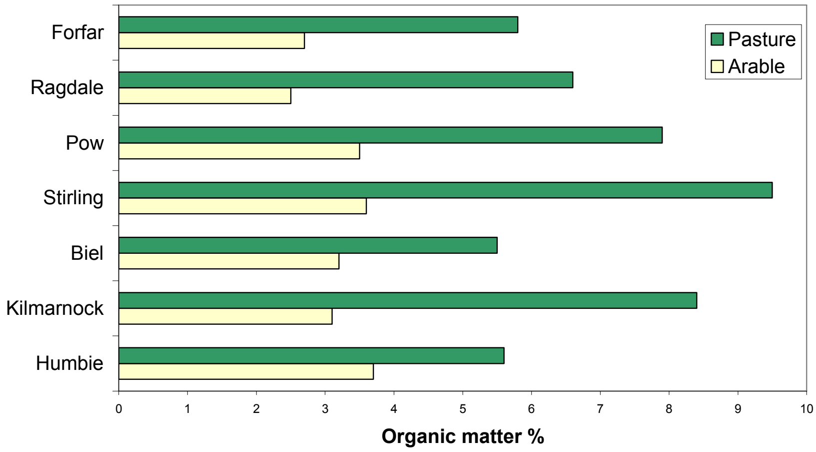
The effects of cultivation on aggregate stability have been widely studied in soils in England and these show marked reductions in aggregate stability in soils under arable crops when compared with similar soils under long-term pasture. The reduction in aggregate stability is primarily caused by loss of components of the soil organic matter such as bacterial polysaccharides when soils are cultivated and there are clear correlations between stability and organic matter content. In Scotland, Chaney and Swift (1984) compared aggregate stability between pairs of soils of the same series under arable and pasture land uses. These data indicated a marked reduction in aggregate stability and organic matter concentration for arable soils when compared with a soil of the same series under grass pasture (Figure 5.1). While organic matter varies due to factors such as texture and climate, organic matter concentration in all arable soils was reduced by around 50% when compared with the grassland equivalent. Organic matter concentration was closely correlated with the mean weight diameter of water-stable aggregates (a measure of aggregate stability). The reduction in mean weight diameter of water-stable aggregates in all arable soils indicates that these soils are more susceptible to structural damage and crusting under intense rainfall.

Figure 5.1: Effects of land use on soil aggregate stability and organic matter content.

Aggregate stability of arable and pasture soils



Organic matter in arable and pasture soils



Problems of soil compaction related to heavy machinery are not confined to agricultural soils. The weight of machinery in forestry operations such as ground preparation and harvesting is considerable and forestry operations, particularly at harvest, can cause serious damage to soil structure. The Forests and Water Guidelines (Forestry Commission, 2003) include measures to protect soils liable to compaction, albeit with the aim of preventing pollution of watercourses with sediment. This effectively limits consideration of likely structural damage to cases where offsite effects are expected. A protocol has recently been developed to assess damage by machinery on site and is being applied to a range of UK sites (McKay, in press). This quantifies soil degradation using simple measures made at 5 m intervals along trafficked routes. Depth of ruts is categorised into 7 classes ranging from zero to over 60 cm depth. Exposure of soil is categorised into 3 classes (none, exposure of organic horizons, exposure of subsoil mineral horizons). This will provide evidence of actual damage and recovery on a consistent and objective basis on the site of the damage. On the basis of field trials in NE England and SW Scotland, Wood et al. (2003) found that use of a layer of logging residues on machinery extraction was sufficient to prevent significant changes in bulk density, soil strength and water movement even under high trafficking rates on peat soils.

On non-agricultural soils there is also some evidence of compaction and loss of vegetation cover following excessive trampling by overgrazing or on heavily used footpaths. This is considered further in chapter 6.

5.4.2 Current status of threat and gaps in data/evidence

There are no national data on soil structural degradation or compaction from which to assess extent of soil compaction in Scotland either as a percentage of agricultural or forest soils affected or as severity of compaction. The qualitative descriptions of structure collected in the National Soil Inventory (NSIScot) give a general indication of the structural condition of cultivated topsoil, but these are not systematically linked to management treatments. NSIScot did not collect data on soil bulk density or other quantitative measures of soil structure. However, the relationship between field-saturated hydraulic conductivity (Kfs) and soil structure (Lilly, 2000) allows inference of soil compaction using soil structure records as proxy data. Soil structure classes having Kfs less than 10 cm day^{-1} were taken as ‘compacted’ for this purpose and they occur at 2.1% of the NSIScot points.

Overall there is therefore limited evidence on which to assess the threat of soil structural degradation and compaction at the national scale. For agricultural soils there is little hard evidence of soil compaction; any evidence tends to be anecdotal in the form of poaching by grazing animals, run-off down tramlines and obvious rutting by farm machinery. However, based on the evidence of the case studies reviewed here, there is a good understanding of the processes of structural change and the factors influencing compaction. Avoidance of soil compaction as a result of agricultural activities can be achieved through provision of clear guidelines for maintaining soil structure and ensuring that these guidelines are followed. Here the expectation under the GAEC Framework for Scotland (2005) that farmers will maintain their land in good agricultural and environmental condition will be an important policy instrument for avoidance of compaction and structural damage. However, there is a clear need for better methods of assessing structural condition in order to ensure compliance with requirements. Similarly adherence to the Forests and Water Guidelines should avoid compaction and structural damage following forestry operations. McKay (in press) will contain evidence on the scale and intensity of damage to forest soils by heavy harvesting machinery.

5.4.3 Future trends

The summary of evidence previously indicates that we have a general understanding of the processes and factors leading to structural damage and compaction as a result of agricultural and forestry operations. Policy instruments are available to ensure that structural damage does not occur, although we need better methods for rapid assessment of the structural condition of soils. Perhaps the most significant future trend likely to affect the structural condition of soils are predicted climate change impacts. Predictions of increased rainfall in the winter half of the year (Chapter 3) will lead to generally wetter soils. It will therefore be increasingly important to ensure that the use of heavy and powerful machinery in both farming and forestry operations is confined to times when the soil is in a suitable condition such that damage can be avoided. Similarly if the reductions in soil organic matter percentages reported for England and Wales (Chapter 2) are also found in Scotland, there will be parallel reductions in the stability of soil aggregates and in the resistance of soils to plastic deformation. Reductions in aggregate stability will increase the probability of surface crusting under intense rainfall, which may also become more frequent in a changing, wetter climate. Decreased resistance of soils to plastic deformation may reduce the cultivation “window” between the drying out of soils in the spring and rewetting in autumn, again increasing the possibility of compaction.

Given the links between structure and organic matter, monitoring of the quality of soil structure will be important if organic matter concentrations are found to be declining in agricultural soils in Scotland. In a similar vein, future trends towards wetter winters also suggest that monitoring of soil structure and compaction will be necessary.

5.5 Conclusions

- Structure is a fundamental property of the soil and plays an important role in determining its physical condition, aeration, water holding and water transmission properties. Structure thus influences the ability of soil to fulfil its biomass production and environmental interaction functions effectively.
- Structure is strongly influenced by land management. Arable cultivation reduces soil organic matter and, through this, aggregate stability and resistance to plastic deformation. Heavy and powerful machinery used in both agricultural and forestry leads to soil compaction.
- There are few systematic data to assess the extent of soil compaction nationally, but those data which exist suggest that it is of localised occurrence. Case studies have quantified the links between organic matter reductions and structure and the effects of different traffic management systems on soil compaction. The benefits of reduced ground pressure machinery systems in limiting compaction have also been shown but these are offset by an increased area of soil affected.
- Current policies such as the expectation of maintaining good structure under the GAEC framework and the Forests and Water Guidelines are specifically aimed at

avoiding structural damage. However, it is recommended that a programme of assessing and monitoring the condition of soil structure and compaction is implemented to check compliance with policy requirements.

- Future climate trends leading to reductions in soil organic matter and wetter soils may lead to greater likelihood of soil compaction and structural damage in the next few decades. This further underlines the importance of implementing programmes of systematic monitoring of soil organic matter and structural condition.

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Chapter 6 Soil Erosion

This chapter outlines the major processes of soil erosion relevant to Scotland and their significance for soil functioning and summarises the policy instruments relevant to the control of soil erosion. The major part of the chapter collates the evidence for the occurrence, spatial location and rates of soil erosion in Scotland and evaluates the major controlling factors of soil erosion, the severity of the threat and the gaps in the available evidence. Finally, the likely trends in soil erosion in the future decades are summarized.

6.1 Summary

- Soil erosion is a natural process which occurs in all soils to a greater or lesser extent. The major processes considered are water erosion, mass movements and wind erosion, although tillage displacement is increasingly recognised as a significant contributor to soil erosion rates.
- Datasets such as the NSIS and LCS88 have been used to determine the location and extent of soil erosion but these require care in their interpretation. However, the episodic occurrence of soil erosion causes significant difficulties for the systematic collection of data on erosion.
- A number of models have been produced that predict in relative terms the inherent risk of erosion by water occurring on both mineral and organic soils and of sediment loss.
- Minimising soil erosion is a GAEC requirement that farmers must meet to receive their single farm payment. The incidence of soil erosion on cultivated land may thus decrease, but this needs to be monitored.
- There is concern that predicted changes in the intensity and duration of heavy rainfall events may increase the risk of extreme erosion events. Such events pose a significant threat to river water quality.
- In upland Scotland, erosion of peat covers the largest area and this may increase under climate change. The factors controlling peat erosion and implications of peat erosion for soil carbon storage need further research.
- Predicted changes in the intensity and duration of heavy rainfall events may increase the risk of major events such as landslides. GIS analysis could be performed to identify specific features, such as settlements or transport links, most at risk from landslides.

6.2 Introduction and Description of Threat

Soil erosion is a natural process which occurs in all soils to a greater or lesser extent. Soil erosion becomes of concern when the rate exceeds “natural” or “background” rates which can be considered as broadly equal to the rate of formation of new soil material by weathering processes. Based on estimates of soil renewal rates, Kirkby (1980) proposed a soil loss tolerance value of 0.1 mm year^{-1} for the UK.

Soil erosion at rates exceeding background values is termed “accelerated erosion”. In humid temperate climates such as that of Scotland, much accelerated erosion is the result of human activities that lead to removal of the protective vegetation cover.

However, mass movements such as landslips also occur in the over-steepened, glaciated hillslopes of Scotland (Ballantyne, 1991). The material eroded from soils is a major contributor to the sediment load carried by streams and rivers and can disrupt transport links, therefore erosion has implications both on- and off-site.

The major processes of soil erosion to be discussed in this section are:
i) Water erosion including gullying, rilling and sheet erosion
ii) Mass movements such as landslides
iii) Wind erosion.

Water erosion is initiated when the rainfall rates or rapidly melting snow exceed the infiltration capacity of the soil and water runs off the surface carrying detached soil particles in suspension or as bedload. Transport is generally more effective when water flow occurs in defined channels and sheet erosion, rills and gullies effectively represent a hierarchy of severity of erosion at a site. Soils are most susceptible to erosion when they are bare, but erosion can occur in cropped fields where there is partial cover or along areas deliberately left bare such as tramlines in cereal fields. Much soil erosion in Scotland is relatively limited in its spatial occurrence and often much of the eroded topsoil is trapped at downslope field boundaries or deposited on gentle within-field slopes. Mass movements generally occur under conditions of saturation. The sediment:water ratio of mass movement sediments is much greater than that during water erosion and individual occurrences can be much larger in scale. Wind erosion is less common in humid temperate climates but can affect soils in high mountain environments and soils left bare following cultivation, particularly those of fine sandy to silty texture.

Impacts of soil erosion on soil functions and related threats

Food and other biomass production

One major impact of soil erosion is that it generally involves loss of the productive and fertile topsoil leading inevitably to a potentially significant threat to the biomass production of the soil. During the 1930s, drought in the Midwestern United States led to the “dust bowl”, during which severe wind erosion of cultivated topsoils occurred across parts of Oklahoma, Texas, Kansas, Colorado and New Mexico. The dust bowl was the trigger for the foundation of the US soil conservation service, which led to the development of cultivation methods aimed at reducing soil erosion. Soil losses in Scotland tend to occur on a fairly localized scale and eroded soil is often trapped at field boundaries such as walls and hedges. In some instances farmers simply move eroded soil back upslope. Given the relatively low frequency of erosion events and the short transport distances of eroded soils any threat to the biomass production function by soil erosion in Scotland must be viewed as small. It remains the case, however, that cultivation practices and exposure of bare soil during the winter months can provide the conditions for locally severe erosion particularly in areas with sandy textured soils.

Environmental Interactions

Other on-site effects of soil erosion include loss of the carbon storage function of soils as soil losses generally come from the more organic topsoil layers. The potential implications of soil erosion for carbon storage have been discussed recently (Quinton et al., 2006). Grieve (2000) showed that carbon losses of almost 50% can occur in upland soils with a peaty surface horizon when the protective vegetation cover is lost.

Also in upland areas, the incidence of erosion on peaty soils may be a contributory factor to declines in the carbon concentrations in upland soils which have been reported recently and also to the increases in fluxes of DOC from upland peaty catchments. Further research to quantify the links between soil erosion and the carbon storage function of soils will undoubtedly be needed.

Soil erosion has significant off-site effects on surface waters through:

- silting up and reduced capacity of water-supply reservoirs
- loss of fish spawning areas through the deposition of fine sediment on river-bed gravels
- contamination of river waters by nutrients (mainly phosphorus) or pesticides adsorbed on eroded sediment particles

These effects are now considered within river basin management under the Water Framework Directive (WFD), and this has led to many policy initiatives which currently protect soils such as the Forests and Water Guidelines. This is a trend which is likely to continue in future as the implementation of the WFD continues.

Biodiversity
As with food and biomass production, loss of fertile topsoil through severe erosion can have a significant impact on soil biota and on ecosystem functioning.

Provision of a platform
Erosion can damage the built infrastructure by undermining foundations and depositing sediment. The landslides which were triggered by extreme rainfall during the summer of 2004 caused significant damage to parts of the trunk road network.

Provision of raw materials
Large scale erosion of peat represents the major threat to the soil's function in providing raw materials.

Protection of cultural heritage
Soil erosion poses a threat to archaeological features such as buried cropmarks, as loss of topsoil will ultimately lead to plough damage to such features preserved in cultivated soils.

6.3 Policy

Farmers receiving direct payments are expected to maintain their land in Good Agricultural and Environmental Condition (GAEC) as described in The GAEC Framework for Scotland (2005). Measures to reduce the likelihood of soil erosion include the following requirements: "All cropped land over the following winter must, where soil conditions after harvest allow, have either crop cover, grass cover, stubble cover, ploughed surface or a roughly cultivated surface. Fine seedbeds must only be created very close to sowing." There are also voluntary codes of practice such as the PEPFAA code and the Farm Soils Plan that give advice on how to minimize the risk of soil erosion.

The sustainable use of soil is embedded within the Forestry Standard, the document that sets out the Forestry Commission's stance on sustainable forestry and guidance is given with the Forests and Soil Conservation Guidelines (Forestry Commission 1998, update in press). In addition, the Forests and Water Guidelines include several measures to prevent the movement of eroded soil from a site to watercourses.

6.4 Evidence

6.4.1 Current Status – State of Soil

Evidence of threats to the current status of the soil resource has been gathered from a number of sources:

- National Soils Inventory for Scotland (NSIS): Although not explicitly designed as a survey of soil erosion, evidence of soil erosion was recorded at Inventory points in the field. The major advantage of this approach was the national coverage and objectivity of the grid sampling scheme, but sites were generally visited from April until October when erosion in lowland areas is least evident.
- Land Cover of Scotland (LCS88): This survey, which was based on aerial photograph interpretation, recorded the extent of eroded blanket bog and montane vegetation, but provides no evidence of other forms of erosion in the uplands or of erosion in lowland areas (MLURI,1993).
- Commissioned surveys of erosion incidence: SNH commissioned a survey of erosion in upland Scotland based on further interpretation of LCS88 aerial photographs. Results relate to a stratified random sample of 20% of the upland area. A similar field-based survey of erosion in upland areas in England and Wales commissioned by DEFRA provides further data on the threat of erosion to upland soils. The Forestry Commission has also undertaken a survey to monitor the degree of soil erosion explicitly associated with harvesting operations.
- The Scottish Road Network Landslides Study (Scottish Executive 2005): This provides the most recent analysis of the occurrence and risk of landslides in Scotland. Although the study was focussed on assessing the potential for landslides occurring adjacent to the road network, many of the principles and procedures outlined in the report can be extrapolated to the wider landscape.
- Case studies reported in scientific papers: These range in scope from reports of specific incidences of erosion, generally following extreme precipitation events to surveys of erosion within defined areas. From the perspective of determining the extent of the erosion threat nationally, the major disadvantage of such case studies is sampling bias, as these focus on more extreme events. However they do allow quantification of the potential severity of the problem.
- Long-term river records: Mean net erosion rates within river catchments can be determined from sediment loads carried by rivers. The harmonised monitoring data maintained by the Scottish Environment Protection Agency (SEPA) includes records of river flow and suspended sediment concentration measured at approximately monthly intervals since the early 1970s. These form the basis of an assessment of changes in net erosion rates over the last three decades, but do not quantify soil redistribution within catchments by erosion and deposition.

- Modelling of erosion susceptibility: The potential risk of soil erosion in Scotland has been modelled using two different procedures. Lilly et al. (2002) used a rule-based approach to identify the inherent geomorphological risk of soil erosion while Anthony et al. (2006) used a process-based model to predict sediment and nutrient movements to waterbodies.

6.4.2 National Soils Inventory for Scotland (NSIS)

The National Soils Inventory for Scotland (NSIS) is an objective sample of Scottish soils. Soil and site conditions of 3094 locations throughout Scotland (although the NSIS points in the Orkney Islands were not sampled) were available and the presence or absence of erosion features was recorded at 2845 of these points (Table 6.1). The vast majority of sites (86%) were not eroding at the time of the sampling. Gullying and rill erosion were the most frequently recorded erosional features. Rill erosion was recorded at 100 sites with either peat soils or organo-mineral soils suggesting that gully erosion was either extending upslope or at an incipient stage. Only 9 sites with erosion were on cultivated land (<0.5%). This may partly reflect the timing of data collection which would have been mainly during the period April to October, as any winter erosion would have been remediated prior to the site visit. Case studies also indicate that erosion of cultivated soils is localised in its occurrence; national monitoring schemes are therefore unlikely to record it adequately.

Table 6.1: Number of inventory points with erosion features recorded grouped by land cover type.

	All land covers	Grasslands only	Arable land only
Gullying	198	1	0
Wind erosion	32	4	1
Landslip	20	0	0
Rill erosion	103	1	2
Sheet erosion	34	0	0
No erosion	2458	516	262
Not recorded	35	3	0
Total number recorded	**2845**	**522**	**265**

Wind erosion was primarily found on mountain tops (soils were alpine or oroarctic podzols) or coastal links soils (regosols). The occurrence of erosion features at survey points was also compared with the soil type found at each point. Peat covers around 22% of the land area of Scotland and, according to the NSIS, almost a third of the peat sites visited were eroding.

Overall, the NSIS provides an objective sample of 5 main types of erosional features and covers all of Scotland (apart from the Orkney Islands). The regular grid pattern allows areas of erosional features to be determined. However, although the presence or absence of erosion was recorded at each site, the actual area and depth of gullying was not quantified and the severity of erosion cannot therefore be determined. The usefulness of the survey is also constrained by the prolonged period over which the data were collected (around 10 years), the timing of the sampling (spring to autumn) and the lack of strict definitions for each erosional feature.

6.4.3 Land Cover of Scotland 1988 (LCS88)

The Land Cover of Scotland 1988 (LCS88) dataset comprises 126 main categories of land cover identified from air photographs of approximately 1:25,000 scale. The photographs were taken primarily in 1988 though a few were taken in 1989. The photographs were interpreted by a team of skilled interpreters who had extensive field experience in matching tonal patterns on air photographs with vegetation communities in the field. Erosional features were identified in only two categories of land cover: eroded blanket bog and eroded montane vegetation.

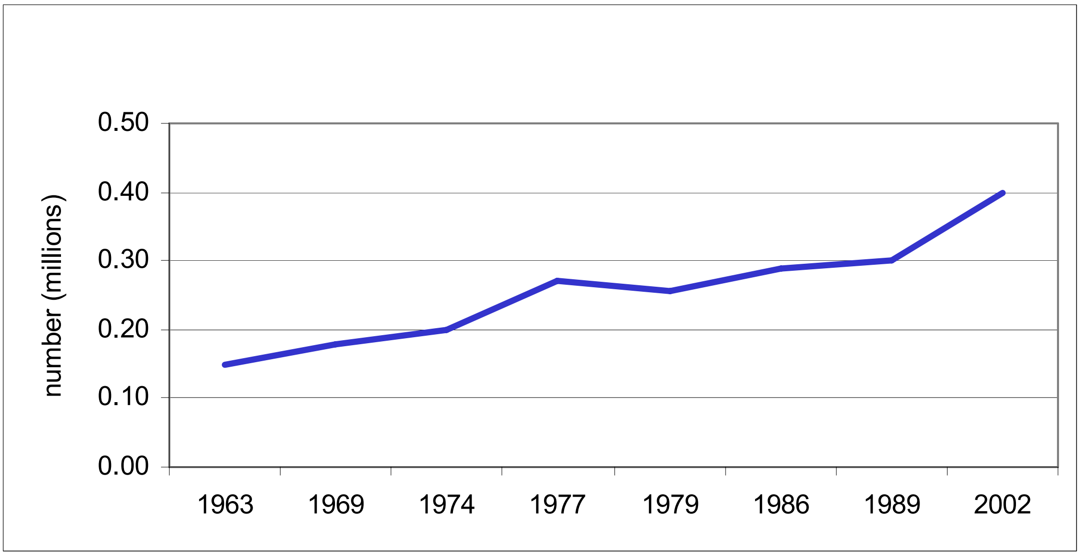
The LCS88 dataset shows that just less than 6% of Scotland had eroding blanket bog which is approximately 34% of the total area of blanket bog identified. This compares with around 7.5% of Scotland or 31% of all peat categories as calculated from the NSIS. The area of erosion in the montane zone is calculated as around 3% of Scotland from the LCS88 but only 0.5% from the NSIS. This may be explained by the fact that all montane land cover classes were considered to have erosional features, which may not always be the case. Given that a map unit of eroded blanket bog will have substantial areas of both bare and vegetated (that is, uneroded) peat, the actual area of eroded and bare peat will be less than 7.5%. This also holds true for calculations based on the NSIS.

6.4.4 Commissioned surveys of erosion incidence

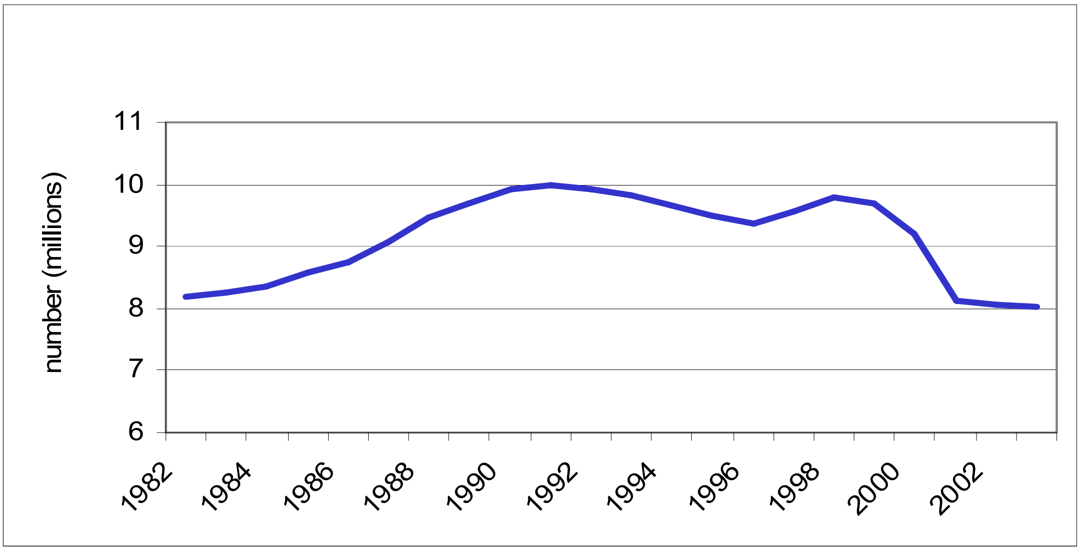
Grieve et al. (1994; 1995) quantified the area of erosion from aerial photographs in a 20% sample of the Scottish uplands. In total, approximately 12% of the sampled area had erosional features recorded. Peat erosion accounted for the greatest extent, 6% of the sample area, and the extent was very similar to that derived from analysis of the LCS88 and NSIS data. It must be emphasized however that these data do not indicate that 6% of the upland area of Scotland has been lost to erosion, but simply that erosion has affected peat soils in 6% of the area. The actual area of eroded peat will be significantly smaller than this.

Figure 6.1 Totals of a) deer and b) sheep numbers in Scotland in recent decades (From Hunt, 2003; Scottish Executive Abstract of Scottish Agricultural Statistics 1982-2003).

6.1a) Scottish deer population totals.



6.1b) Scottish sheep population totals.



The greatest occurrence of peat erosion (20% of samples) was found in the Monadhliath Mountains. However the occurrence of the most severe class erosion was greatest in Eastern parts of the country, particularly the eastern Grampians, where land use and grazing pressures were considered to be greatest. This spatial association of erosion and land use pressure, together with the trend of increasing deer numbers in the last four decades (Fig. 6.1a) indicates a significant area of concern over erosion in the uplands. Grazing by sheep is also often implicated in soil erosion in the uplands and the number of sheep grazed in Scotland rose by almost 2,000,000 in the 1980s before leveling off, and then more recently declining following the outbreak of Foot and Mouth Disease in 2001 (Fig 6.1b).

The recent DEFRA-commissioned study of the extent of soil erosion in the upland areas of England and Wales (McHugh et al., 2002) was a ground-based survey measuring similar parameters to those measured in the SNH-commissioned study of upland Scotland (Grieve et al., 1994; 1995). McHugh et al. (2002) found that the extent of degraded soil represented around 2.5% of the area surveyed, a smaller percentage than that reported by Grieve et al. (1995). McHugh et al. (2002) quantified only the area of degraded soil, and thus the results are not directly comparable with the area of soil affected by erosion computed in the Scottish study.

Although the areas affected vary, the very clear message emerging both from national data sets and from systematic studies of soil erosion at the national or regional scale is that the incidence of soil erosion in upland areas is greatest on peat soils. Given the significance of peat soils for terrestrial carbon storage and biodiversity, erosion of peat soils in upland areas of Scotland remains a subject of major concern.

6.4.5 The Scottish Road Network Landslides Study

This study (Scottish Executive, 2005) recognised five distinct types of landslide varying in the nature of displacement and the liquid content of the sediment. However, most landslides that occur in Scotland are of the flow type, a spatially continuous movement of a material as a viscous fluid. Flow type landslides include the particularly dramatic ones that occurred in the summer of 2004 and disrupted parts of the Scottish trunk road network. It should be noted that this type of event is neither new nor uncommon; events have been recorded since 1744 and more recently events have occurred throughout the Northern, Western and Central Highlands although not on the scale of those of 2004.

The key contributory factors to debris flow occurrence were identified from a comprehensive literature review and a workshop of experts from different fields. The factors influencing debris flow occurrence were categorised into three types:

1. *Hazard factors affecting debris flow occurrence*. These include topographic factors (slope angle, height, aspect), geological, geotechnical and hydrogeological factors (geological formation, landslide history, likelihood of earthquakes, shear strength, void ratio, relative density and permeability and surface drainage), meteorological factors (rainfall, snow melt) and vegetation and land use.
2. *Hazard factors affecting debris flow runout*. These include slope angle, height and magnitude (affecting the volume of material delivered to deposition zone), channel characteristics and vegetation and land use.
3. *Factors affecting exposure to debris flow hazards*. The key factor in relation to the exposure that results from a debris flow is whether or not the flow reaches a vulnerable element in this case a trunk road or associated infrastructure. Clearly, if there is no possibility that the flow will reach a trunk road (or associated infrastructure) then both the hazard and the hazard ranking become, for the purposes of this study, zero. Factors such as road usage and emergency response times were assessed here but they are not particularly relevant to the present study.

A GIS screening analysis of likely debris flow occurrence and subsequent exposure and hazard was carried out. As a first pass, there are three critical factors that could be obtained rapidly and remotely from a GIS to assess whether these conditions are in place:

- A source area where the slope angle is greater than 26° and less than 50°.
- A run-out zone where the slope angle is greater than 8°.
- A trunk road is present within either of the above zones.

It should be noted that peat can flow at much lower angles than these and it would be appropriate also to perform an alternative first pass in which a search is carried out for all trunk roads passing through areas of peat.

The identification of high risk areas was then interfaced with an assessment of exposure to that risk, primarily road usage. In this way some key stretches of the trunk road network were identified as being of high perceived hazard. Management and mitigation options were also identified. Overall the report highlights the importance of water as the main contributory factor triggering debris flow events. Climate change models for Scotland in the 2080s indicate that summer precipitation will decrease but winter precipitation increase. However, summer storms are believed to be at least partially responsible for triggering the events of August 2004, and climate data may not give a full picture of the relationship between precipitation and landslides.

6.4.6 Case studies reported in scientific papers

Table 6.2 (Davidson and Grieve, 2004) summarises data from event-based studies of soil erosion from a range of sites in Scotland. Most instances follow high-magnitude, relatively rare, rainfall events and affected soils which were bare, for example, due to the cultivation of winter cereals. Many studies also linked incidence to direction of cultivation (e.g. Davidson and Harrison, 1995). Although these data indicate that erosion of lowland soils does occur, there has been some debate over whether erosion rates should be considered significant. Frost and Speirs (1996) considered that on soils derived from soft sediments such as glacial tills, the impact of soil erosion on in-field soil quality was questionable. However, other on-site effects such as threats to underlying archaeology are also relevant (Davidson *et al.*, 1999), and off-site effects, particularly the movement of eroded soil to water courses are of major significance.

Table 6.2: Event-based studies of erosion of lowland agricultural soils in Scotland.

Location	Sediment yield (t ha^{-1})	Rainfall (mm)	Duration (h)	Date	Source
Kelso	80.0	28.1	24	December, 1982	Frost and Speirs, 1984
Kelso	48.0	12.7	n.d.	May, 1983	Frost and Speirs, 1984
Town Yetholm	75.0	110.0	72	March-April, 1992	Davidson and Harrison, 1995
Lambie-lethan	69.0	78.1	57	September, 1985	Duck and McManus, 1988
Barry	14.7	n.d.	31	September, 1985	Duck and McManus, 1987
Douglas-town	1.7	55.0	24-27	March, 1992	Kirkbride and Reeves, 1993
Kincaldrum	1.2	55.0	24-27	March, 1992	Kirkbride and Reeves, 1993
Hatton	2.2	55.0	24-27	March, 1992	Kirkbride and Reeves, 1993

Studies in England and Wales underline the importance of winter cereals for soil erosion and the greater occurrence of erosion on sandy textured soils (Brazier, 2004; Quinton and Catt, 2004; Evans and Brazier, 2005). Evans (2005) reported that it is unlikely that the severity of erosion in England and Wales has increased within the last 20 years but the evidence also underlines the need for better schemes for monitoring erosion.

Evidence of absolute rates of soil erosion over longer time periods is available from studies using the caesium isotope ^{137}Cs as a tracer. ^{137}Cs was added to soils from atmospheric testing of atomic weapons and events such as the Chernobyl incident in 1986. The isotope is strongly adsorbed to soil clay particles. Redistribution of soil particles following ^{137}Cs deposition provides an estimate of absolute rates of soil redistribution during the last 40 years. Bowes (2003) mapped soil losses from soil ^{137}Cs inventories in 25 m square cells along transects across cultivated fields on sandy soils in east central Scotland. Net annual soil redistribution in all the fields sampled ranged from losses of 3 kg m^{-2} to gains of 6 kg m^{-2}. However it must be stressed that these losses apply to small areas. Field boundaries effectively trap much of the eroded soil within the field and net losses from the field were much lower. This may partly explain why ^{137}Cs estimates of erosion rates are often greater than data obtained from surveys of larger spatial units (Brazier, 2004).

Estimates of erosion rates using ^{137}Cs budgets have also led to increased recognition of tillage displacement as an important contributor to net erosion within cultivated fields. While tillage erosion is not as important as water erosion in most landscapes (Van Oost et al., 2005), it can lead to significant localized soil thinning within fields, for example on convex slopes. Such soil thinning represents a particular threat to archaeological cropmarks in particular areas (see chapter 9). Davidson et al. (1998) estimated that a mean erosion rate of about 0.5 mm year^{-1} could lead to damage to a cropmark site on a convex slope in Perthshire within a few decades.

Case studies of relevance to the erosion of soils in the uplands have considered the effects of forestry management and grazing by herbivores on erosion. Most erosion from forest areas occurs is linked to disturbance during the planting and harvesting phases (Stott and Mount, 2004), often originating in ditches and stream banks. However, this is a temporary phenomenon and a recent study in Wales has shown that recovery occurs within 4 years as revegetation of exposed banks occurs (Stott, 2005). Several studies have shown that the Forests and Water Guidelines are generally effective in limiting soil damage and minimizing the effects of forest operations on sediment inputs to streams (Nisbet et al., 2002) although Carling et al. (2001) highlighted several areas where further research is needed, most notably in understanding the long-term sustainability of soil structure through several forest crop rotations.

The importance of wind in peat erosion has also been highlighted in studies in the Northern Pennines (Warburton, 2003). Wind erosion of peat normally occurs when the peat surface dries and cracks. Surface layers can then become detached and be blown in strong winds. However, Hulme and Blyth (1985) observed erosion of these surface layers from erosion channels by water during a severe thunderstorm. The thickness of these layers ranged from 1 to 20 mm and it was reported that almost all were removed during the one hour storm. Birnie (1993) assessed erosion rates from an exposed hill peat in Shetland using pins driven into the peat surface. Although the results were variable and complicated by the loss of pins through trampling by stock, he estimated erosion losses of between 1 and 4 cm year^{-1} due to the effects of trampling and rubbing by sheep as well as geomorphic and weathering processes.

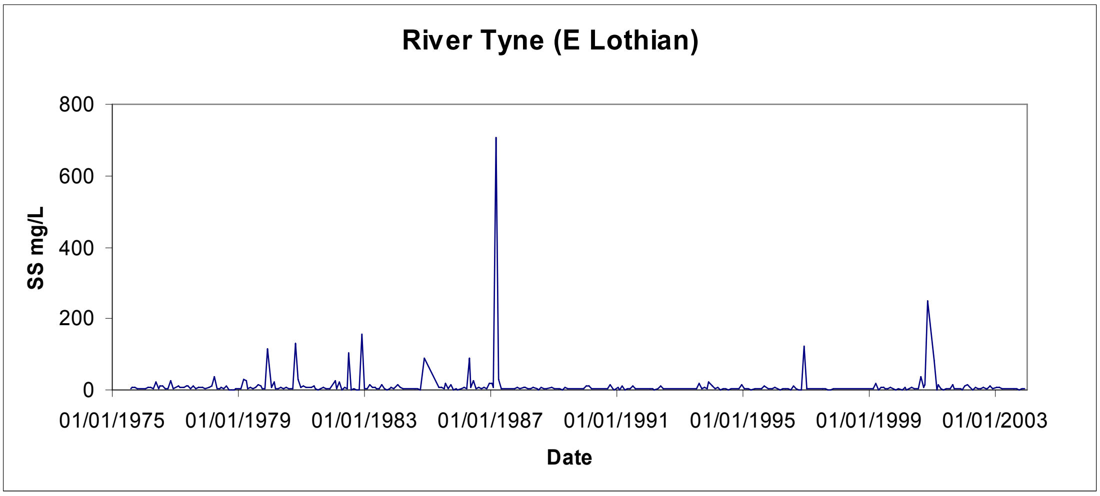
The effect of grazing pressure on erosion rates on the Trotternish Ridge in north-east Skye was monitored between October 1998 and October 2003 (Waterhouse et al., 2004). The land is steep with inherently high erosion rates and is used as common grazing by crofters. Using erosion pins, average gully extension was measured at 105 mm a^{-1}. Gully areas where rabbits were active showed the greatest erosion as a result of both burrowing and overgrazing. Trampling by sheep prevented revegetation of disturbed sites though the natural geomorphic processes also contributed to soil creep and mass movement.

6.4.7 Long-term river records

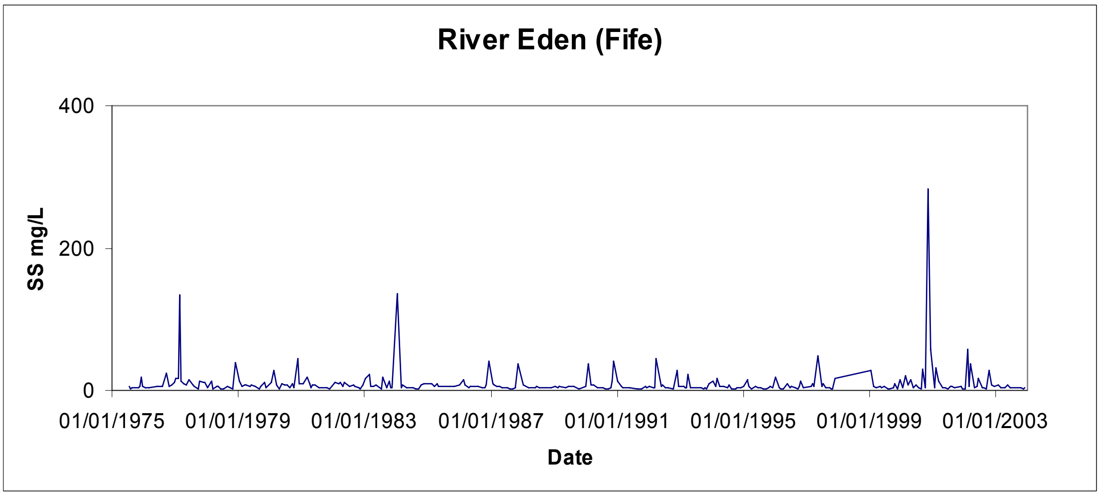
Data from harmonized monitoring provides some insights from which long-term trends in net soil erosion losses from catchments may be inferred, although the low frequency of sampling (monthly) and gaps in data sets limit the usefulness of these data for assessing sediment fluxes. Figure 6.2 shows trends in suspended sediment concentrations since 1975 for rivers draining two catchments in E Lothian and Fife. If there were any drastic change in erosion in these intensively arable areas we might expect to see this reflected in greater suspended sediment concentrations and there is no clear evidence of such a trend in these graphs. Suspended sediment concentrations in rivers are strongly related to discharge (flow). For the River Eden, the regression of concentration on discharge is highly significant ($r^2 = 0.391$, $p < 0.001$), but date was not significant when added as an additional variable, suggesting that the relationship between sediment concentration and discharge has not changed over the 25 year period.

Figure 6.2: Trends in suspended sediment concentrations (SS) for two Scottish rivers.

a)



b)



6.4.8 Modelling of erosion susceptibility

The risk of soil erosion occurring in Scotland has been modelled following two different procedures.

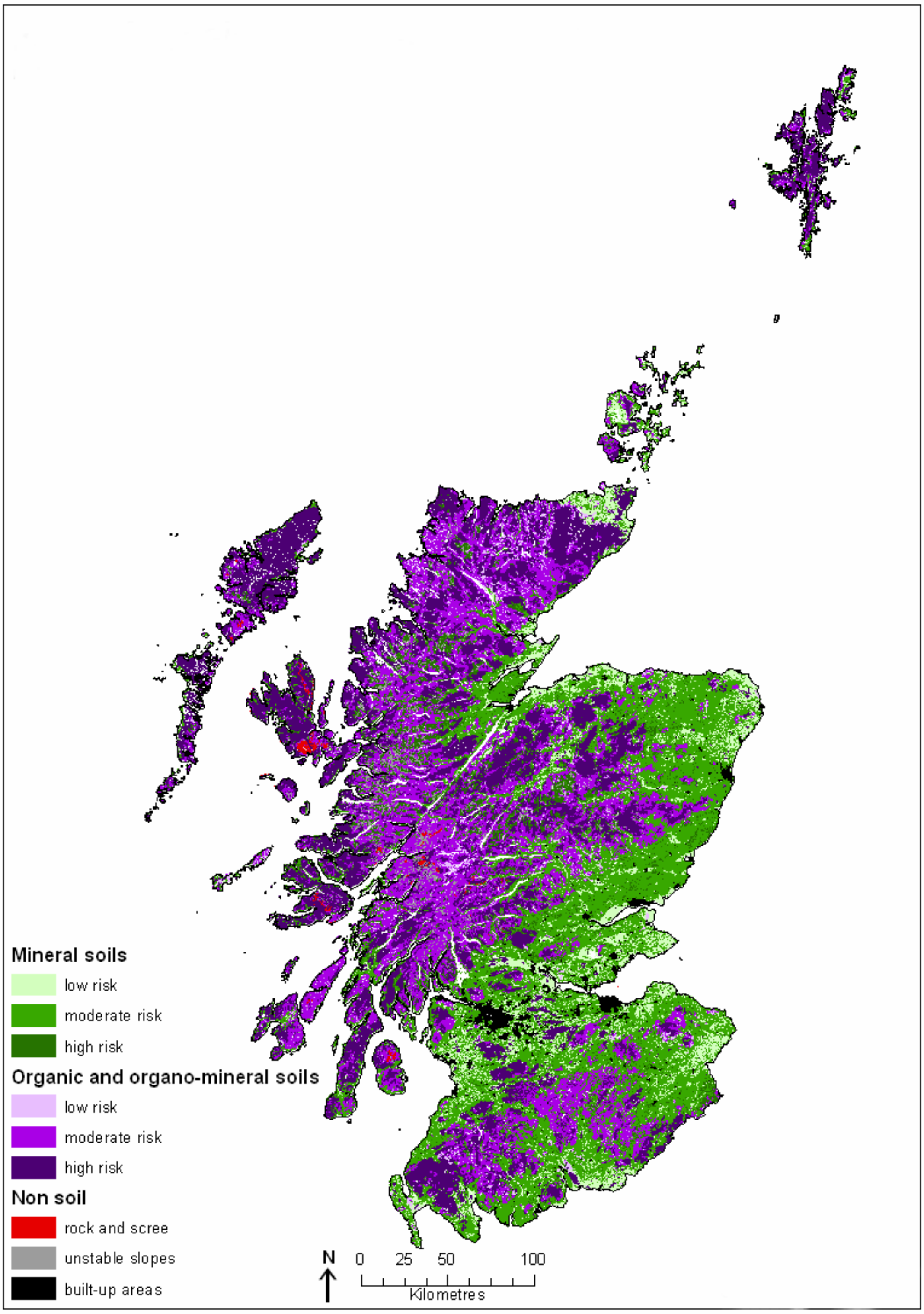
- Lilly et al. (2002) used a rule based approach to identify the inherent geomorphological risk of soil erosion by overland flow, whilst
- Anthony et al. (2006) adopted a more process based approach integrating water balance models with understanding of soil erosion processes at a field scale and was designed to predict sediment and phosphate movement to waterbodies as part of a diffuse pollution screening tool.

Both approaches relied to varying degrees on national datasets of soil texture, HOST class and digital elevation models (DEM) and produced output at a fairly crude scale (1 km^2 grid cells).

The inherent geomorphological risk approach (Lilly et al., 2002) assumes that all soils are bare and that erosion can be modelled using the inherent characteristics of the soil to absorb water from rainfall or snowmelt. The likelihood that a soil would erode was determined according to the erosive power generated by soils becoming saturated and initiating overland flow. The steepness of the slope would determine the erosivity of this flow. As much of the information available on the mechanisms of soil erosion is for mineral soils, a pragmatic approach to assessing the likelihood of erosion on upland organic and organo-mineral soils had to be adopted. Anecdotal evidence suggested that peats were more susceptible to erosion than peaty soils (peaty gleys, peaty podzols and peaty rankers) even where slope and site conditions were similar. Thus peats (organic soils) were simply assumed to be at high risk (Figure 6.3).

This work has been extended for upland soils where the frequency of disturbance to the vegetation cover was added. Thus soils with a semi-natural vegetation cover that was unlikely to be removed were deemed to have a low risk of erosion even if the soils were highly susceptible. Land uses such as forestry or those involving muirburn would have a greater likelihood of bare or disturbed soil and be at greater risk. When vegetation cover was taken into account the areas with greatest susceptibility to erosion fell from 26 to 8% while the area of land with the lowest susceptibility rose from 2.5 to 42%.

Figure 6.3: Distribution of the modelled inherent erosion susceptibility to overland flow.



A similar exercise was undertaken by Vinten et al. (2005) for Scottish Parishes where winter cereals were grown. Soils under winter cereals are thought to be at greater risk of erosion than those under spring cereals due to the prevalence of bare soil during the winter when the soils are at or near field capacity. They combined the proportion of soils with a moderate or high erosion risk in a parish as predicted by Lilly et al. (2002) with that of the proportion of winter cereals grown in a parish and calculated the area of land at risk of erosion (Table 6.3). This has not however been extended to include other crops.

Table 6.3: Soil erosion classes in Agricultural Land Use Categories with tilled land.

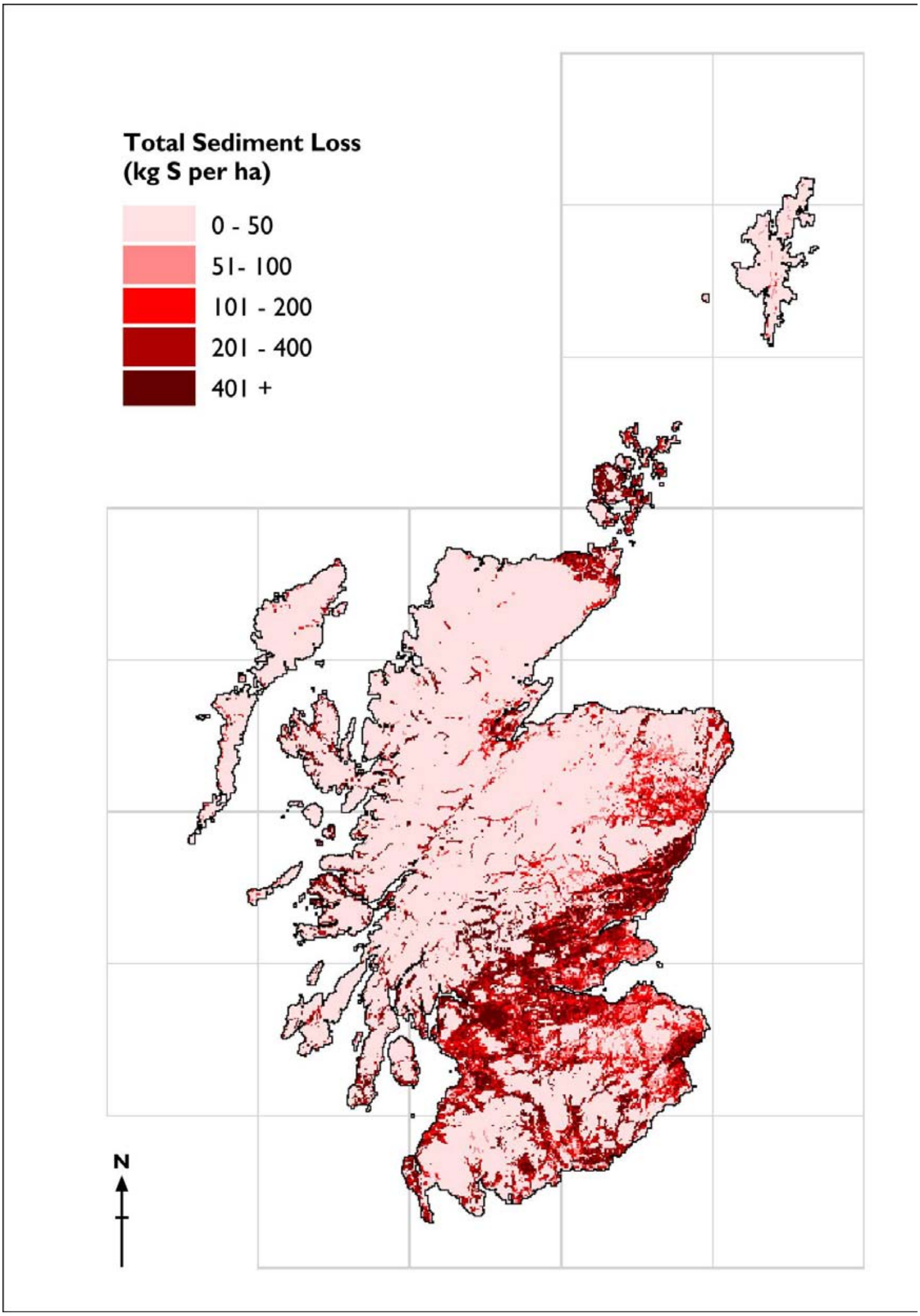
		Dominant Agricultural Land Use Category		
Soil Erosion Classification		spring cropping	spring and winter cropping	mixed, ley and permanent pasture
	Low	764	1,553	232
Mineral soils	Moderate	2,422	3,928	1,045
	High	138	266	88
	Low	31	50	11
Organic soils	Moderate	153	112	127
	High	64	66	70
Rock and scree		0	< 1	< 1
Unstable slopes		2	3	1
Built-up areas		196	275	29
TOTAL		**3,770**	**6,253**	**1,603**

The diffuse pollution screening tool developed by Anthony et al. (2006) covered a wide range of potential pollutants amongst which was suspended sediment. This model differed from that of Lilly et al. (2002) in that it attempted to predict sediment yields. The screening tool incorporated a landscape connectivity index based on soil runoff characteristics, slope angle and shape and soil texture. The landscape connectivity model was then combined with a water balance model and a model of soil detachment and transport within the PSYCHIC modeling framework (DEFRA Project PE0202). The map output is at a resolution of 1 km^2 grid cells and the amount of sediment includes point source contributions from sewage treatment works discharges and septic tanks (Figure 6.4 and Table 6.4)

Table 6.4: Modelled total annual sediment losses (tonnes per year) to surface waters, by source.

Diffuse Sources					Point Source
Urban	Roads	Agriculture	Forestry	Septic Tanks	Sewage Discharges
46,820	29,598	773,845	13,449	7,513	7,198

Figure 6.4: Spatial distribution of the total modelled annual sediment loss from point and diffuse sources to ground and surface waters in Scotland.



Overall erosion models provide a useful indication of the geographical variation in erosion susceptibility, highlighting areas potentially at risk and areas where the environmental function provided by soils where rainfall infiltrates may be inadequate to protect surface waters. They also provide a framework for evaluating the effects of changing rainfall or cropping on potential erosion rates. However, the predictions from soil erosion models are often insufficiently verified against field data (Brazier, 2004). **There is thus a clear need for targeted measurements of actual erosion rates for calibration of model predictions to increase confidence in the outcomes from soil erosion modelling.**

6.4.9 Current status of threat and gaps in data/evidence

There is a substantial body of evidence on the processes of soil erosion and the factors controlling these processes in lowland Scotland. Severe erosion of cultivated soils is highly episodic and localized in its occurrence. Studies have highlighted the importance of land use practices which leave soil surfaces bare during the winter months and the particular susceptibility of sandy-textured soils to erosion in the lowlands. Long-term river records do not suggest an increase in such erosion in recent decades although monthly sampling is too infrequent to prove this conclusively. Compliance with GAEC conditions and the requirements of the WFD should also minimize soil erosion, although **collection of data on the incidence of erosion will necessary to monitor the effectiveness of such policy instruments**. In a similar manner, case studies relevant to the uplands have also underlined the success of policy instruments such as the Forests and Water Guidelines in reducing the transfer of eroded soils to water courses.

In the uplands, surveys of erosion incidence both in Scotland and in other parts of Great Britain have shown that peat soils are the type with the greatest area of erosion, linked in part to their inherent susceptibility and in part to pressures such as large numbers of grazing animals. This must be seen as a significant threat to upland soils, given the importance of peat soils particularly for carbon storage. **Surveys have provided useful data but there remains a significant gap in our knowledge of the current status of erosion on peat soils, since the surveys reviewed here are based on aerial photography from the late 1980s.** There are also uncertainties over the mechanisms of erosion in peat soils as well as the links between land use and peat erosion. The evidence for such a link is based on a very limited analysis of the spatial association of severe erosion and greater stocking densities. **This would benefit from a more rigorous analysis in order that stocking densities consistent with maintaining the integrity of peat soils can be established. A greater understanding of the mechanisms leading to the initiation of erosion in peat soils would also be of benefit in this respect.**

There is also a need for better determination of erosion rates so that predictions from erosion models can be properly calibrated and verified. This could be achieved by a limited programme of field monitoring at research sites together with determination of mean long-term rates for specific soil types and land uses using techniques such as ^{137}Cs inventories.

6.5 Future trends

Policies such as the GAEC requirements, the Forests and Water Guidelines and the Water Framework Directive are explicitly directed towards minimising soil erosion and should reinforce recent trends in reducing erosion of agriculture and forest soils. However, future trends in soil erosion linked to extreme weather conditions are more difficult to predict. Climate models suggest an increase in rainfall for Scotland, and major flood events have attracted considerable media attention in the last few years. A recent analysis predicts that for the UK as a whole, event magnitudes at a given return period will increase by 10% for short-duration (1-2 day) events and by up to 30% for longer frequency (5-10 day) events (Ekstrom et al., 2004). Analysis of extreme rainfall data for the period 1961 to 2000 indicate that event magnitudes have significantly increased particularly for Scotland. For example the 50 year rainfall event in Scotland has become an 8 year event for Eastern Scotland and an 11 year event for Southern Scotland during the analysis period (Fowler and Kilsby, 2003).

Such predicted increases in the frequency of extreme rainfall events suggest that soil erosion incidence linked to extreme weather conditions may increase in the next few decades. It is therefore expected that erosion events similar to those tabulated previously (Table 7.2), landslides such as occurred in the autumn of 2004 and bog bursts like those seen on Shetland in 2003 and other significant erosion of peat may increase in frequency in the future. However, climate models generally predict average conditions and the errors on the predictions are substantial. Models are incapable of predicting localised summer storms. It is therefore difficult to suggest policy changes by which such the effects of such events may be avoided. Agricultural and forestry policies aimed at reducing the erodibility of soils and runoff from soils will undoubtedly limit the impact of extreme events. Predicting and mapping the areas most susceptible to such events will also enable better targeting of protective measures for infrastructure such as roads.

6.6 Conclusions

- Soil erosion at rates exceeding background rates is termed accelerated erosion. In Scotland accelerated erosion has generally been the result of human activities which lead to removal of the protective vegetation cover. Tillage also increases soil erosion rates through downslope displacement of soil.
- Accelerated erosion of soils has important implications for a number of soil functions. Loss of the more organic topsoil represents a threat to both the biomass production and carbon storage functions of the soil. Erosion also represents a threat to the filtering and buffering function of the soil, leading to important off-site effects such as contamination of rivers with sediment and associated nutrients and pesticides.
- Current policies aimed at limiting soil erosion include the expectations within the GAEC Framework and the Forests and Water Guidelines. The Water Framework Directive also places emphasis on reducing loss of soils to surface waters. Voluntary codes such as PEPFAA (Prevention of Environmental Pollution From Agricultural Activity) and the Farm Soils Plan will also help reduce erosion.
- In the lowlands, studies of individual erosion events highlights the susceptibility of bare sandy soils during the winter months, and the significance of practices such as cultivating directly up and down slopes. National inventories do not adequately quantify such events, which pose a significant threat to the quality of surface waters and to archaeological cropmark features. **We therefore recommend monitoring of erosion events to ensure the success of agricultural policies designed to reduce erosion.**

- Surveys of erosion in the uplands have shown that peat soils are particularly susceptible by erosion, with estimates that some 6% of upland Scotland is affected. Erosion of peat soils in upland Scotland poses a significant threat to the carbon storage function of these soils, and peat erosion remains a subject of major concern. **Further research into the link between climate and land use change and peat erosion and the significance of peat erosion for carbon loss is urgently needed.**
- The evidence also highlights the importance of extreme rainfall events in the occurrence of events such as the severe landslides which occurred in the late summer of 2004.
- Models of soil erosion provide an indication of geographical variations in erosion and areas potentially at high risk. **There is a need for better quantification of actual erosion rates to calibrate the models and validate their outcomes.**
- Climate change models predict that Scotland will become warmer and wetter particularly during the winter months. If the incidence of extreme rainfall events increases, there are likely to be more frequent occurrences of erosion events, including erosion of bare cultivated soils, landslides and large scale peat erosion. **Hazard mapping offers a possible means of targeting protective measures.**

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Chapter 7 Soil contamination

There are a wide range of potential pollutants that can contribute to soil contamination. These pollutants enter the soil system by either atmospheric deposition or land-based human activities. This chapter is divided in three sections, describing soil contamination by:

- Atmospheric pollutant nitrogen and sulphur, with a brief mention of radiocaesium
- Land-based activities, particularly pathogens and pesticides
- Heavy metals, including air-borne, sewage sludge and contaminated land

7a Soil Contamination by Atmospheric Pollutants

7a.1 Summary

- There is a strong link between acidification of soils and emissions of sulphur and nitrogen.
- Many Scottish soils are particularly sensitive to acid inputs of sulphur and nitrogen from the atmosphere. This is due to many upland soils being derived from slow weathering, acidic soil parent materials and comprising organic rich soils.
- The sensitivity of soils to acidification has been assessed through the use of a critical load approach applied to the 1:250 000 soil map units of Scotland.
- Emissions and deposition of sulphur have been reduced through international abatement strategies whereas nitrogen emissions and deposition have declined by a very small amount.
- Exceedance of Critical Loads for soil acidification in Scotland has been estimated for the period 1995 to 1997 to be 85%. This will decline to 35% by 2010 due to reduced emissions and deposition.
- Exceedance of Critical Loads for eutrophication in Scotland has been estimated to range from 2 % for acid grassland to 76 % for coniferous woodland and will decline by only approximately 15 % by 2010.
- Recovery of soils to previous levels of base saturation, is likely to take decades, in contrast to the signs of recovery in some water bodies, and their fish populations, which have recovered their acid neutralizing capacity over a few years.
- Accidental emissions such as the Chernobyl accident, and their location and impacts are impossible to predict.

7a.2 Introduction and Description of Threat

The burning of fossil fuels and industrial emissions to the atmosphere of pollutants such as sulphur, nitrogen and heavy metals give rise to the deposition of these pollutants, often thousands of km away from their source. The impact of these pollutants on soils and their related ecosystems is variable in time and space and is determined by a number of factors such as: deposition history, pollutant mobility and accumulation in the soil and ecosystem sensitivity. Within Europe the approach selected to scientifically assess and to evaluate potential policies to abate the impact of these pollutants has been the development of the critical load approach (see under NEGTAP below).

7a2.1 Acidification

Acidification occurs when gaseous emissions of SO_2, NO and NO_2 are converted to sulphuric or nitric acids which fall as 'acid rain'. The acid inputs provide both a source of protons to exchange for base cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and mobile anions (SO_4 and NO_3) to remove displaced cations from the soil through leaching. A wide range of soils in Scotland are susceptible to acidification. Some guidance on which soil types are the most sensitive is provided in Langan and Wilson (1993). This study partitioned the soils of Scotland into the five critical load classes (after Nilsson and Grennfelt, 1988). The most susceptible soils are developed on quartzites and granites. The next most sensitive soils have low base saturation, and are developed in metamorphic schists, gneisses and granulites of pre-Cambrian age covering large areas of upland Scotland. Soils in these two classes have inherently low base saturation, which is further reduced by acid inputs. The low weathering rates in these soils imply that recovery of base saturation levels will take decades during the reduced emission levels currently in existence. This is in marked contrast to water courses and lochs, which have already exhibited clear signs of recovery. There are also natural processes of acidification in soils involving respiration to produce carbon dioxide, organic acid produced by decomposition of organic matter and base cation uptake by plants. A recent estimate for the 1990 decade (Fowler *et al.,* 2002) suggested that acid inputs exceeded the critical loads for more than half the 1 km grid squares .The largest areas of exceedance were in central and southern Scotland. Peatlands and acid grasslands were the most affected habitats. The main findings of a review of the impact of nitrogen deposition in forest ecosystems (Emmett, 2002) were that soil is the main sink for increased N deposition. There are limits to how much N can be stored in soil in the long term. Nitrate leaching will eventually occur in N-saturated soils. The review states that ammonium uptake by vegetation and soil microbes and increased nitrification can lead to acidification of some sensitive soils and a reduction in the availability of other nutrients.

Langan et al. (2004) report that a significant proportion of different woodland habitats in Scotland and more widely across Great Britain have been recipient of pollutant deposition in excess of their critical load compared with the 1995-97 data. In comparison to future modelled deposition loading for 2010 there is a significant decrease in the area in which the critical load is exceeded. This data is reproduced in the Table 7.1 below. The geographical distribution of these areas of exceedance can be obtained by reference to the original paper.

Nitrogen can also play a role in the acidification of soils depending on the nitrogen transformations in the soil. However, currently the emphasis of the impact of nitrogen deposition on natural and semi-natural ecosystems is its role in eutrophication.

Table 7a.1 Critical load exceedance by country and woodland habitat type calculated using deposition data for 1995-97 and predicted modelled data for 2010.

	Area and percentage of habitat exceeded							
	Managed coniferous km^2 / (%)		Managed broadleaved km^2 (%)		Unmanaged woodland km^2 (%)		Total km^2 (%)	
	1995-97	2010	1995-97	2010	1995-97	2010	1995-97	2010
England	1,463 (86.0)	1,047 (61.5)	4,150 (73.7)	2,996 (53.2)	1,533 (64.1)	869 (36.3)	7,146 (73.5)	4,912 (50.5)
Scotland	3,025 (64.1)	1,649 (34.9)	748 (66.2)	472 (41.8)	433 (42.6)	140 (13.8)	4,206 (61.2)	2,261 (32.9)
Wales	1,011 (97.3)	657 (63.3)	709 (89.4)	530 (66.9)	350 (88.6)	249 (62.9)	2,070 (93.0)	1,436 (64.5)
Total	5,499 (73.7)	3,353 (44.9)	5,607 (74.2)	3,998 (52.9)	2,316 (61.0)	1,258 (33.1)	13,422 (71.3)	8,609 (45.7)

7a.2.2 Eutrophication

Nitrogen is a major nutrient in soils and eutrophication by reduced (NH_3 and NH_4^+) and oxidized (mostly NO_3^-) forms of N is becoming more important as sulphur emissions reduce. The extent of exceedance of critical loads of eutrophying inputs during the 1990s varied according to habitat. According to Fowler *et al.* (2002) the largest exceedances of critical loads for nutrient nitrogen for woodland ground flora occur across extensive areas of the lowlands in south, central and north-east Scotland. Peaty soils are also sensitive to eutrophying inputs, but do not occur extensively in areas where nitrogen deposition is high.

7a.2.3 Radiocaesium contamination

Soil contamination by radiocaesium has occurred as fallout from nuclear weapons testing and as a result of the accidental release from Chernobyl in 1986. Weapons testing has ceased. Radiocaesium from the Chernobyl accident affected areas of the uplands in Scotland when deposited during rain events. Caesium remains available for uptake by vegetation in peaty soils. Uptake by animals is highest in summer when vegetation growth is highest and grazing animals are on higher ground.

7a.3 General Policy Issues

The UK approach to gaseous emission reductions is set out by the Department of the Environment, Transport and the Regions (The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, 2000). In relation to acidification and eutrophication, this strategy document uses air pollution limits in ambient air for oxides of nitrogen and sulphur dioxide taken from various European Air Quality Daughter Directives, which control emissions of sulphur and nitrogen by setting:

- Maximum sulphur content of heavy fuel oil and gas oil
- Emission standards for motor vehicles.

7a.4 Evidence

7a.4.1 Current Status

There is a lack of long term soil monitoring data in Scotland and the UK. However there are a small number of site manipulation studies and modelling approaches that have tried to identify the extent of the impact, particularly of atmospheric deposition of nitrogen and sulphur.

The effect of acid deposition on ecosystems in Scotland

The pH of peat across Scotland has been related to the level of acid deposition (Skiba *et a*l., 1989). Dystrophic peats were found to have pH below 3.0 where deposition exceeded 0.8 kg H^+ ha^{-1} $year^{-1}$. Additional evidence for change with time, between 1956 and 1997, in Grampian region (Miller *et al.,* 2001) at an upland site managed as a heather dominated rough pasture receiving no fertilizer showed an increase in exchangeable hydrogen throughout all soil horizons in the order of 100-400%. The same study also reported large decreases in available magnesium and calcium in the humic layer. White and Cresser (1998) reported that there was a strong positive relationship between soil pH and rainfall pH and soil pH and deposition inputs of strong acid anions in soils developed on granitic and quartz rich parent materials across a pollution gradient in eastern Scotland. In a study of soil profiles in forests of NE Scotland, Billett *et al.* (1988) demonstrated that between 37 years between two sampling dates (1949 and 1986) the surface organic horizons had been acidified between 0.07 and 1.28 pH units in 80% of the sites and that at 70% of the sites the mineral horizon had been acidified below 40 cm. The authors account for this acidification as due to both base cation uptake within the forest biomass and that in the deeper mineral horizons soil acidification as a result of acid deposition inputs was a contributor.

Eutrophication in ecosystems in Scotland

Data from two Countryside Surveys (Barr *et al*., 1993; Haines-Young *et al*., 2000) was used (McGowan *et al.* 2001) to examine the evidence for eutrophication in Scotland. In the second survey, a greater number of species suited to fertile conditions occurred within lowland raised bogs, blanket bogs and dwarf shrub-heath across Scotland, while the number of species declined by 6-7 % in dwarf shrub-heath. Upland soils show an increased nutrient status, which has been used to explain a shift from heaths to grasslands in the uplands of Scotland. In the arctic-alpine heaths, *Racomitrium lanuginosum* has declined by 75 to 95 % over the last century (Thompson and Baddely, 1991). However, it is important to note that other factors such as increased competition between plants and different land management impacts such as fire? and grazing will have significant influence on the occurrence and growth of many dwarf-shrub species.

7a.4.2 Data Availability, suitability and quality:

There are a number of reviews and primary sources of material and references available that detail spatial and temporal impacts of atmospheric pollution on ecosystems. A selection of the most relevant ones is:

- The UK Air Pollution Information System (APIS) is located at www.apis.ac.uk: APIS is a support tool for staff in the UK conservation and regulatory agencies, industry and local authorities for assessing the potential effects of air pollutants on habitats and species. As such, it aims to enable a consistent approach to air pollution assessment across the UK. The web pages consist of a database which can be queried by the user. The site does not currently allow the user to search the database by country and in that sense is not Scottish specific. Recently amended by CEH with new model for ammonia emission impacts for Scotland (SE report unpublished 2006). However, there are four ways in which you can search the database, one of which is by location. Using this facility, together with either a known locality, National Grid Reference (NGR), or the inbuilt NGR location map, it is possible to search the available data for further information on that site. The other methods of searching the database are by:- Habitat of which there are 32 categories (e.g. raised bog , montane heath) which can also be matched against Biodiversity Action Plans or the Habitats Directive, Annex 1 species; Pollutant type, a choice of querying by acid deposition, ammonia, N deposition, nitrogen oxides, ozone and sulphur dioxide is available; Issue in which the user can choose from acidification, eutrophication, photochemical oxidants, accumulation of toxic substances, direct toxicity of atmospheric pollution and particulate matter. The site also contains an overview section in which the user can search by pollutant impact by issue, impact by ecosystem or legislation. Finally the site contains a glossary, unit conversion and an extensive reference list from where the original findings have been published.

- The air quality archive **www.airquality.co.uk/archive/reports/reports.php?action=category&section_id=10** This site setup on behalf of the Department of the Environment, Rural Affairs Department and the Devolved Administrations contains a digest of background information on air pollution, available data from UK networks, local air quality monitoring, research information and reports.

- The National Expert Group on Transboundary Air Pollution (NEGTAP) report **www.nbu.ac.uk/negtap/docs/finalrep_web/NEGTAP_C5Soils.pdf**. This work provides a comprehensive review and details the evidence and uncertainties for sulphur, nitrogen and ground level ozone and their impacts on ecosystems, including soils in the UK. The report is structured around principal chapters dealing with emissions; deposition of sulphur, nitrogen, ozone and acidity; modelling concentrations and depositions; effects on soils; effects on freshwaters; effects on vegetation; the European perspective and recovery. The chapter dealing with soils starts with a description of the process of soil acidification and the role of acid deposition. The chapter moves on to discuss soil indicators of change and the evidence base from which this has been taken. The evidence base is provided from a number of studies that includes sites and studies from Scotland. The chapter concludes with a description of the approach used to predict the impact of acid deposition on UK soils based on the principles of the United Nations- Economic Commission on Europe (UN-ECE) Convention on Long Range Transport of Air Pollution. Under this convention it was agreed to adopt an effects based approach to international negotiations on reductions of air pollutants. The favoured approach to this requirement was to use a targeted approach based on critical loads. A critical load is defined as the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on ecosystem structure and function. The approach and methods of calculations are presented in the references given below and included in the report.

- **Hydrology and Earth System Sciences**, special issue on the sustainability of UK upland forestry (2004, Volume 8, Number 3). This journal contains a number of papers (Hall *et al*. (2001); Hodson and Langan (1999); Hornung *et al*. (1995)) relating to the impacts of atmospheric pollution on forests in Scotland and the UK. These include the results of a manipulation experiment characterizing the impacts of acidity and nitrogen loading on Sitka Spruce (Sheppard *et al*., 2004) and the development of the acidity critical load approach to assess woodland habitats in Great Britain (Langan *et al*., 2004)

7a.4.3 Future trends

- For Scotland and more generally for the UK and Europe, emissions and therefore the potential impacts on soils and ecosystems from air pollution are lessening. The main references are: (**www.nbu.ac.uk/negtap/docs/finalrep_web/NEGTAP_C5Soils.pdf**) and Birnie *et al*., (2001).
- There is little unequivocal evidence of recovery from soil acidification with most data suggesting continuing acidification into the 1990s. However there is some evidence of pH increases in upland soils in 1998/99 (compared with 1978) and on arable and grassland soils over the last 10 to 20 years, see: (**www.nbu.ac.uk/negtap/docs/finalrep_web/NEGTAP_C5Soils.pdf**). The partial revisiting of the NSI in Scotland funded by SEERAD will shed further light on any trends. In addition, CS2007 should produce trend data that will inform this debate.

7a.4.4 Impacts on soil functions

Biomass production

Arable crops and improved grassland require soil pH to be at certain levels for optimal growth – pH 6.0-6.2 for arable crops and pH 5.6-5.8 for improved grassland. Clearly soil acidification will affect these values, but management intervention through liming can control pH. Most cultivated Scottish soils are maintained at artificially high pH values and liming is a standard part of farm practice. However financial pressures on farming may lead to lack of maintenance in soil pH values on cultivated land.

Most woodland species and semi-natural plant species are tolerant of acid conditions and will not be affected by soil acidification. Only some broadleaved species such as ash that favour more base-rich conditions may be affected.

Environmental interactions

Soil acidification contributes to surface water acidification so in this respect there is a negative interaction; this is probably the biggest impact on any soil function. However there are encouraging indications that recovery is taking place (McCartney et al., 2003). Soil acidification can also have a deleterious influence on the ability of soils to buffer other pollutants such as heavy metals.

Biodiversity

There is limited evidence that soil acidification or eutrophication has had an effect on the range of semi-natural habitats that Scottish soils support; indeed increased acidity will if anything help any initiative to reinstate habitats that favour acid conditions. The biodiversity within the soil may be changed subtly by changes in soil pH, but that is not to say that a change is necessarily negative or positive. Changes in soil microbial biomass and microbial activity were reported in a simulated nitrogen input experiment (Johnson *et al*., 1998). The results of this study showed significant increases in microbial biomass and activity in nitrogen-limited heathland. The soil under acidic grassland showed a decrease in microbial biomass and there was no change at the calcareous grassland site.

Soil acidification generally has little impact on the *provision of a platform, provision of raw materials and protection of cultural heritage* functions.

7a.4.5 Related threats

Soil acidification interacts with the threat of contamination by increasing the potential for pollutants to be mobile in more acid soils. There are potentially strong linkages between future emissions and impacts that atmospheric pollution may have under varying scenarios of climate change.

7a.5 Conclusions

Scotland contains large areas of soils derived from acid parent materials. These soils have inherently low base status and have been affected by acid deposition. The effects include removal of base cations and their replacement on the exchange complex with hydrogen or aluminium. Low weathering rates and the potential for desorption of sulphates mean that these affected soils will take of the order of decades to recover to pre-industrial revolution levels, if they ever will. These soils will remain in this acid sensitive state for a long period even under the current régime of reduced emissions. Evidence for increased eutrophication appears to suggest that a wider range of species are colonizing affected peat soils. The amounts of nitrogen deposition have not been reduced by the same proportion as those of sulphur, so nitrogen deposition remains a threat to upland soil quality.

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7 b Soil contamination by pesticides

Use of pesticides in agriculture and forestry and accidental spillages can contaminate soils and water courses. This section presents and assesses the evidence of the threat from pesticides to soil function.

7b.1 Summary

- Pesticides are controlled by a strict regulatory framework within both the EU and UK.
- UK Ministerial approval for use is under scientific advice from The Advisory Committee for Pesticides.
- Although a limited number of pesticides in rivers and groundwater are monitored, data sets are not complete and pesticide concentrations or exceedances of quality standards are not regularly published.
- Evidence from England and Wales in an experiment with five pesticides shows no adverse effects on crop productivity or on microbial biomass or its activity, as assessed by C or N mineralization.
- Evidence on the effect of an organophosphate pesticide on soil microbial biomass from four sites throughout Scotland was inconclusive.
- Pesticide usage surveys in Scotland have been used in the development of a screening tool for pesticides. There are several separate surveys undertaken but it would be of considerable benefit if they were to be combined to give a common dataset.

7b.2 Introduction

Pesticides are widely used within agriculture to control or eliminate unwanted insects, fungi and weeds, thereby improving crop yield, quality and reliability. Pesticides are biocides and therefore highly toxic substances. They are used within a strict regulatory framework which should ensure that contamination of soils and water from pesticide usage does not occur. Nonetheless there are cases of misuse and spillages which do result in pollution incidents prosecuted by SEPA.

Pesticides have a range of potential impacts on soil functions, but the most likely threats are to:

Environmental interaction

Pesticides reaching surface or ground waters through leaching, drainflow, surface runoff or spray drift may impact on the quality of surface waters, but pesticide usage should have no significant impact on the filtering function of the soil itself, unless the absorption capacity of a soil for a particular substance is exceeded. This latter situation is unlikely to occur as it would only result from long periods of application at rates considerably in excess of approved usage rates. Residues in the soil could potentially impact on microbial decomposition processes in the soil and thus have some impact on soil carbon storage.

Support for ecological habitats and diversity

Pesticide usage is aimed at eliminating target plant, insect or fungal species, thereby deliberately reducing above ground diversity. There are also potential threats to non-target organisms.

Biomass production

Use of pesticides is aimed at increasing biomass production directly. The only potential threat to biomass production would be from residues building up in the soil to toxic concentrations.

Pesticides are unlikely to have any impact on the soil's ability to provide raw materials, act as a platform for built infrastructure or protect cultural heritage.

7b.3 Policy

The regulatory framework for the use of pesticides is enshrined in various pieces of Scots and UK legislation (The Water Environment and Water Services (Scotland) Act 2003; The Food and Environmental Protection Act 1985; The Control of Pesticides Regulations 1986; The Plant Protection Products Regulations 1995; The Plant Protection Products (Basic Conditions) Regulations 1997; The Pesticides (Maximum Levels in Crops, Food and Feedingstuffs) (Scotland) Regulations 2000) and, in the case of sheep dips, the Veterinary Medicines Regulations 2005. The major driver for policy is, however, now EU directive 91/414/EEC, the 'Authorisations Directive' which provides the framework within which pesticides are authorised for use across the European Union.

Approval of pesticides for use in the UK is granted by UK Government ministers. Ministers are guided by advice from an independent scientific advisory committee (The Advisory Committee for Pesticides) which bases its advice on an assessment by scientists from DEFRA's Pesticides Safety Directorate of a data package provide by the approval holder (normally the manufacturer. The assessment includes calculation of likely concentrations of the pesticide and its metabolites in the soil and in surface and ground water. Calculations are based on field and laboratory determinations of persistence and mobility and computer models and field trials of loss from the soil and movement to surface and ground waters. Predicted concentrations in soil and water are compared with toxicity thresholds for various organisms and approval is only granted where there is an assurance of no significant environmental damage.

The Directive and Scots and UK legislation provide the framework under which pesticides are approved and used and they are reinforced by a wide variety of guidelines, covering both agricultural uses of pesticides and other uses. These guidelines include the Prevention of Environmental Pollution From Agricultural Activities Code Of Good Practice (PEPFAA Code) (Scottish Executive, 2005), The Use of Herbicides in the Forest (Forestry Commission, 1995) , The Safe Use of Pesticides for Non-agricultural Purposes (Health and Safety Commission, 1991) and The Groundwater Protection Code: Use and disposal of sheep dip compounds (Defra, 2001)

7b.4 Evidence

Current status

EU Directives, and associated UK and Scottish legislation should ensure that approved pesticides do not cause environmental and ecological harm. Soil plays an important role in mediating the impacts of pesticides on groundwater through adsorption and immobilisation of active substances; however adsorption within the soil may lead to the build-up of pesticide residues detrimental to soil quality. In one long-term experiment in England, five pesticides were applied in various combinations over a 17 year period and no adverse effects on crop productivity were found (Bromilow et al., 1996). The continuous use of the same pesticides, either singly or in combination, also had no measurable long-term harmful effects on the soil microbial biomass or its activity, as assessed by C or N mineralization (Hart and Brookes, 1996). In Scotland, synthetic pyrethroid was applied to plots at four sites and organophosphate was applied at two of these sites in the spring of 2002 (Aitken, *et al*., 2002). The soils were sampled between 30 and 62 days later. All the soils had similar loamy textured topsoils (sandy clay loam, sandy loam or sandy silt loam) and only one was described as having a high organic matter content. Analyses of the soils showed that the pesticides had degraded and that there had been little adverse effect on the soil microbial biomass, mineralisable nitrogen or soil respiration rate though there may have been a weak indication of an adverse effect by the organophosphate on the soil as measured by the Biolog. However, greater differences were attributed to soil variability than to the effects of the applied pesticides. Thus, there is little evidence of pesticides having a detrimental effect on the biomass production or microbial biodiversity function of the soil.

Approved pesticides should also not contaminate surface and ground waters, although there appear to be few independent data to confirm this. The Environment Agency of England and Wales has a programme of routine monitoring of pesticides in surface and ground waters (http://www.environment-agency.gov.uk/yourenv/eff/1190084/business_industry/agri/pests/).Under this programme, concentrations of a wide range of pesticides are monitored normally 4 times per year at more than 1,500 freshwater sites. The annual reports based on monitoring does reveal some exceedance of environmental quality standards but the pesticides implicated are often either no longer used or about to be withdrawn. This monitoring raises no serious concerns over the use of pesticides arising from agricultural practices in England and Wales. In Scotland, SEPA monitors some 12 pesticides in groundwater at 248 sites across Scotland and a smaller number at the 58 harmonised monitoring sites on Scottish rivers. However, data sets are often incomplete and there are no published reports of exceedance of environmental quality standards or of trends in concentrations for Scotland.

Anthony et al. (2006) modelled the risk of applied pesticides reaching water courses in sufficient quantities to impact on aquatic life. One of the intermediate stages in this modelling work was to identify the annual load of pesticides applied to land in Scotland based on estimates of crop type taken from SEERAD's Agricultural and Horticultural census data and pesticide usage surveys. The data were summarised to a resolution of 1 km^2 grid cells. The modelled out put was divided into 2 groups: Priority substances that are toxic and persistent in the environments including Atrazine, Chlorpyrifos, Endosulfan, Isoproturon, Simazine and Trifluralin and, secondly, the remaining pesticides in common use, grouped according to the action and leaching potential of the active ingredient.

7b.4.1 Data availability

Pesticide usage in Scotland is monitored by the Scottish Agricultural Science Agency (Table 1) with arable surveys reported biennially and all others reported every four years since 1990. As the timing of surveys varies between land use type it was not possible to gather all data for a single reference year for use within the diffuse pollution screening tool (Anthony et al., 2006). Data were available separately on the application of pesticides to arable crops (Kerr and Snowden, 2001), grassland and fodder crops (McCreath, 1998), sheep dip (Thomas, 1998) and aerial spraying for bracken control (Wardman and Thomas, 1998). These reports summarise the quantities of active ingredient applied by crop type and the percentage of crop receiving each pesticide. These usage surveys are designed to provide an estimate of national pesticide usage and there are inherent statistical errors when these data are disaggregated using agricultural census information and presented at a 1 km^2 resolution. Anthony et al. (2006) also caution that the pesticide usage data is dated and there may have been changes in their since the survey was completed.

Table 7b.1 Year of pesticide usage surveys in Scotland (from Anthony et al., 2006).

Crop types and land use	Survey Year
Arable	2002
Protected crops	1999
Forestry	-
Mushrooms	-
Soft fruit	2001
Vegetables	1999
Top fruit	-
Grassland and fodder	1997
Hardy nursery rops	2001
Outdoor bulbs and flowers	2001

Loadings for each 1 km^2 grid cell were calculated based on the surveys of pesticide usage, the recommended application rate per treatment and the percentage of the cropping area that received one or more treatments (Table 2 and figure 1). The map clearly shows that the majority of pesticide usage is concentrated in the arable areas of eastern Scotland with more limited usage in the south west which is dominated by improved grassland.

Figure 7b.1 The distribution of total pesticide loading in Scotland based on land cover and agricultural census data (from Anthony et al., 2006)

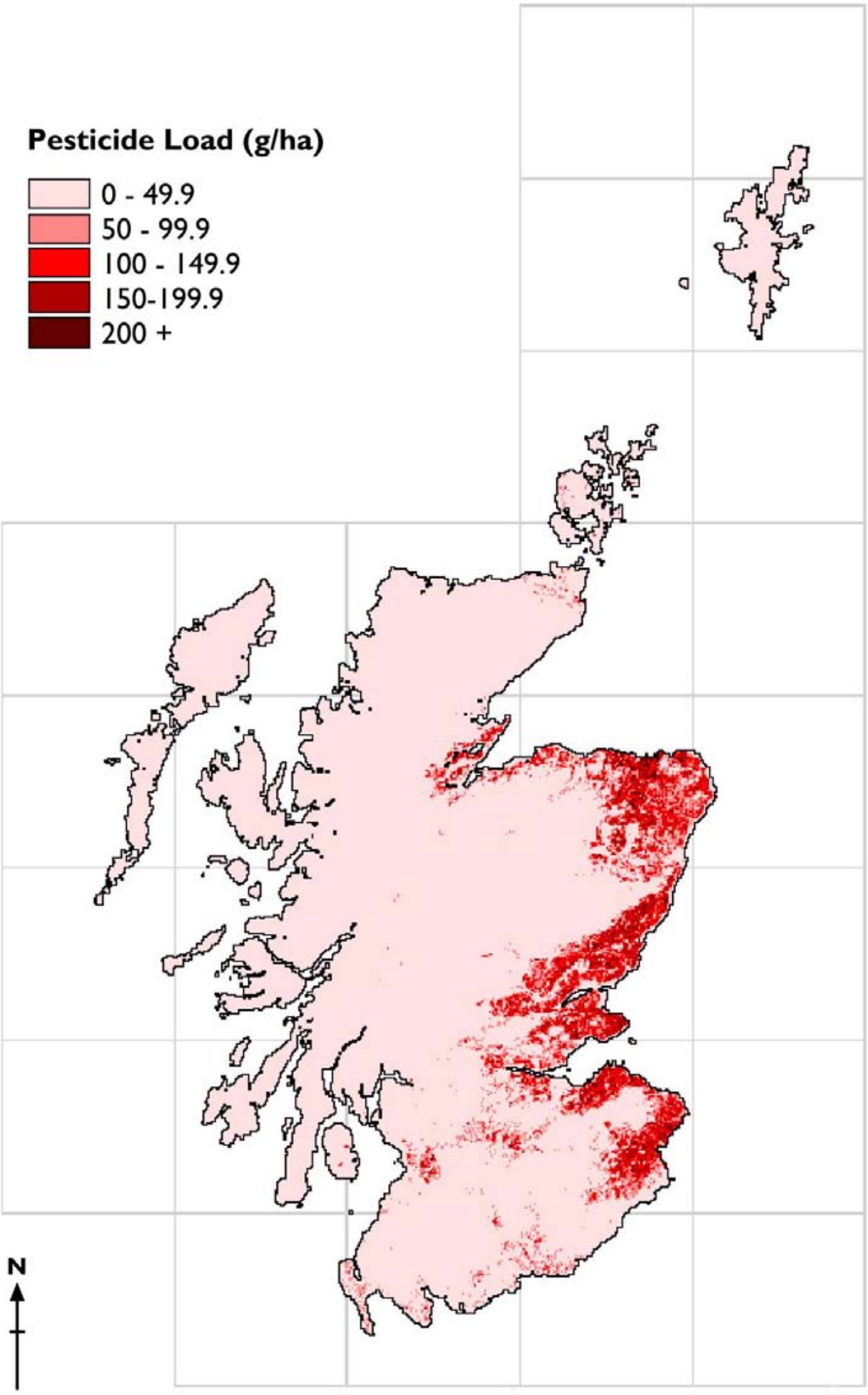

Table 7b.2 Modelled total annual loads of Priority Substances and selected pesticides applied in Scotland (from Anthony et al., 2006).

Active Ingredient	Pesticide Load (tonnes)
Simazine	2.18
Atrazine	-
Trifluralin	35.33
Diuron	0.02
Chlorpyrifos	12.05
Isoproturon	100.59
Non Priority Substances	152.13

7b.4.2 Gaps in data or evidence

Pesticide concentrations in surface and ground waters in Scotland are monitored but the results are not systematically published. However, in the light of the data published for England and Wales, it is unlikely that these data will indicate any significant threat to waters in Scotland.

The evidence of minimal reduction in soil microbial communities (Hart and Brookes, 1996) could be strengthened with further work.

7b.5 Future trends

Pesticide usage is unlikely to increase in the short to medium term and is likely to become more stringently regulated as food safety becomes an increasingly important issue.

7b.6 References

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The Use of Herbicides in the Forest (Forestry Commission, 1995)

The Safe Use of Pesticides for Non-agricultural Purposes (Health and Safety Commission, 1991).

The Veterinary Medicines Regulations 2005 SI 2745

The Groundwater Protection Code: Use and disposal of sheep dip compounds (Defra, 2001)

7c Anthropogenic Pollution by Heavy Metals

This section describes current data sources of heavy metal levels in Scottish soils and the impacts associated with heavy metal addition to soil through atmospheric deposition or organic waste recycling.

7c.1 Summary

- Heavy metals occur naturally in the environment and some fulfil a number of key functions in relation to plant growth and health.
- Some soils have naturally high levels of metals, for example ultrabasic rocks and some support plants and communities of high conservation value.
- Atmospheric deposition of heavy metals is generally low over Scotland and is predicted to decline.
- Organic wastes including sewage sludge are one of the prime anthropogenic sources of heavy metal inputs into soils and their application is highly regulated. The recycling of other wastes with elevated metal levels either follow voluntary codes (farmyard manure and slurry application on the farm at which the waste was produced) or under exemptions within the framework of the Waste Management Licensing Regulations. Under the second scenario there is a requirement that the waste brings either agricultural or ecological improvement. Exceedence of the metal limits set out in the sewage sludge regulations can be used as evidence by the regulatory authorities for the lack of improvement.
- Sewage sludge, and other organic waste recycling to land, is projected to continue and a watching brief on the results from the sewage sludge network is highly recommended. **There is emerging evidence that relatively low metal concentrations, of Cu but particularly of zinc, at levels below the current regulatory threshold, are having a significant impact on biological fertility.**

7c.2 Introduction and Description of Threat

Heavy metals occur naturally in soils as a lithogenic signature inherited from the geological parent material from which the soil has formed. Where these natural background levels are enhanced by additions, damage to the soil can occur. There are two main ways that added metals can enter the soil. The first of these is by atmospheric deposition whilst the second is by the application of fertilizers and certain organic wastes such as pig slurry, sewage sludge (Nicholson *et al.*, 1993) and wastes generated by specific industries e.g. distilling. Of these wastes, only sewage sludge is regulated in terms of heavy metal additions to soil and only then for addition to soil for agricultural purposes. Some other wastes have much higher concentrations of specific metals (Towers and Campbell 1998). In the case of other wastes, however, SEPA does in practice have good grounds for refusing to register exemptions under Waste Management Licensing if the limits for metal concentrations in soil stated in the Sludge Regulations were likely to be exceeded. SEPA could argue that the waste would damage soil quality, which would breach the requirement under Waste Management Licensing Regulations for the party applying the waste material to demonstrate the waste brings ‘agricultural improvement’ or ‘ecological improvement’.

Metal addition to land by waste recycling is much more confined than that resulting from atmospheric deposition and nowadays is primarily targeted onto cultivated agricultural land. In the past, wastes were applied in some areas to semi-natural vegetation to improve the sward quality for grazing, but this practice has ceased. More recently, sewage sludge has been applied to forestry and in land restoration projects but there have been some concerns about application rates and techniques. The most obvious damage has occurred to water courses as a result of over application and although no damage to soil has been reported, any effects may be occur on the longer term.

Sewage sludge to land is very well regulated and documented in terms of volume and quality of the sludge and the quality and location of the receiving soil. Much less is known about the other wastes with enhanced levels of heavy metals although the SEERAD June census data may provide some indication of the likely location and volumes of application of specific wastes such as pig slurry. In addition some activities involving use of waste materials for treatment of soil for agricultural benefit or ecological improvement qualify for a registered exemption from licensing if they meet the requirements detailed in Regulations 7, 9 and 19 and Schedule 3 of the Waste Management Licensing Regulations 1994 (as amended). As a result of amendments to the Regulations in 2003 and 2004, some exempt activities, including all those relating to recovery of waste on land, are now required to keep records, for a period of at least two years, of the quantity, nature, origin, destination and method of recovery or disposal of all waste used in connection with an exempt activity. These records have either to be submitted to SEPA or made available on request. SEPA therefore has records which includes soil and waste analysis of all such exempt activity in Scotland.

Records relating to exempt waste applications to land held by SEPA often contain heavy metal concentration data for wastes and soils. As applications for waste management licensing exemptions must demonstrate that ‘agricultural improvement’ or ‘ecological improvement’ will occur as a result of the disposal of the waste to land, the limits for metals in soils quoted in the Sludge (Use in Agriculture) Regulations (1989) are often used by SEPA as guideline values to assess whether the waste application is likely to have negative effects on soil quality.

The first real indication that heavy metals may be impairing soil function came in the late 1980s and early 1990s when there was some evidence that heavy metals from sewage sludge were causing damage to the soil microbial population. While regulations exist for the amount of heavy metals that can be introduced into agricultural soils through the application of sewage sludge, these are based on known effects on plant growth and productivity. In the late 1980s and early 1990s, there was some evidence that heavy metals from sewage sludge were causing damage to the soil microbial population and its functioning. This culminated in the production of the ‘Bradshaw Report’ (1993) which recommended the establishment of a series of experimental sites where different sludges would be applied under standard protocols and a set of standard analysis undertaken on the receiving soils. Previous studies in England showed that following long-term application of sewage sludge, accumulated heavy metals had a marked effect on the microbial population and diversity of soil function. In particular, the survival of effective *rhizobia* which trap atmospheric nitrogen in soils was reduced and the strains which adapted to the increased heavy metal concentrations were ineffective. This was considered to have a long term consequence on the fertility of the soil.

Other potential consequences of elevated soil heavy metal levels are perturbation of the C and N cycle, soil respiration and reduction in functional diversity. Heavy metals are not known to have any impact on the protection of cultural heritage but depending on soil metal concentrations, there is a small chance that there may be a negative interaction on the provision for building and raw material functions.

Erosion of soil with enhanced levels of metals and subsequent transport to water courses will pose greater risks than uncontaminated soil. The same general statement also applies to soils that are subject to landslides or at risk from flooding (see Chapter 6)

7c.3 General Policy Issues

Sewage sludge is considered a waste. It may, however, be applied to agricultural land under the Sludge (Use in Agriculture) Regulations (1989) and the Sludge (Use in Agriculture) (Amendment) Regulations 1990, which enforce the provision of EC Directive 86/278/EEC. These set maximum annual applications for metals contained in sludge and maximum permitted metal concentrations in agricultural soil treated with sludge. Guidelines for the use of sewage sludge on agricultural land are given in the Code of Practice for the Agricultural Use of Sewage Sludge (HMSO, 1996). In Scotland these are summarised in the PEPFAA code of good practice, where reference is made to the recommendation of the RCEP (1996) that untreated sludge is not used on agricultural land. Sewage sludge may also be applied to non-agricultural land under a paragraph 8 Waste Management Licensing Exemption, but the operator must demonstrate the sludge will bring ‘ecological improvement’ in order to comply with the Regulations. The Manual of Good Practice for the Use of Sewage Sludge in Forestry (Forestry Commission, 1992) (Forestry Commission Bulletin 107) also endorses the applicability of these regulations in the forestry industry. This document has been recently updated by Moffat (2006) and has been extended to include the use of sludge in land reclamation.

7c.4 Evidence

7c.4.1 Evidence of current status

Unlike a number of the other pollutants, there is relatively good information on the background levels of heavy metals in Scottish soils. The best source of information is the SEPA publication on background levels of pollutants in Scottish soils (Paterson *et al.*, 2002, (http://www.sepa.org.uk/pdf/publications/reports4sepa/contaminants_scottish_soils.pdf). Data exist for 19 metals, from the National Soils Inventory for Scotland, and summaries for cadmium, chromium, lead, nickel, copper and zinc appear in Paterson *et al.* (2002). The values for all the metals are lower than those in the equivalent datasets for England, Wales and Northern Ireland.

Data on heavy metal concentrations in soils are also available from Countryside Survey 2000 (CS2000). Comparison of median values for selected metals from the

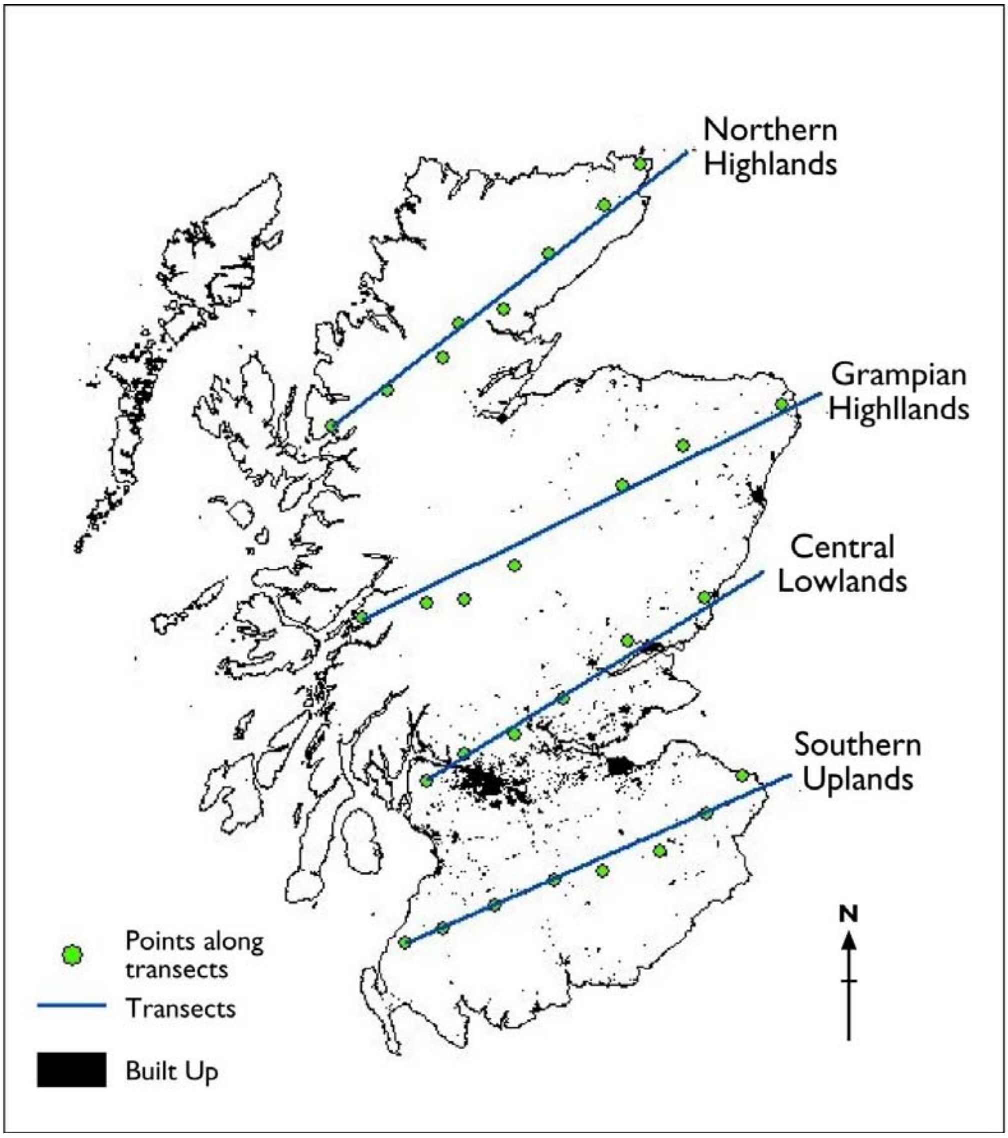
NSIS and CS2000 datasets are remarkably similar considering the different structure of the sampling grid and the details of how the soils were actually sampled (Table 7c.1).

Table 7c.1 Heavy metal concentrations (mg kg^{-1}) in soils of Scotland from NSIS and CS2000 data (median values).

	Sample number	Cd	Cu	Ni	Pb	Zn
NSIS	720	0.29	7.8	6.2	30.6	34.9
CS2000	450	0.15	5.7	5.9	28.0	35.6

Soil pollution transects (Fig. 7c.1 http:/www.macaulay.ac.uk/tipss) are a third source of data. Although fewer in number, transects provide a useful indication of metal concentrations in soils relative to built up areas; namely, upland uncultivated land where inputs are more likely to be from atmospheric deposition. Cadmium and lead have higher values in the two southern transects than in the other two transects whereas the other elements have by far the highest concentrations (Table 7c.2) in the Central Lowlands transect . This is a clear indication that intense industrial and other activities in the Central Belt are the prime source for the diffuse anthropogenic background for these contaminants. The data for Fe confirm this conclusion and identify iron and steel making as a probable major contributor to the anthropogenic inputs of Cr, Cu, Ni and Zn.

Figure 7c.1 Location of sampling points on Scottish soil transects relative to built-up areas (www.macaulay.ac.uk/tipss).



There is little information on the background concentrations of Hg in Scottish soils, mainly as result of inadequate analytical methods for the low background concentrations found in soils. Recent improvements in analytical methodologies make it feasible to measure Hg concentrations in soils and a systematic survey would be beneficial in establishing baseline levels for any evaluation of Hg accumulation in soils. Although major emissions of Hg occur in the tropics, the metal migrates to cooler latitudes (a "distillation" effect) and is now present throughout the globe. Scottish soils could therefore in theory be vulnerable to deposition of Hg but there is little evidence if any for diffuse contamination of Scotland's soils. The chemistry of Hg is complex and its toxicity highly dependent on chemical form. Mercury deposited from the atmosphere is generally inorganic but microbial processes in soils can convert Hg into highly toxic methylmercury. Similarly, there are no systematic data on arsenic levels which is potentially toxic at low concentrations in soil and water. In the UK arsenic contamination is associated primarily with tin mining which is not widespread in Scotland. However, elevated levels have been found in small localised areas due to the long term use of seaweed as a soil amendment (Castlehouse *et al.*, 2003).

Table 7c.2. Mean values and ranges (mg kg^{-1}) for a range of heavy metals in the four transects across Scotland.

Contaminant	**Statistics**	**Northern Highlands**	**Grampian Highlands**	**Central Lowlands**	**Southern Uplands**
Cd	**Mean**	**0.53**	**0.85**	**1.10**	**1.28**
	Range	0.33-0.72	0.42-1.48	0.16-2.39	0.62-2.48
Pb	**Mean**	**29**	**64**	**119**	**139**
	Range	15-51	23-122	20-240	76-230
Cr	**Mean**	**2.1**	**4.5**	**22**	**8.6**
	Range	1.4-3.2	1.7-14	5.1-74	3.3-18
Cu	**Mean**	**4.7**	**8.9**	**22**	**12**
	Range	3.3-5.8	4.1-16	14-34	9.1-17
Ni	**Mean**	**2.2**	**3.7**	**22**	**6.5**
	Range	1.8-3.1	2.5-5.9	8.6-49	4.6-9.3
Zn	**Mean**	**38**	**59**	**94**	**67**
	Range	23-61	40-92	69-134	50-83
Fe	**Mean**	**1,501**	**3,886**	**16,136**	**3,980**

7c 4.2 Availability of data for monitoring trends

There are a number of datasets that might be used for this purpose and include:

- NSIS (n = 721). This has already been done in England and Wales where there is an apparent decline in most metals. However it is considered that a major factor in this is that the changes are linked to changes in analytical techniques and may not reflect real change.
- CS2000. Around 400 soil samples from approximately 100 separate 1 km squares in Scotland (H. Black, pers. comm.) were analysed for seven heavy metals as part of CS2000.
- The TIPPS transects (n = 29).
- The sewage sludge network sites (n = 2). As already described, these have devised to specifically monitor metal build-up in soils and the microbiological response to that.
- The Soil and Herbage study (n = c.30). This dataset is due to be available soon and will contain information on heavy metal levels in soil and herbage.
- The Environmental Change Network (ECN) sites (n = 3).

7c.5 Evidence of threat and damage

Modelling

Estimates of atmospheric inputs have been modelled by MacDonald *et al.* (2001) and there is a clear differentiation between the relatively high deposition rates in the

Central Belt and the lower rates over much of the Highlands. Deposition rates in the Southern Uplands fall between these two extremes indicating 'import' of metals from other parts of Europe, including England. It is fortuitous that the soils more sensitive to heavy metal addition are broadly co-incident with lower levels of deposition (Anthony et al., 2006). These findings have been supported to a large degree by Ashmole *et al.* (2001) who have developed a critical load approach to heavy metals. This suggests that critical loads have not been exceeded for cadmium anywhere or for lead at the upper critical limit of 8 µg l^{-1}. However, the critical load and critical limit have been exceeded in some areas at the lower critical limit for lead (2 µg l^{-1}). It should be stressed that these results are based on modelling. As such they cannot be viewed as evidence of damage but are indicative of where the greatest likelihood of damage may occur based on current understanding of processes.

Deposition of metals from the atmosphere is in decline (MacDonald *et al.*, 2001) and it is likely that this trend will continue.

Experimental studies

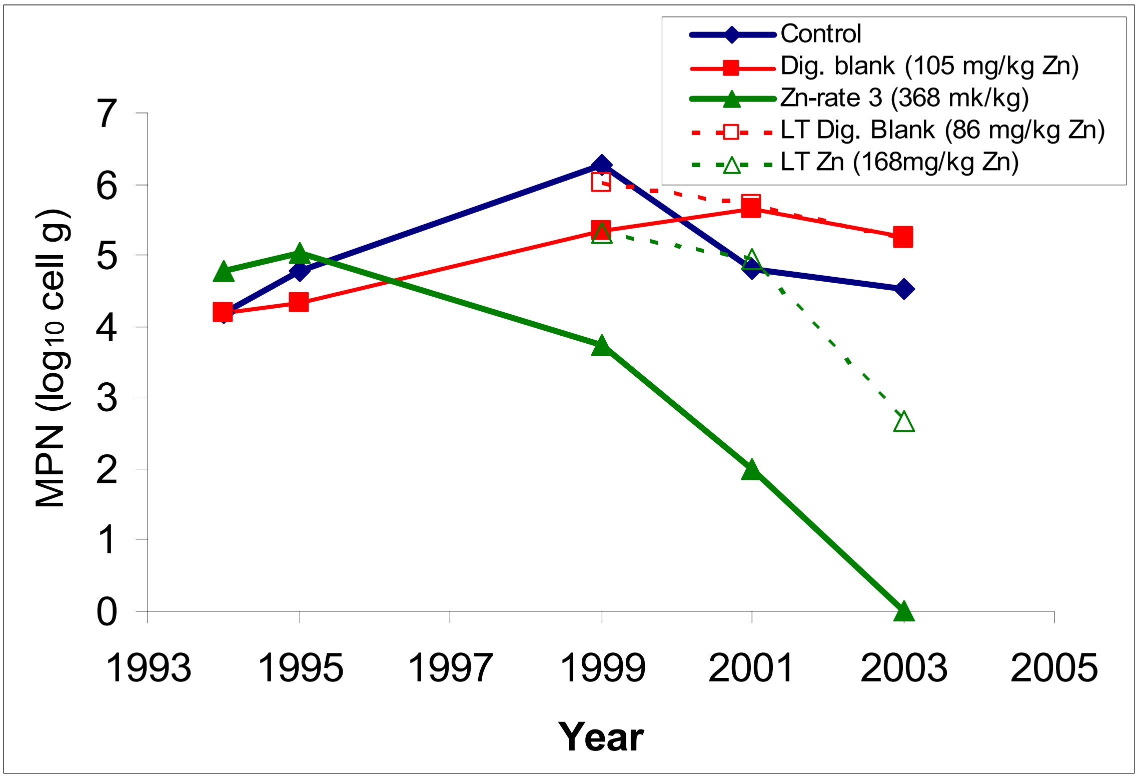
In the Leadhills area of Southern Scotland, near the site of former smelting and mining (Schön and Paterson, in preparation), the metal contents of the soils are considerably enhanced compared with those obtained for similar soils outwith the immediate area of mining and smelting. The levels of contamination with lead, zinc and copper are extremely high in the alluvial soils in the floodplain of the Glengonar Water (up to 22,000 mg kg^{-1}) but high levels, particularly of lead, are also observed in soils from higher ground around a local smelter. These high levels of lead in the environment have been linked to a number of biological impacts including elevated levels of lead in the blood of the local population, particularly children, signs of chronic lead poisoning in fish stock from the headwaters of the Glengonnar Water and the suggestion that lead in the local environment may lead to a skeletal disorder of lambs grazing contaminated pastures. Whilst there is no direct evidence of damage to the soil *per se*, there are significant and serious biological impacts.

A major study was started in 1993 (referred to in Section 7c.2) on the effect of sewage sludge on soil fertility. A consortium of funders (DOE, MAFF, UKWIR, The Welsh Office and SOAEFD) commissioned a group of organisations (ADAS, WRc, IACR Rothamsted, MLURI and SAC) to set up nine experimental sites in England, Scotland and Wales. The same sewage sludges, naturally high in copper, zinc or cadmium were applied at specific rates so that a range of soil metal concentrations, relative to the current regulatory limit were achieved. The two sites in Scotland (Hartwood and Auchincruive) represent typical grassland. The sites were chosen to cover a range of soil types from well-drained sandy soils to the poorly-drained and fine textured soil at Hartwood.

The effects of the metal additions on soil microbial activity (biomass carbon, soil respiration and rhizobia) were key to this study. The general trend across all sites was for no effect of metals on the soil respiration rate suggesting there was no metal-induced microbial stress. On the other hand a significant decrease in microbial biomass-carbon was observed at Hartwood for the Cu treatments. This effect was also seen at some, but not all, of the other sites. This decrease can be interpreted as copper toxicity to the microbial population. The same effect has been observed at some sites for the Zn treatments but these did not include the Scottish sites at Hartwood or Auchincruive.

The most significant finding of the study has been the elimination of rhizobia in the high zinc treatment plots at Hartwood and signficant reductions in other Zn treatment plots (Fig. 7c.2). This reduction in rhizobia numbers, since the first additions of the Zn-containing sludges, appears now to be progressive with time. The y-axis of Fig 7c.2 has a logarithmic scale so the reductions in rhizobia numbers were by several orders of magnitude. The rhizobia numbers in the Zn 3 treatment have been reduced below detection limits by 2003. In addition, clover plants grown in the affected soils were unable to nodulate and fix nitrogen. Decreasing rhizobia numbers have also been observed in the long term build up Zn treatments (LT Zn) which has Zn concentrations of 86 mg kg^{-1}. If this trend were to continue then complete loss of rhizobia might occur on all the soils with Zn elevated by sludge addition

Figure 7c.2 Trend in Rhizobia numbers (MPN) with time in control plots and plots amended with sludge with Zn at different elevated concentrations in soil.



The reason for the drastic elimination of rhizobia in some of the plots cannot be stated with certainty but the body of evidence is that the presence of Zn added with sludge was the main factor. All plots at Hartwood were successfully maintained at pH 5.8 so the relatively low soil pH could not be an explanation for zinc availability *per se*. Although most of the treatments received large doses of organic matter at the start of the experiment, this was not the case for the LT Zn treatment which received only a small addition of sludge each year. Furthermore, the Cd-rich sludge treatment (Cd4), with highest coincident elevated Zn levels, also showed signs of reducing Rhizobium numbers (data not shown) and these sludges had a different quality of organic matter.

Consequently, the only common factors between the Zn 1, Cd 4 and LT Zn treatments seem to be the inherent soil characteristics and the common Zn concentration. Although the reduction in rhizobia numbers has been most marked at Hartwood, similar trends are now being/have been observed at some of the other eight sites (www.ukwir.org/news/figures/03sl014%20exec%20summ.doc) so the inherent soil characteristics are probably not a factor in the rhizobia toxicity but in the relative rates at which rhizobia numbers drop. The added Zn is therefore the most likely agent of rhizobia toxicity.

This project provides sound scientific evidence that Zn accumulation can be detrimental to biological fertility where sewage sludge and other wastes are applied to land and that certain soils in Scotland may be particularly sensitive. The soils at Hartwood are relatively extensive in the Central Belt where much of the sludge is likely to be spread and research is continuing to identify why this soil should be so sensitive. The significance of these data is that the loss of rhizobia is now being seen at Zn concentrations below the current maximum limits and with sludge additions that are permissible under current legislation. Although the clover rhizobia used in this trial are relevant primarily to grassland, the effects seen could be indicative of further effects on soil microbes and on biological fertility in general.

Metal levels in sewage sludge have declined over the last 20 years, on average by around 50%, with the reduction in cadmium being 76% (Smith 2002). Data on trends on other organic wastes are unavailable. These trends are encouraging and in their recent draft sewage sludge strategy, Scottish Water and the PFI operators intend to recycle approximately half of the projected volumes of sewage sludge (currently 151 000, rising to 175 000 tonnes dry solids in 2025) to agricultural land. Recycling strategies for sewage sludge are usually quite precautionary and monitor build–up of metals at regular intervals to maintain a safety margin between actual and maximum permissible levels. However, given the results that are emerging from the UKSS network, some additional caution should be exercised and perhaps there is a greater need to identify Zn-rich sludges and target applications to less sensitive soil types until this phenomenon is more fully understood.

Other sources and future scenarios

Phosphate fertilisers are known to contain small concentrations of cadmium and this can vary depending on the product in question. Perhaps surprisingly, little is known about the Cd content of fertilisers used in Britain and therefore, the amount of Cd entering the soil through this source cannot be determined (Chaudri *et al*., 1995). More recently Adams *et al*. (2002) have suggested that the extent of cadmium contamination in commonly used British agricultural fertilizers is a possible area for future research. Given the length of time that fertilizers have been applied to agricultural land, there is no evidence that levels of cadmium in soil have been elevated above that where food or environmental safety may be compromised nor indeed are starting to approach it.

Concern has been expressed that other metals derived from industrial processes are being released into the environment and are accumulating in soils. Interest in some elements has grown in part because new analytical methods for measuring the very low levels found in the environment have been developed in recent years. Toxic elements such as Sb and Tl occur at low levels in the environment but their industrial use is increasing. The need for improved waste water treatment to protect the environment from Tl produced in industrial processes has been highlighted (Peter and Viraraghavan, 2005) but evidence for widespread accumulation of Tl is lacking. Most evidence for increased levels in the environment has come from contaminated soils close to industrial plants but the analysis of peat cores by Shotyk and colleagues (Frank *et al*., 2003, Krachler *et al*., 2003, Krachler and Shotyk, 2004, Krachler *et al*., 2005, Roos-Barraclough *et al*., 2006, Shotyk *et al*., 2005a, Shotyk and Krachler, 2004, Shotyk *et al*., 2005b, Shotyk *et al*., 2004) have demonstrated the increased deposition of some of these metals since the start of the industrial era. An indication of the background levels of almost all elements in Scottish soils was given by the analysis of the major parent materials (Ure *et al*, 1979) but there have been no studies aimed at demonstrating accumulations of these elements. The linkage between accumulations and threats to the environment or human health is still probably speculative.

The removal of leaded petrol from the marketplace in most developed countries has had a marked effect on the diffuse deposition of Pb to soil. For example, the rates of deposition to the upland catchment at Glensaugh have been reduced many fold over the last few decades (Farmer *et al*., 2005). The reduction of lead in traffic emissions has, however, led to increases in other metals. There is some concern that the now widespread use of platinum group elements (PGE) in the catalytic converters used in cars will lead to a steady and diffuse accumulation in soils. The levels in soils are very low and there have been no long-term studies on accumulations so the long-term consequences of the release of PGE to the atmosphere and the impacts on soils are unknown. The removal of lead from petrol has resulted in other organic compounds being used to increase the octane number of petrol. One of these is methyl cyclopentadienol manganese tricarbonyl (18 mg l^{-1}). In those countries where use of this compound is allowed Mn has effectively replaced Pb as an emission in car exhausts. This has raised concerns because Mn is not only an essential element but is also toxic at high concentrations. A thorough review of the literature came to the conclusion that the very weak cause-and-effect relationships do not justify concern about environmental exposure to manganese (Finley, 2004). The effects of increased levels of Mn in soil are unknown but the accumulations will be small compared with the background levels – Mn has been used as a fertilizer for many years with no adverse impact - so the effects are also likely to be small.

7c.6 Conclusions

- Heavy metals occur naturally in the environment and some for example, copper, if deficient, can adversely affect plant growth. At high levels, most of these metals are phytotoxic or zootoxic and are considered as pollutants.
- Total metal concentrations in soils are relatively well characterized but there are important omissions e.g. arsenic and mercury. We recommend consideration be given to collecting systematic wide area data on these elements to determine background levels and spatial trends.
- Atmospheric deposition of heavy metals is generally low over Scotland and is predicted to decline.
- Organic wastes including sewage sludge are one of the prime anthropogenic sources of heavy metals into soils and application is highly regulated. The application of sewage sludge to land is highly regulated whereas the application of

most other organic wastes is subject to exemption issued by SEPA under the Waste Management Licensing Regulations. **We recommend that consideration be given to how other organic wastes could be considered under a framework similar to that for sewage sludge.**

- Sewage sludge, and other organic waste recycling to land, is projected to continue and a watching brief on the results from the sewage sludge network is highly recommended. **There is emerging evidence that relatively high metal concentrations, particularly of zinc but at levels below the current regulatory threshold, in sewage-sludge amended soil is having a serious impact on biological fertility.**

7c.7 References

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Chapter 8 Loss of soil to development and mineral extraction

This chapter discusses soil sealing through residential, industrial or transport development and mineral extraction, the scale of the issue in a national and regional context, the impact on soil by these developments and information on trends, scale and location of developments.

8.1 Summary

- Data on the loss of land and soil as a result of development is not collected in a consistent manner either at the national or regional level.
- Based on the limited information available, land appears to be being developed at a higher rate than at any time during the last 50 years; this raises questions about the sustainable use of resources and whether soil is being recognised and protected by the planning system.
- Soil lost to development is unable to fulfil any of its other functions; some such as biomass production is almost eliminated.
- There should be encouragement to re-use the soil that is removed during the construction phase.
- Based on previous data, a disproportionate area of our good quality and most flexible soils is lost to development; many of Scotland's settlements are located next to the best land within that area. As new developments tend to 'grow' from existing urban areas, this trend is likely to continue.
- Given the recent findings on reductions in soil organic matter levels (Chapter 2) and role that Scotland's organic soils have in Scotland's climate change programme (Chapter 3), **it is recommended that data on peat extraction be collected centrally by the Scottish Executive.**
- **It is recommended that mechanisms be set in place to capture data on land and soil loss to development. In addition to location and area, information on soil type and quality should also be recorded.**

8.2 Introduction and Description of Threat

Built development frequently results in the loss of existing soil cover and of many of the functions it previously performed. This does not directly equate to soil loss as the soil is usually stripped prior to construction and reused elsewhere in verges, amenity ground or as part of the remediation process on brownfield or derelict sites. However, soil reused in this way cannot be directly compared with soil in its original state as in all likelihood it will have been disturbed and the original horizons mixed to some degree.

Not all the land that is developed is 'sealed' and a certain proportion is retained as open space in the form of gardens, parks, amenity areas etc. There is an increasing awareness and requirement that these provide vital 'lungs' within our cities and towns. There is a consultation currently (August - November 2006) on planning for open space in new developments (excluding domestic gardens) in which minimum open space standards are recommended (Scottish Executive 2006). These vary according to the type of development; for most types of development, the suggested area is between 6 – 18 m^2 per 100 m^2 of gross floor area. This equates to 6-18% but when roads and pavements are taken into account, the proportion of the total area will be less. In residential areas, the figure is expressed differently as 60m^2 per household. Similarly not all land with existing urban areas is completely sealed, the most obvious of these are parks and domestic gardens.

Mineral extraction includes removal of the soil resource itself, for example peat, or disturbance of the soil to allow extraction of the underlying material for example sand, gravel, bedrock or increasingly in more recent times, coal.

8.2.1 Impact on soil functions

Biomass, food and fibre 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 has largely gone for good.

Environmental Interactions

This function has been seriously diminished, but is retained to some small degree in gardens, amenity areas, roadside verges etc. However the major impact on soil function is the reduction in infiltration of water which leads to change in hydrological regimes in rivers, specifically greater runoff and peak flows. Increases in the area of sealed hard surfaces will be offset to some extent by the implementation of Sustainable Urban Drainage Systems (SUDS) which uses the natural capacity of soils to help prevent or minimise flood risk.

Support of ecosystems, habitats and biodiversity

The current planning system and designation of sites of high conservation interest should prevent 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. However, there are likely to be specific areas where conflicts may arise, notably on the location of wind farms and where conservation and development objectives may clash, for example within National Parks.

Green space within urban areas does provide the necessary ‘lungs’ for the well-being of the location itself but also of its residents and can contain elements of biodiversity not found in rural areas. Many of these are highly desirable, for example where contaminated land has been restored or where derelict land is being managed in such a way so that biodiversity objectives are promoted. However, many non-native species are introduced into urban areas which, in this context, is undesirable. Overall, soil sealing has a highly negative impact of the biodiversity function of soil.

Provision of raw materials

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 clearly this requires a high degree of co-ordination. It must also be recognised that there are environmental and economic costs associated with the transport of soil as well as the social costs of dust and noise nuisance.

Protection of cultural heritage.

Soil protects archaeological remains but also provides a record within it of previous cultivation and improvement and therefore of the development of landscapes and societies. It might be argued that urbanisation is another step within the process of change, but the disturbance and redistribution of soil associated with that does destroy any historical record of change captured within the soil.

8.3 Policy

Planning policy and locational priorities for different types of development are identified within structure and local plans. These will have gone through a public consultation process and various committee debates at Unitary Authority level before being approved by the Scottish Executive. Soils are not explicitly protected but those within SSSIs and the Natura suite of protected sites will have indirect or implicit protection from development as clearly any disturbance on the scale caused by building operations will have a serious impact on the integrity of designated sites. In addition, development plan policies designed to prevent urban sprawl (including the designation of clear settlement boundaries) and to protect countryside and green belts afford significant protection to soils.

The Town and Country Planning (Scotland) Act 1997 requires that development plans include measures for the “conservation of natural beauty and amenity” and the “improvement of the physical environment”. There are a number of Scottish Planning Policies (SPPs), National Planning Policy Guidelines (NPPGs) and Planning Advice Notes (PANs) that provide further information and advice on a wide range of planning issues. See:
http://www.scotland.gov.uk/Topics/Planning/AdviceGuidance/PANs
http://www.scotland.gov.uk/Resource/Doc/83958/0036126.pdf

Until 2002 National Guidelines existed that sought to protect the most versatile agricultural land from development unless there was no other suitable site for the purpose. In 2001, the Scottish Executive issued a consultation paper proposing that the blanket national protection afforded to prime agricultural land (Land Capability for Agriculture Classes 1, 2 and 3.1 (Bibby *et al* 1991)) be removed and that the planning authorities be given flexibility to determine for themselves whether such land should be used for new development. After consideration, the Executive decided to remove the blanket protection and argued that ‘Prime agricultural land will continue to be protected through relevant policies in National Planning Policy Guidelines and Circulars (for example, Green Belt policies) and Ministers will still have an overview of prime land, given their role in approving structure plans and being informed of any significant proposals contrary to structure plans.

Within the Scottish Executive's Sustainable Development Strategy (Scottish Executive 2005), it is acknowledged that we must live within the limits of our natural resources. The introduction of **Strategic Environmental Assessment** means that development plans will in future be considered at a very early stage to identify and mitigate potential impacts on, for example, biodiversity, soil, water, air and landscape. The Scottish Parliament has recently passed a Bill extending the scope of European requirements to cover all public sector plans, programmes or strategies with significant environmental effects.

8.4 Evidence

8.4.1 Current status

Built-up land is quite difficult to define and as a result a definitive statement on its location and extent is difficult to obtain. In 1988, the Land Cover of Scotland dataset estimated that 1.8 per cent of Scotland was described as urban and a further 0.6% as rural development. This latter category included features that clearly equate with soil sealing, such as road and rail infrastructure, factories and airfields, whilst others are clearly associated with mineral extraction activities such as quarries. The National Countryside Monitoring Scheme (LCMS) arrived at a figure of 1.7% of urban land cover for the late 1980s (http://www.snh.org.uk/strategy/Landcover/results/built.asp). A follow up analysis covering 1990-1998 (the Countryside Monitoring Scheme) estimated the urban area at 2% and for transport features at 1% although these numbers have been rounded. The Scottish Office (1998) classified 2.6% of the Scottish land surface as urban. More recent estimates could not be found readily on the Scottish Executive website. Care must be taken in the interpretation of these numbers; the differences are likely in part at least to be due to differences in definition and method of data capture.

The area of urban land as a proportion of the total area varies widely across Scotland and any national data masks that variation. Clearly the four major cities have the highest proportions but there are a number of other Unitary Authorities that have urban percentages much higher then the national average. They are all in the Central Belt and include East Dunbartonshire (14.6%), East Renfrewshire (8.3%), Falkirk (6.8%), Fife (8.8%), North Lanarkshire (15.3%) and West Lothian (10.7%). Along with the City authorities, these are all close to or well above the EU average of 7% (Prelier 2005) . Disaggregating Scotland in this way does identify the well recognised population imbalance across Scotland and those areas where pressure on land is greatest. More information can be found at: http://www.scotland.gov.uk/library/stat-ses/sest2-1.htm

8.4.2 Data availability

Precise and consistent data on changes in urban land area are difficult to obtain. The best source of change in the second half of the 20th century is the LCMS as a consistent methodology was applied between 1946 and 1988. The method was based on a random sampling strategy rather than a full census. Increases of 22% and 46% were reported in transport corridors and urban land respectively and in 1988, when combined represented approximately 2.7% of the land area of Scotland. No significant change was found in the area occupied by quarries. The increase of 46% in urban area equates to approximately 400 km^2 (40,000 ha) most of which was lost from improved grassland and arable land. For more details see (http://www.snh.org.uk/strategy/Landcover/method.asp)

Between 1970 and 1999, 25,217 ha of agricultural land were converted to roads, housing and industry and 9,481 ha to mineral workings (Scottish Office 1998, quoted by Birnie et al., 2002). These figures may be an underestimate of the conversion of all land to built infrastructure. In absolute terms they represent annual conversions of approximately 850 and 316 ha respectively.

The most recent data on conversions from agricultural land are presented in Table 8.1. Conversions to recreational land are included for comparison. Between 1989 and 1996, the conversion of land to roads, housing and industry was approximately 700 ha yr^{-1}. In the succeeding seven years this rose to c. 1,200 ha yr^{-1}. As previously described, these figures do not equate directly to soil sealing as a proportion of the land will be retained as amenity grounds, domestic gardens etc. There is a range of different standards set by different Councils for the provision of open space and for garden sizes and a number of these are difficult to convert to percentage areas as they are based on population rather than area. If we assume that the suggested thresholds in the current consultation (Scottish Executive 2006) represent a reasonable consensus of current guidance, then around 10-12% of these recent developments, excluding domestic gardens, might be considered to remain unsealed. However, the soils are likely to be in a different state and will perform quite different functions than prior to development.

There is also an increase in the rate of conversion of land to mineral workings, although these figures are heavily skewed by individual years.

Table 8.1 Conversion of agricultural land to selected other uses.

Year	**Roads, housing, industry**	**Recreation**	**Mineral workings**
	hectares	***hectares***	***hectares***
1989-90	583.7	332.8	914.8
1990-91	544.0	360.6	766.0
1991-92	649.5	415.9	95.9
1992-93	733.9	197.0	197.5
1993-94	791.3	677.3	24.3
1994-95	874.3	388.1	106.4
1995-96	747.4	5,335.4	-167.9
1996-97	1,201.3	1,577.7	177.8
1997-98	1,339.0	626.0	2,381.1
1998-99	1,234.3	714.8	106.2
1999-00	870.4	1,511.4	312.0
2000-01	1,012.2	6,897.3	-63.5
2001-02	1,222.2	191.8	102.2
2002-03	1,402.9	178.9	-375.2

Source: http://www.scotland.gov.uk/Publications/2005/06/2290402/05121

There is clear, albeit incomplete, evidence that soil sealing has been taking place over the last half century, and at an apparently increasing rate in recent years, during a time when the total population was static.

This trend has taken place at the same time as substantial and welcome decreases in the amount of vacant and derelict land in Scotland. Decreases in the amount of derelict land and vacant urban land recorded fell from 15,400 ha in 1993 to 10,661 ha in 2004. Compared with the previous survey, 466 ha of vacant and derelict land were brought back into productive use. The main new use for this land was residential development (285 ha). There is clearly development pressure on both brownfield and greenfield sites and although the former offer a number of advantages in relation to the sustainable use of Scotland's land, many of these should be restored for use as amenity land.

Source: http://www.scotland.gov.uk/Publications/2004/12/20392/48569

There are a number of datasets and techniques that could be deployed in the future for monitoring rates and locations of built development. These include:

- Land Cover of Scotland 1988 (MLURI, 1993). This dataset provided an excellent snapshot of land cover at a specific date but it is almost 20 years old.
- Countryside Survey 2000. This dataset is based on a sampling framework of 1 km^2 squares in which land use was mapped in both 1990 and 1998. Estimates are available for these two dates but differences in the interpretation in the two maps prevent their use in estimating change over time (Haines-Young *et al* 2000)
- Land Cover Map (LCM 2000). This dataset, captured from satellite imagery, does offer potential for future monitoring (Fuller *et al* 2005).
- OS mapping. There is a lag between changes actually occurring and those changes being recorded, with the majority being picked up after 5 years of surveying.
- Remote sensing. In their report in 2004, describing the potential of remote sensing to deliver soil monitoring, Wood et al. concluded that it had the greatest potential for monitoring soil quantity rather than soil quality. LCM 2000 is an example that might be used to demonstrate this potential.
- Agricultural Census data. Table 8.1 above has been derived from these data, but considerable doubt has been cast on their accuracy in England and Wales (Sinclair 1992). Adjustments were necessary to provide categories for earlier years and to offset the effects of definitional changes and the report contends that the official figures fails to record the urbanisation of 180,000 ha of land between 1945 and 1990.
- The Scottish Vacant and Derelict Land Survey.

Data on **peat extraction** appears to be equally fragmented and in 2004, in response to a question asked in parliament on how much peat is extracted annually from peat extraction sites, the minister Ross Finnie indicated that this information is not held centrally. In 1988, (MLURI 1993), approximately 30 km^2 of peat was being actively harvested on a commercial basis. However this is much smaller than the 500 km^2 that is being used on a domestic scale throughout the crofting counties. Unlike traditional hand cutting for domestic use, modern commercial peat extraction is large scale and mechanised and can present a significant conflict with nature conservation and archaeological interests. Under the EC Habitats Directive (CEC 1994), active raised and blanket bogs are classed as "priority habitats", which means that a selection of pristine examples are designated as Special Areas of Conservation (SACs). Sites thus designated will not normally be acceptable for development.

Given the recent findings on reductions in soil organic matter levels (Chapter 2) and role that Scotland's organic soils could potentially play climate change (Chapter 3), it is recommended that data on peat extraction be collected centrally by the Scottish Executive. Peat extraction contributes vitally both economically (e.g. to the whisky industry) and socially (e.g. to the crofting community), so a ban on peat extraction is both undesirable and unacceptable. However it is important that extraction be carried out with great care to ensure that environmental impacts are minimised.

Since the demise of deep mining, **opencast coalmining** is an activity that has grown over the last 15-20 years. Better information is available on the extent of opencast coal sites compared to development (Table 8.2).

Table 8.2 Areas (ha) of derelict and non-derelict land approved for opencast coal mining

Year	**Non-derelict**	**Derelict**
1988/89	215	71
1989/90	318	-
1990/91	831	48
1991/92	1042*	
1992/93	603	147
1993/94	57	32
1994/95	652	47
1995/96	394	17
1996/97	1,583	31
1997/98	501	145
1998/99	109	-

* not differentiated

Source: Planning Officers Society, reproduced in Chapman et al., 2001.

These figures do not indicate whether the areas outlined have actually been exploited in full, but they are useful for indicating the scale of the issue. Information on the location of these sites is not collected centrally, but is held by the relevant planning authority. Planning guidance is given within Scottish Planning Guidance guideline SPP 16 (Scottish Executive 2005 http://www.scotland.gov.uk/Publications/2005/07/13111617/16198). Protection of soil is not explicitly covered although there is a section on restoration, after care and after use and a recommendation that PAN 64 'Reclamation of surface mineral workings' (Scottish Executive 2002 http://www.scotland.gov.uk/Publications/2003/01/16122/16256) should be followed. Of particular interest is the section on agricultural land that indicates that 'prime quality agricultural land should normally be protected against permanent development or irreversible damage'. This appears counter to policy changes specifically on the protection of agricultural land discussed above.

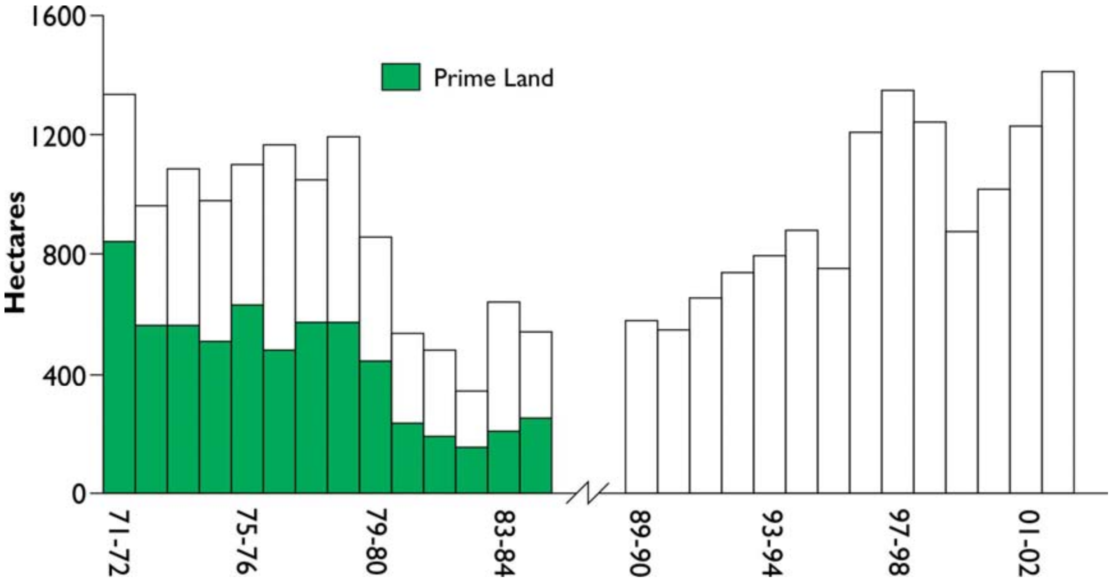
More recent data on approvals for opencast coal sites can be found at:
http://www.bgs.ac.uk/mineralsuk/minequar/coal/occ/home.html

8.4.3. Gaps in data / evidence

The data presented above are at the national level and although useful for indicating the scale of the issue at this level, it provides no indication of where it is occurring, the quality and type of soil that is being displaced and the range of functions that those soils were performing. This type of information is captured, but is less easily accessible than previously (M. Johnstone, pers. comm.). A request was made to SEERAD to obtain some of this more detailed information but on closer examination, the data were not in a form that was readily useable or interpretable.

Data on the quality of agricultural land that became developed were routinely captured and presented during the 1970s and 1980s (Davidson, 1992) approximately half was prime agricultural land (Figure 8.1). Prime agricultural land however represents only 7% of the total land area of Scotland. There was a marked decrease in new development during the first half of the 1980s (500-600 ha yr^{-1}) from that during the 1970s (1000-1,200 ha yr^{-1}). This trend has been reversed in recent years and rates of loss of land to development are now at the levels of the early 1970s. Figure 8.1 also demonstrates the reduction in quality of information with no indication on the type of land that is being lost.

Figure 8.1. Loss of prime agricultural land from 1971-1985 (Davidson 1992) and of loss of undifferentiated agricultural land in Scotland from 1989-2003 (Table 8.1).



A study was conducted for Angus Council to examine how their current and proposed Local Plans would address both Central and local government objectives of sustainable development, soil protection and of sustainable agricultural production (Project Management Scotland Ltd 2004). Land quality, based on the Land Capability for Agriculture classification, was determined for those areas identified for potential development with the Local Plans. In the current local plan (up to 2006), 37.4% of the total area allocated for built or irreversible development is prime agricultural land, whilst in the proposed local plan, this rises to 62.7%. The report concludes that local delivery of central government objectives is particularly difficult in areas such as Angus where most of the towns are surrounded by an agricultural hinterland of predominantly agricultural land. This tension is likely to be replicated throughout much of the eastern lowlands of Scotland and even in the west, where prime land is much scarcer because of climatic constraints, some development is likely to take place on the better soils. This study (Project Management Scotland Ltd 2004) provides a valuable contribution to the debate on land development vis-à-vis soil protection, but is flawed where it makes the assumption that land lost to development is proportional across all land classes; this assumption leads to a serious underestimate of prime land loss and an overestimate of losses of the poorer quality LCA classes.

In the absence of localised data that explicitly identifies the quality of land being developed, Fife was used as a trial area to test whether different ages of digital data could be used to identify and characterise land lost to development. It was based on the hypothesis that the area of built-up land indicated on the various datasets would increase in size through time. To test this, the 1: 25,000 soil data (the mid 1960s), the 1: 25,000 scale LCA data (the early 1980s) and the 1: 25,000 scale LCS88 data (MLURI 1988) were examined within a GIS. The experiment was only partly successful, in that the definition of built up land and the accuracy of their depiction on each dataset varied. It did not prove possible to determine the LCA class of much of the developed land, but there was a 31 km^2 (37.5%) increase in built up area between the oldest and most recent dataset and the soils that have been replaced could be identified. The LCA class and the overall functionality of these soils could be determined retrospectively, and although it is beyond the scope and timescale of this project, it is an option for future study.

8.5 Conclusions

- Data on the loss of land and soil to sealing (development) is not collected in a consistent manner either at the national or regional level.
- Based on the limited information available, land appears to be being developed at a higher rate than at any time during the last 50 years; this raises questions of the sustainable use of resources and whether soil is being recognised and protected by the planning system.
- Soil lost to development is unable to fulfil any of its other functions; some such as biomass production is almost eliminated.
- There should be encouragement to re-use the soil that is removed during the construction phase.
- Based on previous data, a disproportionate area of our good quality and most flexible soils are lost to development (LCA classes 1, 2 and 3.1); many of Scotland’s settlements are located next to the best land within that area. As new developments tend to ‘grow’ from existing urban areas, this trend is likely to continue.
- **It is recommended that data on peat extraction be collected centrally by the Scottish Executive.**
- **It is recommended that mechanisms be set in place that captures data on land and soil loss to development. In addition to location and area, information on soil type and quality should also be recorded.**

8.6 References

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Chapter 9 Threat to soil as a cultural resource

This chapter reviews the role of soil as a cultural resource, its role in the preservation of archaeological evidence and of any threat to these roles.

9.1 Summary

- Human activities in the past and present can have a major effect on soil formation and thus soils need to be considered as cultural resources.
- The value of such resources is expressed in the record of human activity as evident in soils and also through the provision of a buried environment for the preservation of archaeological features.
- Much is known about cultural soils in general terms, but no detailed data exist on their extent and nature.
- Cultural soils are distinctive and **valued,** thus meriting protection.
- Soil erosion is a threat to cropmark sites.
- There is a lack of data on changes in soil conditions relevant to the preservation of archaeological evidence.

9.2 Introduction and description of threat

This chapter overviews the threats to the cultural value of soils in Scotland through considering issues at the landscape and site scales. Soils evolve in response to a variety of factors and there is increasing recognition that human influences can be considerable. This is particularly the case in a country such as Scotland where there has been substantial effort since prehistoric times to improve soils, primarily for food production. The consequences are that most Scottish soils today exhibit many properties which are a legacy from past land management and improvement (Davidson and Smout, 1996). Soils thus contain evidence of human use in the past giving them an important cultural value today. The other reason why soils are of cultural importance is that they contain and preserve features of anthropogenic origin, in particular archaeological sites and associated artefacts. The aim of this chapter is to evaluate the evidence for changes in soils of significance at the landscape and individual site scales. In a current project being undertaken by Davidson and Wilson on behalf of English Heritage, the most significant threats to archaeology and the historic environment were considered to be:

1. Erosion (including sediment redistribution) and plough damage which cause physical damage to cultural remains and degrade the stratigraphic context for artefacts.
2. Dewatering and associated changes in soil moisture regimes and redox conditions; changes to more oxidising conditions are a particular threat to the survival of fragile organic materials and pollen.
3. Changes in soil and groundwater quality, particularly pH, through atmospheric deposition, land use and land management practices, and changes in drainage which can lead to increased degradation of certain types of artefact.
4. Loss of soil organic matter. Soil organic matter can be an archaeological resource in its own right, preserving evidence, for example, of past land management activities. Hence, its degradation results in loss of information. Soil organic matter is also

important in stabilising soils. A reduction in soil organic matter concentration can leave soils more susceptible to erosion.

Soils' role in cultural heritage has some effect on the other soil functions. Where they protect archaeological remains, they should not be ploughed and used for crop or woodland production (although in a number of instances these soils have been ploughed, often by accident) and they should not be used as a raw resource or be developed.

9.3 Policy

Because of the lack of data, consideration has not been given to assessing the effectiveness of current policies in terms of protecting cultural soils.

9.4 Evidence

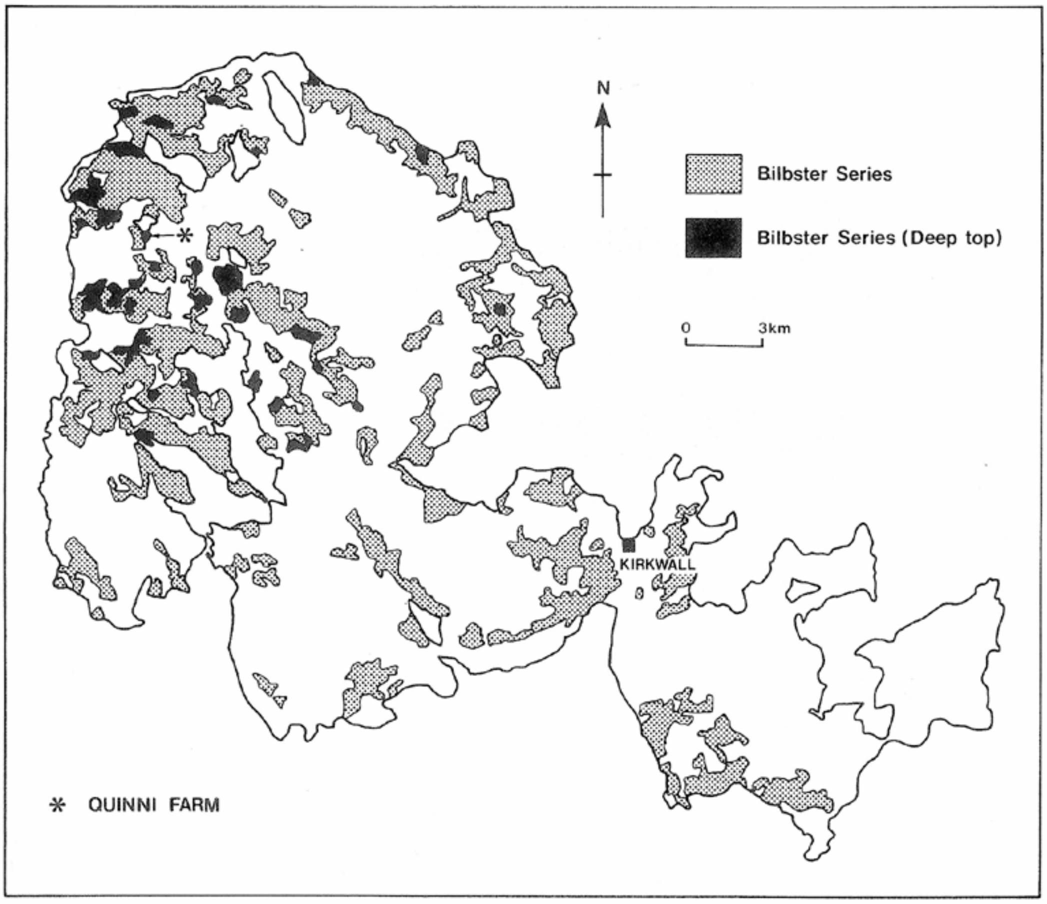
9.4.1 Cultural soils

The former Soil Survey of Scotland when mapping soils from the 1950s to 80s considered soils as 'natural entities,' so there was little consideration given to anthropogenic influences. In the Soil Survey Memoirs which accompany some published maps there is reference to the effects of land drainage and stone clearance. It is only on the Soil Survey map for Orkney that a deep-top phase of the Bilbster Series is mapped and attributed to past land cultivation/manuring (Figs 9.1 and 9.2). Such a soil is best described as a Hortisol and was formed by the addition of organo-mineral materials as manure to fields over centuries. Such soils are thus valued for their cultural and agricultural qualities.

Current research is establishing the presence of similar soils on the south of Fair Isle (Pears, pers. comm.) and on the edge of post-Medieval burghs in Scotland as at Nairn (Davidson et al., 2006), Pittenweem, Lauder and Wigtown (Golding, pers. comm.) where disposal of town waste played an important role in soil deepening. These valued soils on the edge of old towns are at greatest risk of loss due to sealing. The presence and importance of such soils have not to date been appreciated in Scotland. Plaggen soils are perhaps the best known anthropogenic soils and occur extensively on the North European Plain. In Scotland, their occurrence is limited to small and very remote localities – St. Kilda (Meharg et al., 2006) and Papa Stour in the west of Shetland (Davidson et al., 1998). On St. Kilda the topsoil on the old arable land below the village was deepened to 1.5 m, primarily as a result of manuring using fuel residues from the hearths and waste from the byres. One consequence was the enhancement in such elements as lead and zinc in the old arable land (Davidson et al., 2006). The deepened soil on St. Kilda is integral to the cultural record and contributes to the World Heritage status of the site. Interestingly, exactly the same applies on the west Mainland of Orkney with the deepened soils as part of the international designation there. Deepening of soils in Scotland was also achieved in many marginal areas through the formation of rigs – the ridging of soil to improve depth and drainage; rig-and-furrow is the most extensive archaeological feature in Scotland (Halliday, 2003). Historic Scotland through the formation of the Medieval or Later Rural Settlement (MoLRS) advisory group in 1991 (MacInnes, 2003) in combination with the Royal Commission of Ancient and Historic Monuments for Scotland (RCAHMS) through their detailed field surveys have done much to provide data and increased awareness of cultural landscapes including soils.

One consequence has been the development of ‘Guidelines for the preservation of areas of rig and furrow in Scotland’ which includes guidance on soil investigation (Barber, 2001).

Figure 9.1 Distribution of the Bilbster Series and its deepened phase on Mainland Orkney.



Distribution of the Bilbster Series and the deep top soil on the Mainland of Orkney. The study site of Quinni farm is indicated.
(Source: Soil Survey for Scotland (1979) 1 : 50 000 Soil Survey Map for Orkney)

Figure 9.2. An example of a deepened soil on the west Mainland of Orkney

9.4.2 Soils and archaeological sites

Change at the landscape scale

The Monuments at Risk Survey 1995 (MARS) outlined rates and causes of identified monument loss in England, showing that 16% of recorded monuments had been completely destroyed by 1995, 8% since 1945. In 2002 Oxford Archaeology undertook on behalf of DEFRA a study on *The Management of Archaeological Sites in Arable Landscapes* (DEFRA project code BD1701). Emphasis was given to such processes as cultivation of previously uncultivated sites, lateral impingement on undisturbed archaeological deposits, deeper ploughing, soil compaction, physical damage to artefacts and the effect of soil conditions in increasing the corrosion of metal artefacts. This report proposes a simple method of assessing the risk of damage occurring to particular sites. Considerations include the nature of the archaeological remains and quality of their survival, depth of current ploughsoil and extent/ thickness of previous ploughsoils, colluvium and alluvium over archaeology, soil characteristics (erodibility, drainage requirements, susceptibility to compaction etc), slope characteristics relevant to the likelihood of erosion, cropping patterns and rotation, and cultivation methods, depths and timing. Results are presented in the form of site maps showing risk to damage as a result of these factors.

In Scotland Burke (2004) undertook a large desk-based study, using a wide range of data on monument condition change and environmental characteristics, and demonstrated a number of relationships between monument distributions, rates of monument loss and environmental characteristics. The results of the desk-based study were calibrated using data obtained from aerial photographs, field survey and condition reports on scheduled monuments obtained from Historic Scotland. These results suggest that among monuments extant in 1850, a minimum of 38% have been reduced in extent, with at least

5% destroyed. Monument loss has been greatest in lowland areas, particularly in arable land, while monuments in upland areas have been subject to fewer pressures and, with the exception of those monuments found in areas of forestry, have survived better than their lowland counterparts.

Change at the site scale

Archaeological features are preserved within soils, thus any soil changes have potential impacts on the nature and quality of the archaeological record. Such changes can arise from surface erosion processes or from subsurface processes of soil change.

(1) Erosion

Cropmarks are subsurface archaeological features evident on aerial photographs of arable land and are caused by variations in soil moisture or depth. Features such as ditches, walls or banks can be identified under favourable soil moisture and land use conditions. Cropmarks are extremely important archaeological features and their identification plays a key role in the location of new sites. They are most evident in areas with sandy soils such as on river terraces and areas of glacial outwash. Concern is that if soil erosion occurs with concomitant surface lowering, then ploughing will cause progressive damage and ultimate loss of the feature. As a landsurface is lowered through erosion, then cultivation will progressively damage and ultimately destroy any buried archaeological features. Of the c. 7,800 scheduled ancient monuments in Scotland, approximately 1,000 are cropmark sites (Burke, pers. comm). In addition, approximately 250-300 scheduled ancient monuments in Scotland contain the remnants of field systems and other cultivation remains including rig and furrow.

A recent cropmark survey in the Lunan Valley, Angus, has been undertaken by Dunwell and Ralston (2005); one aim was to provide guidance on the management of cropmarks which occurred dominantly on the sandy soils of the Boyndie and Corby Associations. Excavation at selected cropmark sites demonstrated damage by cultivation. Use was made of the DEFRA system to assess the risk of damage and most of the excavated sites were judged to be at moderate risk. There are few studies which have quantified rates of loss on cropmarks due to the difficulties of such investigations. ^{137}Cs measurements from four sites in the Quantock Hills, Somerset suggests that over 4 mm of soil are being removed from some archaeological sites each year, suggesting that archaeological sites in the area are under threat over a timescale of 140 – 160 years (Wilkinson et al., 2006). It is presently unclear how typical the erosion rates calculated for the Quantock sites are, but similar rates are likely for other intensively cultivated areas, implying a significant threat to sub-surface archaeological sites. An erosion rate of similar magnitude has been determined for a cropmark site in Perthshire (Davidson et al., 1998; Tyler et al., 2001). The very few studies which do exist thus highlight the potential impact of erosion from water and tillage processes on archaeological cropmark sites. Areas of high potential erosion on light textured soils often coincide with areas of archaeological importance.

(2) Subsurface change

Changes in soil conditions, especially in drainage, oxygen status and pH, can result in an acceleration or deceleration in the rate of decay of different archaeological materials (Table 9.1).

Table 9.1: Preferential conditions (pH, drainage and oxidation) for preservation of different archaeological material, based on English Heritage (2002).

	Likelihood of survival	**Drainage and oxidation**	**pH**	**Comments**
Stratigraphy	**	Waterlogged		Preservation aided by deep, rapid burial below fine textured sediments.
Wood	**	Waterlogged and anaerobic, or desiccating	Acid to Alkaline	
Plant remains	*	Waterlogged and anaerobic, or desiccating	Acidic	
Seeds	*	Waterlogged and anaerobic, or desiccating	Acidic to Neutral	
Charred organic remains	**	Waterlogged and anaerobic or desiccating	Acidic to Neutral	Preservation affected by charring conditions.
Pollen	*	Waterlogged and anaerobic	Acidic	May survive in acidic oxic environments
Molluscs	*	Waterlogged and anaerobic	Alkaline > pH7	May survive in oxic alkaline conditions, and neutral soils.
Insects	*	Waterlogged and anaerobic	Acidic to neutral	
Bone	**	Waterlogged and anaerobic, or desiccating	Neutral or alkaline	Survival affected by pre-burial treatment, species and size
Skin	*	Waterlogged and anaerobic or desiccating	Acid	
Leather	**	Waterlogged and anaerobic, or desiccating	Acid to moderate basic	
Textiles	*	Waterlogged and anaerobic, or desiccating	Neutral or moderately alkaline	
Ceramics	***	Anaerobic or desiccating	All	Neutral or alkaline conditions favor low-temperature fired materials.
Iron	**	Anaerobic	Neutral or alkaline	
Copper	***	Anaerobic	Neutral or alkaline	
Glass	***	Anaeorbic or desiccating	Neutral or alkaline	
Plaster and Mortar	**	Anaerobic or desiccating	Neutral or alkaline	

Likelihood of survival refers to moderately acid, moderately drained soil conditions. * poorly resistant - rarely survive; ** moderately resistant; *** highly resistant - usually survive. NB all materials are susceptible to physical damage in the ploughzone.

9.5 Gaps in evidence

Cultural soils

Much is known about cultural soils in general terms, but no detailed data exist on their extent and nature except in a few areas such as Orkney and other parts of the northern isles. More recent studies are beginning to reveal the existence of distinctive cultural soils on the fringes of 18th and 19th century towns. Cultural soils are distinctive and **valued,** thus meriting protection. The value arises from the cultural information contained within such soils as well as from the enhanced fertility status. However, there is a dearth of information on the effectiveness of scheduling in terms of protecting cultural soils.

Soils and archaeological sites

The fundamental problem in Scotland is that there is a lack of monitoring of properties of direct relevance to the preservation of archaeological features. There is also a lack of data on changes in soil conditions relevant to the preservation of archaeological evidence. Because of this, it is difficult to address 'what if' type questions, for example, changes in drainage in an urban area where there are extensive deposits.

9.6 Conclusions

- there is need to collate existing data from a range of sources on cultural soils and to ensure that such information is incorporated into national soil datasets to guide policy.
- policy initiatives are necessary to provide protection to these soils, particularly in areas subject to soil sealing.
- datasets on cropmark sites and soil erosion risk need to be integrated in order to guide policy on the managements of such sites.
- consideration is given to monitoring soil conditions in selected and vulnerable archaeological contexts
- studies should be undertaken to assess the effectiveness of scheduling with particular reference to the impact of ploughing and tillage erosion.

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Chapter 10 Salinisation

Salinisation is identified as a significant threat in Europe by the Soil Thematic and is also worldwide a very significant problem in arid areas of Australia, America and elsewhere. Salinisation is classically the processes where salts are mobilized in soil profiles by irrigation or capillary action and where evaporation causes the salts to accumulate. This only occurs where irrigation waters are salty and excesses of sodium can adversely impact soil physical structure undermining plant growth and the filtering capacity of the soil.

There is little evidence for the classical salinisation process occurring in Scotland and irrigation is not even widely practiced let alone with salty water. If climate change led to more irrigation this threat might need to be re-visited.

There are however a number of other pathways for salt to have an impact on soils in Scotland:

- Atmospheric deposition of sea salt has local impacts for example along maritime coasts of islands and small areas of the western seaboard of Scotland
- While salt cations and exchangeable salts are measured in Scottish soils there is no data on water soluble sodium chloride or sodium adsorption that would be required to measure parameters to assess salinity or sodicity.
- There are natural saline gley soils within saltmarshes, which provide important habitats in south-west Scotland and more locally in estuaries around the country.
- Salt in road grit has local impact on soils on road verges, for example Highland Council spread an average of 60000 tonnes of salt in an average winter (http://www.highland.gov.uk/yourenvironment/roadsandtransport/wintermaintenance/). This salt was spread on 1388km of A roads and 977 km of B roads, and 4310km of C or unclassified roads. This computes to an average of 8.99 kilogram per metre of non-trunk roads. BEAR Scotland are responsible for Trunk roads and no figures were obtained for these.

In conclusion soils in Scotland are relatively unaffected by the classical salinisation process therefore and it is a negligible threat.

Chapter 11 Discussion and Conclusions

Individual chapters of this report have focussed on the major threats to soil function outlined in the introductory chapter and reviewed the evidence for the significance of that threat or group of threats to soil functioning in Scotland. In this chapter we summarise the key findings from each chapter and then attempt to assess the relative importance of each threat in the context of the soil resource of Scotland.

11.1 Summary of main threats to functions of soils in Scotland

11.1.1 Loss of soil organic matter

Loss of soil organic matter is potentially a very serious threat to the soils of Scotland. Evidence from a large number of field and laboratory studies indicates that organic matter influences many soil properties, particularly linked to structure and risk of erosion and compaction, fertility and crop production, soil biota and their diversity and remediation of pollutants. In addition, loss of organic matter directly reduces carbon storage in the soil with potential consequences for climate change. While losses of organic matter from agricultural soils can be reversed by addition of organic wastes, loss from upland peaty soils will be much more difficult to reverse.

Effects of any loss are likely to be seen in all soils, but there are at present few data from which effects can be determined. Carbon and organic matter concentrations in Scottish soils are available from national data sets, but there are uncertainties linked to method of data collection and soil heterogeneity and there is also a lack of any trend data. A recent study in England and Wales, based on an extensive programme of resampling soils at sites on the National Soils Inventory, suggested that there have been significant decreases in soil organic matter concentrations in these countries recently. It is therefore strongly recommended that similar data on soil organic matter in Scotland are collected so that any changes can be quantified.

11.1.2 Climate change

The consequences of climate change are difficult to predict, but potentially serious in the context of current scenarios. Increased rainfall may increase flooding, erosion and compaction, while decreased rainfall may lead to drought and loss of inherent fertility. Climate change may also reduce organic matter concentrations. Changes in temperature and moisture may increase emissions of greenhouse gases, particularly from upland peat soils. The level of uncertainty over climate change effects is high, both in terms of the predicted changes and their impacts. This is primarily due to uncertainties over predictions of climate change as effects of climate on soil are known with more certainty.

Direct effects of climate change are likely to be seen in all soils. Indirect effects such as effect on water holding capacity or workability are most relevant to agricultural soils, although effects of changed rainfall intensity could increase erosion risk in all soils. Although the global effects are only likely to be reversible in the long term, local management strategies are important in minimising greenhouse gas emissions and in mitigating effects such as increased droughtiness or erosion hazard.

11.1.3 Reduction in biodiversity

Reductions in soil biodiversity constitute a reduction in the inherent value of soil, since one of its key functions is maintenance of biodiversity. The consequences are relevant for all soils, but different soils will be impacted in different ways depending on the specific threat. There is generally a low level of understanding and relevant datasets are scarce leading to a high level of uncertainty over this threat. Protecting soil biodiversity as a component of habitats under conservation protection is for the moment the only practical way of ensuring that such biodiversity is not lost. This is, however, a rapidly developing area of soil science and new microbiological and molecular techniques are constantly adding new knowledge to our understanding of soil biodiversity and its functional role.

Some impacts on soil biodiversity are generally difficult to reverse and involve intervention through habitat restoration projects. Loss of specific species and functions such as nitrogen-fixing *Rhizobium* may be mitigated by use of commercial inoculum, but at increased cost. Other forms of contamination may be amenable to remediation or management of pollutant availability (e.g. liming to reduce metal availability).

11.1.4 Structural degradation and compaction

Evidence from case studies indicates that structural degradation and compaction reduces plant growth and yield, reduces large pore space causing loss of habitat for larger soil fauna and potentially increasing N_2O losses from soil and reduces water holding and infiltration capacity of the soil thereby increasing flooding and erosion risk. The overall extent is largely unknown but data that do exist suggest that it is of localised occurrence and affects only a small proportion of soils.

Most damage can be avoided by appropriate soil management techniques set out in good practice guidance in both the agriculture and forestry sectors. Case studies have shown that compaction of agricultural soils is reversible. Structural degradation and its reversal are closely linked to maintaining organic matter concentrations. The worst effects on forest soils can be avoided by strict adherence to guidelines.

11.1.5 Soil erosion and landslides

On-site effects of erosion on biomass production functions are localised. However, the erosion of peat represents a significant threat to the carbon storage function of upland soils and erosion also represents an irreversible threat to buried archaeological features. The most significant off-site impact of erosion in lowland areas is the increased transfer of sediment and associated nutrients to surface waters, reflecting a reduction in the filtering function of the soil. Erosion events with high magnitude can have serious off-site effects such as road blockages with potentially fatal consequences.

The overall incidence of erosion on lowland soils is not known with any certainty, but case studies have provided a good understanding of the factors triggering erosion. There are a number of best management practices that help to minimise the likelihood of erosion and the transfer of sediment to surface waters. Re-cycling of organic matter to soil can also improve soil physical conditions and reduce erosion in these soils. Studies have also shown that erosion of peat is the most extensive type of erosion in upland areas. Areas where erosion is active are smaller but the damage is difficult to rectify. Given the importance of peat soils, research into the drivers and mechanisms of upland peat erosion is needed for their protection.

11.1.6 Soil contamination

Effects of contamination are variable and depend on the source (diffuse or point) and nature of the contaminant. Impacts vary from total loss of soil function in highly polluted sites to lesser impacts over large geographic areas. Off-site effects on surface waters are also important. Acidification by sulphur deposition of sulphur is relatively well understood and characterised spatially, but impacts of nitrogen deposition are the subject of current research. Our understanding of pesticides is relatively good but there is little information on other organic contaminants. National data sets and research studies have provided reliable information on the background levels of heavy metal concentrations in soil and our understanding of their impacts on soil microbiology is the subject of current research.

There is some evidence that soils are recovering from the impacts of atmospheric deposition of sulphur. However, there is less evidence for nitrogen deposition and any recovery is likely to be long-term (decadal). Heavy metal pollution is essentially irreversible. Legislative protection and precautionary principles can prevent build up but some revision of maximum statutory and guideline limits for metals (e.g. zinc) may be needed based on emerging research findings. Management by liming and organic matter additions can also reduce the availability of some contaminants. Several remediation options are available for discrete problems which affect small areas of contaminated land.

11.1.7 Loss of soil to development and mineral extraction

Loss of soil to development eliminates all ecological soil functions. However, there is limited evidence on which to assess the scale of this threat. It has a high local impact and is extensive in the existing populated areas particularly in the Central Belt. Based on the available data, loss of land to development is currently happening at its fastest rate within the last 25 years; current rates are double those in the early 1980s and early 1990s. However, sealing is poorly characterised in terms of scale and location. Although the total area developed can be calculated, the proportion of soil sealed is not known accurately as there are no data for how much soil remains in open spaces and gardens. The quality of land lost to development is also not recorded. Since loss of land to development is largely irreversible as far as natural soil functioning is concerned, it is essential that a better system of recording such losses is put in place.

11.1.8 Threat to soils as a cultural resource

These arise from a number of the other threats including loss of organic matter, soil erosion, soil sealing and climate change. Damage to our cultural heritage diminishes society's appreciation of the past and may impact on Scotland's cultural identity.
Cultural soils occur in small areas and archaeological sites although large in number are not extensive. However, the precise extent of cultural soils is not known and

although individual areas are small, it is becoming clear that they occur around a larger number of Scotland's settlements than first thought. There is evidence from case studies that our archaeological record has been reduced in number and extent over the last 150 years with most loss and damage in arable areas. These losses must be regarded as serious because, once lost or damaged, archaeological features, artefacts and cultural soils cannot be restored.

11.2 Comparing the relevance of threats to Scotland

To determine the overall importance of each threat for each function we scored the consequence, extent, uncertainty and reversibility on a simple three point scale. Details of the methodology we adopted and the results of the analysis are given in Appendices E1 and E2. Table 11.1 is a summary of the relative ranking of the threats, with the scores normalised to 1.

Table 11.1 Comparison of threats across all soil functions

Threat	**Ranking (normalized score)**
Climate change	1
Loss of organic matter	0.87
Sealing	0.64
Contamination by atmospheric N,S	0.60
Loss of biodiversity	0.57
Contamination by heavy metals	0.54
Soil erosion	0.46
Pesticides	0.44
Compaction and structure	0.26
Salinisation	0

Table 11.1 represents the general ranking of the state of knowledge about each threat in relation to each function. More information is given in Appendix E2. The scores are subjective but are based on the expert judgement of the project team. Summation of scores across the different functions implies that all functions are equally important. This is clearly not the case and importance will vary for different stakeholders. However, when the biomass, environmental interaction and ecosystem support functions were given an increased weighting, the general ranking of functions did not change significantly (Appendix E2).

Among the key findings in Table 11.1 are:

- Climate change and loss of organic matter emerge as the most significant threats to the functioning of Scottish soils. Both affect most soil functions with impacts which are national in their spatial occurrence and which are difficult to reverse. However, there are generally greater levels of uncertainty associated with these threats.
- Loss of land to development (sealing), loss of biodiversity and acid deposition also represent significant threats to soil function. Sealing affects almost all soil functions whereas the impacts of loss of biodiversity and acid deposition mainly affect the ecological functions of the soil.

- The threats most commonly associated with cultivation (erosion, loss of structure, compaction) were not judged to pose high risks at the national scale. However, these do pose a threat locally and can have significant impacts such as loss of peatland habitat or damage to subsurface archaeological features.
- Threats from contamination by heavy metals or by land management are also significant but again the overall risk is assessed as smaller and more localised.
- Most of the threats are relatively close together in terms of their assessed impact; only compaction and salinisation have low normalized scores.
- There is no current threat from salinisation to Scottish soils.

11.3 Overall conclusion

The adopted risk methodology and framework is preliminary but provides the first systematic assessment of the relative importance of threats to soils in Scotland. Whilst qualitative in approach, it provides a structure for further debate and a focus for potential policy development around specific key issues. We believe that it provides a robust method to assess threats at the national scale, based on our current understanding, and has the potential to be developed and refined as more data become available.

A common thread in the assessment of every threat was the lack of systematic baseline data in some cases and a lack of trend data for nearly all cases. Long term baseline data from field sites and/or national datasets are clearly essential for the assessment of future change and trends. Many states in the western world (Canada, USA, as well as England and Wales) have fully functioning Soil Information Systems to report on soil monitoring that serve the needs of various stakeholders such as environmental and heritage agencies. Scotland is fortunate to have one of the best soil databases in the world but this has not yet been developed into a soils information system to meet the increased demands for evidence and environmental reporting by regulatory and conservation agencies. There is a clear need to review this issue and we recommend that Scotland develops its own Soils Information System. It is vital that the development of such a system is widely discussed among stakeholders to gain a clear view of its purpose, structure and internal components. It should also bring together the appropriate evidence from a range of sources and provide access to make it available to stakeholders including researchers and policy makers to enhance our understanding and ability to protect Scotland’s invaluable soil resource. Such consultation may also afford an opportunity to join up data on our environment with data on the health of Scotland’s population.

Scotland’s soil supports first class agricultural, horticultural and forestry industries and in addition underpins its beautiful landscapes and habitats of national and international renown. It also makes the biggest contribution to terrestrial carbon storage in the UK. The status of Scotland’s soil is good but we have insufficient evidence to assess recent changes and therefore predictions of change are equally uncertain. This remains the greatest challenge in the coming years for our community of scientists, policy officers, land owners and managers and regulatory agencies.

Appendices. Quality of Soil Information for Scotland

Introduction

Types of Soil information

Soils data can be subdivided into data, information and knowledge. For this project we have divided soil information into:

- Sample data:
  - Soil profile descriptions and analytical data from samples
  - Sample material
- Spatial and other information derived from the sample data:
  - Soil maps at a range of scales
  - Archived survey field sheets (not described here)
  - Digital soils data

Quality Criteria for Soil Data and Information

The available information on Scotland's soil resource is held by several organisations. We have reviewed each set of information and compiled a summary of each data set. The summary uses quality factors based on those published in:

- Principles of Good Metadata Management (IGGI, 2004)
- Information Quality Guidelines (NOAA, 2002)

Each data set is described under four main headings:

- Basic description, comprising:
  - Title
  - Dataset acronym
  - Original purpose
  - Dataset description
  - Data format
  - Data Path
  - Creator or author
  - Author credentials
  - Contributor
  - Gaps / inconsistencies
  - Spatial coverage
  - Time frame
  - Spatial / temporal accuracy or precision
  - Data currency
  - Archival material
- Recording methods and standards:
  - Peer review
  - Standards
  - Recording methods
- Recorded attributes list the information content of the data set.
- Quality factors contain the following items:
  - Critical success factors i.e. what is critical to the purpose
  - Objectivity – random locations etc.

- Usefulness to policy makers
- Integrity – protection from unauthorised access or revision
- Primary data – collected to evaluate the threat
- Secondary data – collected to assess some other threat
- Were data directly collected, produced from a model (GIS or predictive) or compiled from other sources such as database or literature

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Appendix A. Soil Sample Data

The distribution of soil properties and soil types is recorded in the National Soil Database of Scotland, which contains a number of subsets of soil samples, including the National Soil Inventory of Scotland (NSIScot), a seminal information resource of national soils data.

Soil sample material for the profiles in the database is stored in the National Soil Archive of Scotland, housed at the Macaulay Land Use Research Institute. These distributional datasets of soils in Scotland form a basis for informed description of the regional functionality of Scotland's soil resources and are referred to in more detail under the descriptions of each threat.

A1. National Soil Inventory of Scotland.

Includes heavy metal data analysed for topsoil samples.

A1.0 Relevance to threats and functions

Threat	**Direct measurement**	**Surrogate data**
Organic matter status	Soil organic carbon measured in samples from soil horizons in profiles	
Biodiversity change		Vegetation may give some insight
Structure or compaction	Soil structure was assessed at time of sampling	
Erosion	Record of erosion features during soil sampling	Inherent risk of soil erosion
Contamination	Heavy metal content of soils	
Soil sealing	Record of built up area at time of sampling	
Soil as a cultural resource		
Flooding		
Salinisation	Sodium content is measured	

Function	**Direct measurement**	**Surrogate data**
Biomass production	Nitrogen; pH; C/N ratio; …	LCA; LCF; …
Environmental interactions	C content; Soil structure; Soil texture; pH; Clay content; Colour;	…
Biodiversity	…	Roots and vegetation communities; …
Raw materials	Parent material type and lithology; …	…
Platform	…	Groundwater table; Consolidated / Unconsolidated sands; Shrinking clays; Flooding risk; Parent material; …
Cultural heritage	…	Artificial over deepening of top soil; …

A1.1. Basic description

Title	National Soil Inventory of Scotland
Dataset acronym	NSIScot
Original purpose	Provide an unbiased sample to characterise or quantify soil distribution and variability at a broad, regional scale in Scotland.
Dataset description	The NSIScot is a subset of the National Soils Database of Scotland. The sample frame work is a 5km grid based on the National Grid of GB. The data comprise a soil profile description at each 5km intersect of the National Grid. Soil horizon samples were collected on the 10 km intersects and some 5km 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 which had previously been surveyed.
Data format	A view of the National Soils Database of Scotland.
Data Path	The data are stored in Oracle® tables on a unix server at the Macaulay Institute: • BASICINV table contains site characterisation data Descriptions of each soil horizon (soil horizon morphology) and analytical data are contained in three tables: • ORGANICINV table holds data on organic horizons • MINERALINV table holds data on mineral horizons • ANALINV table holds systematic laboratory data derived from samples taken from individual horizons. Every 10km point was sampled and some of the 5km intersects The tables are linked by grid reference and lab numbers.
Creator / author	Soil surveyors employed by the Macaulay Institute.
Author credentials	Soil surveyors with extensive field experience of soil classification and mapping described the soil profile morphology and collected the soil horizon samples.
Contributor	As for creator or author
Gaps / inconsistencies	There are some gaps in the sample cover. Samples were not collected from a number of grid intersects on Orkney. St Kilda was not visited due to cost. Soil samples were collected from some of the 5km points, although this was not in the protocol.
Spatial coverage	Grid sample covering Scotland.
Time frame	Nine years: 1978 to 1987. Data were collected during Spring, Summer and Autumn.
Spatial / temporal accuracy or precision	The intersection between Ordnance Survey northing and easting grid lines at 5 km intervals was plotted onto an aerial photograph. This photograph was used to guide a soil surveyor to the sample location in the field where a soil profile was excavated, described and, at each 10km intersection, soil samples were taken. The approximate location accuracy in m was noted by the surveyor. Horizon and sample depths were recorded to the nearest cm.
Data currency	The data were collected between 19 and 27 years ago. Currency depends on the temporal variation in individual attributes and we may need to break down the information into inherent / changeable. For example, sand content is inherent but organic carbon content is changeable.
Archival material	Field record cards were used at some sites before the introduction of hand-held field computers. The field cards are stored at the Macaulay. Soil sample material is archived at the Macaulay in the National Soils Archive of Scotland.

A1.2. Recording methods and standards

Peer review	Methods published in Brown *et. al.* 1987
Standards	The methodology for soil profile description and sampling was coordinated by the soil surveyors at regular field meetings, held jointly with the soil survey of England and Wales. Additionally, methods were discussed from time to time with soil survey organisations in the United States, Canada and Europe from the inception of the Soil Survey of Scotland.
Recording methods	The field description and recording methods agreed at field meetings were published (Hodgson, 2004) and were adopted by the Soil Survey of Scotland with the exception of texture classification. The grid sample plan for the sampling was agreed with the Soil Survey of England and Wales and DAFS (now SEERAD).

A1.3 Recorded attributes

Site data	**Location** Unique ID; National grid reference; Date of sample; Name of site; Number of site; Surveyor; Ordnance Survey Third Edition Map Sheet Number; Easting (relative to false origin of National Grid); Northing (relative to false origin of National Grid); Elevation of site (m above sea level); Site elevation in Feet; Slope of site in degrees; Slope form; Slope type; Aspect of site; Bearing in degrees; Accuracy of site location **Soil classification, mapping and sampling** Soil Association symbol; Soil Series symbol; Association/Series code; Major soil group; Major soil sub group; Soil drainage; Surface/groundwater gley subgroup; Parent material; Miscellaneous Mapping unit classification; Series Phase; Primary and secondary rock type codes; Pit base descriptor; Sample depths in cm below ground surface; Extra samples (Y if additional samples); Lab number range; Sample Batch Identification **Additional field-recorded information** Site drainage; Erosion; Vegetation classification; Presence or absence of flushing; Rock frequency; Boulder frequency **Additional information** Climate classification (after Birse); Land Capability for Agriculture; Land Capability for Forestry; Administration District code; Record type (A: Archival; I: Inventory; G: Grid; P: Partial; R: Relocated; S: Selected; T: Transect); Systems use flag; Notes; Linked soil data tables (B: BASICINV; O: ORGANICINV; M: MINERALINV; A: ANALINV; N: NIPAQUA)
Organic horizons	Unique record ID; National grid reference of site; Horizon symbol; Depth to top of horizon (cm below ground surface); Depth to base of horizon (cm below ground surface); Horizon boundary distinctness and form; Munsell colour (field measured); Nature of organic matter; Mineral content; Moisture status; Primary structure: degree, size and type; Primary stones frequency, size and shape; Secondary stones frequency, size and shape; Primary roots frequency, size and kind; Secondary roots frequency, size and kind
Mineral horizons	Unique record ID; National grid reference of site; Unique sequence number of record; Horizon symbol; Depth to top of horizon (cm below ground surface); Depth to base of horizon (cm below ground surface); Horizon boundary distinctness and form; Munsell colours of soil matrix, soil peds, dry soil and mottles; Mottle frequency, size, contrast and sharpness; Estimated percentage mottles; Grain size estimate; Field estimate of texture; Estimated percentage silt; Estimated percentage clay; Moisture status; Consistency: wet, moist or dry; Degree of induration; Degree of cementation; Primary structure: degree, size and type; Secondary structure: degree, size and type; Primary stones: frequency, size, shape and lithology; Estimated percentage primary stones; Secondary stones: frequency, size, shape and lithology; Estimated percentage secondary stones; Primary roots frequency, size and kind; Estimated percentage primary roots; Secondary roots frequency, size and kind; Estimated percentage secondary roots
Analytical data Not all determinands measured for each sample.	Unique lab number of sample; Horizon symbol (allocated by Analytical); Depth to top of sample (cm below ground surface); Depth to base of sample (cm below ground surface); Loss on ignition; Flag specifying USDA or BSTC analyses; Percentage International sand; Percentage International silt; Percentage International clay; Percentages of USDA or BSTC sand and silt; Calcium; Magnesium; Sodium; Potassium; Hydrogen; Sum of cations; Base saturation; pH in water; pH in Calcium chloride; Carbon; Nitrogen; C/N ratio; Organic matter; Total phosphate; Exchangeable Carbon; Pyrophosphate extractable aluminium; Extractable iron; Residual iron; Sample Batch Identification; National grid reference of site; Acetic soluble phosphorous; Data verification by Analytical Group
Heavy metals by EDTA extract	Copper; Zinc; Manganese; Nickel; Cadmium; Chromium; Lead
Elements by aqua regia extract	Calcium; Sodium; Potassium; Magnesium; Copper; Zinc; Iron; Manganese; Aluminium; Phosphorous; Nickel; Cadmium; Chromium; Cobalt; Lead; Strontium; Molybdenum; Titanium; Barium

A1.4 Quality factors

Quality Factor	**Description**
Original data	Original data collected from soil pits in the field.
Primary / secondary data	Directly collected primary data. Horizon nomenclature and soil classification are secondary data, interpreted from the observations.
Objectivity of Substance e.g. sampling strategy	The sample strategy comprised a square grid pattern aligned to the National Grid of Great Britain with: • Five km spacing for site and soil descriptions • Ten km spacing for soil samples (sub-set of the five km grid) Field location was by using aerial photographs on which the grid intersect was transcribed from maps.
Objectivity of Presentation	The data are not released in raw form since interpretation is required. Presentations are normally peer-reviewed, either for journal publication or by other agencies.
Analytical QA/QC	Samples were analysed prior to the drawing up of the ISO framework of standard methods. The methods for systematic analysis were documented internally at the Macaulay Institute. Archival soil sample material exists for many samples, unless it has become exhausted, and could be analysed under the current ISO9001 framework.
Utility	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. 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.
Integrity and security	The database is securely maintained and access to the data is controlled within the Macaulay by the Database Manager. Revision is rarely necessary except to correct errors.
Transparency (Leads to reproducibility)	Field recording methods were published.
Reproducibility	The original data were collected by a peer-group of soil survey experts with in-depth knowledge of soils in the field. This expert group has largely disbanded and it is not likely that a reproducible set of results can be obtained without a field-sample training group being established. The original site has been destroyed by the sampling so any return visit will not find the same soil. Successful return visits to the sample points depend on the experience of the field worker in locating sites from features on aerial photographs. The original site location was by aerial photo interpretation of ground features, and may not occur exactly on the National Grid intersect. GPS may not be useful in re-locating the exact point. Experience suggests that the original site record will be of value in the relocation process. Spatial variability in depth and geographically impinges on reproducibility.
Synthesised Product	These are raw data.
Interpreted Product	The horizons are named and the soil is classified on site. This is an interpretation by the soil surveyor from the raw data.
Influential Information	This information was not collected to influence policy.

A2. Representative Soil Profiles of Scotland

Prior to the establishment of standardised recording methods and protocols for the National Soils Inventory of Scotland in 1987, soil profiles were recorded freehand. Consequently, these soil profile descriptions may not contain as much systematic information as the NSIS profiles.

A2.1. Basic description

Title	Representative Soil Profiles of Scotland
Dataset acronym	RSPS
Original purpose	To provide examples of the soils mapped on the 1:63 360 and 1:50 000 scale soil maps.
Dataset description	The RSPS is a subset of the National Soils Database 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. The information was collected during field work for the 1:63 360 and 1:50 000 scale soil survey of Scotland
Data format	These data exist in two formats, depending on date of sampling: • Pre-1979 the information is stored on original soil profile cards • Post-1979 the records are stored in the National Soils Database of Scotland For pre-1979 data, analytical data and minimal site data are entered into the National Soils Database of Scotland.
Data Path	For pre -1979 data, two sets of soil profile cards are stored in separate locations in the Macaulay Institute. The National Soils Database of Scotland data are stored in Oracle® tables on a unix server at the Macaulay Institute: • BASICINV table contains site characterisation data Descriptions of each soil horizon (soil horizon morphology) and analytical data are contained in three tables: • ORGANICINV table holds data on organic horizons • MINERALINV table holds data on mineral horizons • ANALINV table holds systematic laboratory data derived from samples taken from individual horizons. Every 10km point was sampled and some of the 5km intersects • TRACELEM table holds trace element analysis for a subset of profiles. The tables are linked by grid reference and lab numbers.
Creator or author	Soil surveyors employed by the Macaulay Institute.
Author credentials	Soil surveyors with extensive field experience of soil classification and mapping
Contributor	As for creator or author
Spatial coverage	The main agricultural areas of Scotland, with some upland areas also covered.
Time frame	1941 to date, with few records collected post-1979.
Spatial / temporal accuracy or precision	Sites were located using 1:25 000 scale Ordnance Survey maps or 1:25 000 or 1:10 000 scale aerial photographs. Photograph locations were used from around 1966. GPS equipment has been in use recently. Grid references were recorded to the nearest 100m.
Data currency	The samples were obtained up to 65 years ago. Currency depends on temporal variation in individual attributes.
Archival material	Soil profile descriptions were hand-written in the field and soil profile cards were typed from the field descriptions. The soil profile cards are stored at the Macaulay. Soil sample material is archived at the Macaulay in the National Soils Archive of Scotland.

A2.2. Recording methods and standards

Peer review	Soil survey methodology evolved during the progress of the soil mapping across Scotland.
Standards	The methodology for soil profile description and sampling was coordinated by the soil surveyors at regular field meetings, held jointly with the soil survey of England and Wales. Additionally, methods were discussed from time to time with soil survey organisations in the United States, Canada and Europe from the inception of the Soil Survey of Scotland.

Recording methods	The field description and recording methods agreed at field meetings were published (Hodgson, 2004) and were adopted by the Soil Survey of Scotland with the exception of texture classification. Prior to the Hodgson publication, soil classification and recording methodology was published in soil memoirs, although not every map has an accompanying soil memoir.

A2.3 Recorded attributes

Site data	**Location** Unique ID; National grid reference; Date of sample; Name of site; Number of site; Surveyor; Ordnance Survey Third Edition Map Sheet Number; Easting (relative to false origin of National Grid); Northing (relative to false origin of National Grid); Elevation of site (m above sea level); Site elevation in Feet; Slope of site in degrees; Slope form; Slope type; Aspect of site; Bearing in degrees; Accuracy of site location **Soil classification, mapping and sampling** Soil Association symbol; Soil Series symbol; Association/Series code; Major soil group; Major soil sub group; Soil drainage; Surface/groundwater gley subgroup; Parent material; Miscellaneous Mapping unit classification; Series Phase; Primary and secondary rock type codes; Pit base descriptor; Sample depths in cm below ground surface; Extra samples (Y if additional samples); Lab number range; Sample Batch Identification **Additional field-recorded information** Site drainage; Erosion; Vegetation classification; Presence or absence of flushing; Rock frequency; Boulder frequency **Additional information** Climate classification (after Birse); Land Capability for Agriculture; Land Capability for Forestry; Administration District code; Record type (A: Archival; I: Inventory; G: Grid; P: Partial; R: Relocated; S: Selected; T: Transect); Systems use flag; Notes; Linked soil data tables (B: BASICINV; O: ORGANICINV; M: MINERALINV; A: ANALINV; T; TRACELEM); Reference to Soil Survey Memoir, and profile number in the memoir
Organic horizons	Unique record ID; National grid reference of site; Horizon symbol; Depth to top of horizon (cm below ground surface); Depth to base of horizon (cm below ground surface); Horizon boundary distinctness and form; Munsell colour (field measured); Nature of organic matter; Mineral content; Moisture status; Primary structure: degree, size and type; Primary stones frequency, size and shape; Secondary stones frequency, size and shape; Primary roots frequency, size and kind; Secondary roots frequency, size and kind
Mineral horizons	Unique record ID; National grid reference of site; Unique sequence number of record; Horizon symbol; Depth to top of horizon (cm below ground surface); Depth to base of horizon (cm below ground surface); Horizon boundary distinctness and form; Munsell colours of soil matrix, soil peds, dry soil and mottles; Mottle frequency, size, contrast and sharpness; Estimated percentage mottles; Grain size estimate; Field estimate of texture; Estimated percentage silt; Estimated percentage clay; Moisture status; Consistency: wet, moist or dry; Degree of induration; Degree of cementation; Primary structure: degree, size and type; Secondary structure: degree, size and type; Primary stones: frequency, size, shape and lithology; Estimated percentage primary stones; Secondary stones: frequency, size, shape and lithology; Estimated percentage secondary stones; Primary roots frequency, size and kind; Estimated percentage primary roots; Secondary roots frequency, size and kind; Estimated percentage secondary roots
Analytical data Not all determinands measured for each sample.	Unique lab number of sample; Horizon symbol (allocated by Analytical); Depth to top of sample (cm below ground surface); Depth to base of sample (cm below ground surface); Loss on ignition; Flag specifying USDA or BSTC analyses; Percentage International sand; Percentage International silt; Percentage International clay; Percentages of USDA or BSTC sand and silt; Calcium; Magnesium; Sodium; Potassium; Hydrogen; Sum of cations; Base saturation; pH in water; pH in Calcium chloride; Carbon; Nitrogen; C/N ratio; Organic matter; Total phosphate; Exchangeable Carbon; Pyrophosphate extractable aluminium; Extractable iron; Residual iron; Sample Batch Identification; National grid reference of site; Acetic soluble phosphorous; Data verification by Analytical Group
Trace element data for selected soil samples	Total Barium; Total Cobalt; Total Total Copper; Total Gallium; Total Manganese; Total Molybdenum; Total Nickel; Total Phosphorous; Total Lead; Total Strontium; Total Titanium; Total Vanadium; Sum of exchangeable cations + H; Exchangeable Calcium; Exchangeable Magnesium; Exchangeable Sodium; Exchangeable Potassium; Exchangeable Hydrogen; Organic carbon; Extractable Cobalt; Extractable Chromium; Extractable Copper; Extractable Manganese; Extractable Nickel; Extractable Lead; Extractable Titanium; Extractable Vanadium; Extractable Zinc; Extractable Iron; Extractable Molybdenum

A2.4 Quality factors

Factor	**Description**
Original data	Original data collected from soil pits in the field.
Primary / secondary data	Directly collected primary data. Horizon nomenclature and soil classification are secondary data, interpreted from the observations.
Objectivity of Substance e.g. sampling strategy	Samples were collected on a subjective basis. The soil profiles selected for sampling were judged to exemplify the soils mapped. Field locations were recorded from 1:25 000 scale field maps. Aerial photographs were used from around 1966 onwards in some areas.
Objectivity of Presentation	The data are not released in raw form since expert interpretation is required in order to make the best use of the data set. Presentations are normally peer-reviewed, either for journal publication or by other agencies.
Analytical QA/QC	Samples were analysed prior to the drawing up of the ISO framework of standard methods. The methods for systematic analysis were documented internally at the Macaulay Institute. Archival soil sample material exists for many samples, unless it has become exhausted, and could be analysed under the current ISO9001 framework.
Utility	The data inform the soil classification for Scotland and provide ancillary data to characterise soil properties within soil mapping units.
Integrity	The database is securely maintained and access to the data is controlled within the Macaulay by the Database Manager. Revision is rarely necessary except to correct errors. The soil profile cards exist in two sets stored at separate locations within the Macaulay Institute.
Transparency (Leads to reproducibility)	Field recording methods were published.
Reproducibility	The original data were collected by a peer-group of soil survey experts with in-depth knowledge of soils in the field. This expert group has largely disbanded and it is not likely that a reproducible set of results can be obtained without a field-sample training group being established. The original site has been destroyed by the sampling so any return visit will not find the same soil. GPS may not be useful in re-locating the exact point. Experience suggests that the original site record will be of value in the relocation process.
Synthesised Product	These are raw data.
Interpreted Product	The horizons are named and the soil is classified on site. This is an interpretation by the soil surveyor from the raw data.
Influential Information	This information was not collected to influence policy.

A3. Grid or Transect Studies on Soil in Scotland

A3.1. Basic description

Title	Grid or Transect Studies of Soil Profiles
Dataset acronym	
Original purpose	Provide a sample from which the spatial variability of soil properties could be estimated down to 5m distance. Characterise three soil series in Scotland and several experimental farms.
Dataset description	The grid or transect studies form subsets of the National Soils Database of Scotland. The data comprise a soil profile description at each sampled location. There are also analytical data from soil samples.
Data format	A view of the National Soils Database of Scotland.
Data Path	The data are stored in Oracle® tables on a unix server at the Macaulay Institute: • BASICINV table contains site characterisation data Descriptions of each soil horizon (soil horizon morphology) and analytical data are contained in three tables: • ORGANICINV table holds data on organic horizons • MINERALINV table holds data on mineral horizons • ANALINV table holds systematic laboratory data derived from samples taken from individual horizons. Every 10km point was sampled and some of the 5km intersects The tables are linked by grid reference and lab numbers.
Creator / author	Soil surveyors employed by the Macaulay Institute.
Author credentials	Soil surveyors with extensive field experience of soil classification and mapping described the soil profile morphology and collected the soil horizon samples.
Contributor	As for creator or author
Spatial coverage	Transect samples within Balrownie, Corby and Winton soil series mapping units. Grid samples were collected at 25m 100m and 1km intervals in a variety of locations across Scotland.
Time frame	Transect samples in 1987.
Spatial / temporal accuracy or precision	Transect sample spacings were measured on the ground using a tape measure. Grid samples were located by plotting site locations from maps onto aerial photographs.
Data currency	Currency depends on the temporal variation in individual attributes and we may need to break down the information into inherent / changeable. For example, sand content is inherent but organic carbon content is changeable.
Archival material	Direct entry into database. Soil sample material is archived at the Macaulay in the National Soils Archive of Scotland.

A3.2. Recording methods and standards

As for the NSIS data set described in Appendix A1.

A3.3 Recorded attributes

As for the NSIS data set described in Appendix A1, though with limited subsoil samples.

A3.4 Quality factors

As for the NSIS data set described in Appendix A1.

A4. MASQ: Monitoring and Assessing Soil Quality. Part of CS2000. Material extracted from the MASQ Report.

A1.0 Relevance to threats and functions

Threat	Direct measurement	Surrogate data
Organic matter status	Soil organic carbon measured in samples by loss on ignition	
Biodiversity change	Direct measures of invertebrates and heterotrophic bacteria	
Structure or compaction		
Erosion		
Contamination	Heavy metal content of soils (7 metals)	
Soil sealing	Urban areas were excluded from the field survey	
Soil as a cultural resource		
Flooding		
Salinisation		

Function	Direct measurement	Surrogate data
Biomass production	Soil pH was measured and assessed for change0	
Environmental interactions		
Biodiversity		
Raw materials		
Platform		
Cultural heritage		

A4.1. Basic description

Title	Monitoring and Assessing Soil Quality
Dataset acronym	MASQ
Original purpose	To provide good quality datasets for soil invertebrate and microbial communities, soil pH and organic matter and selected heavy metals and persistent organic pollutants.
Dataset description	The Centre for Environmental Hydrology was funded jointly by DEFRA, EA, SNIFFER and NERC, to carry out the project MASQ: Monitoring and Assessing Soil Quality (Black *et. al*. 2002). This formed part of the Countryside Survey 2000 (CS2000), with samples collected in 1998 and 1999. A high proportion of soil samples were collected from the same geographical locations as those for the Ecological Survey of Great Britain (ITE1978).
Data format	Oracle®
Data Path	An Oracle® database - The Countryside Survey 2000 Integrated Data System (CIDS). Project report - MASQ: Monitoring and Assessing Soil Quality in Great Britain. Countryside Survey Module 6: Soils and Pollution. R&D Technical Report E1-063/TR. 2002. H I J Black, J S Garnett, G Ainsworth, P A Coward, R Creamer, S Ellwood, J Horne, M Hornung, V H Kennedy, F Monson, L Raine, D Osborn, N R Parekh, J Parrington, J M Poskitt, E Potter, N Reeves, A P Rowland, P Self, S Turner, J Watkins, C Woods and J Wright.
Creator / author	CEH, Funded by DEFRA, EA, SNIFFER and NERC.
Author credentials	ITE were instrumental in setting up the original survey in 1978.
Contributor	
Spatial coverage	Great Britain
Time frame	Builds on the Institute of Terrestrial Ecology's National Ecological Survey of Great Britain (1978) and the Countryside Survey (1990)
Spatial / temporal accuracy or precision	Sample plots were marked on maps and then located in the field using maps and/or using markers left in 1990 with a metal detector. Once the plot was located survey poles were use tp mark out the
Data currency	Data were collected in 1998 and 1999
Archival material	

A4.2. Recording methods and standards

Peer review	The initial sample design in 1978 was reviewed by the scientific community at the time. Subsequent designs have been through several discussion stages.
Standards	
Recording methods	Full protocols are in the CS2000 Field Handbook. Protocols were developed for the sampling by staff in the Soil Ecology Section at CEH Merlewood. The design was tailored to be compatible with the 1978 soil samples and to allow rapid return of samples for biological analysis. All field surveyors were trained in them prior to the sampling campaign.

A4.3 Recorded attributes

Site data	Location; Environment Zone; Broad Habitats; Aggregate Vegetation Classes; Major Soil Group.
Analytical data from Topsoil samples collected in cores	Soil pH in water; loss-on-ignition (surrogate for soil organic matter). Heavy metals by Inductively Coupled Plasma-Optical Emission Spectrometers (ICP-OES): Cadmium (Cd), Copper (Cu), Chromium (Cr); Lead, (Pb), Nickel (Ni), Vanadium (V) and Zinc (Zn). A novel analytical method was developed using GC-MS for the analysis of polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs). Soil invertebrates were extracted and identified. Numbers and functional diversity of heterotrophic bacteria were identified.

A4.4 Quality factors

Quality Factor	**Description**
Original data	Yes. Data from field samples.
Primary / secondary data	The sample frame was drawn using a range of secondary data interpreted from several sources. The analytical data are primary data.
Objectivity of Substance e.g. sampling strategy	The sampling strategy was designed to provide a restricted, stratified random sample of 1 kilometre 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 have been added over the intervening years and for CS2000 there are now 40 land classes having 569 sample squares in GB with 203 in Scotland. Soil sampling was restricted to the 256 squares visited during the 1978 campaign. Sample locations within each 1km square were selected according to protocols in the unpublished CS2000 field handbook. Top soil samples were taken with corers.
Objectivity of Presentation	The results were presented in a scientific report to the project funders. This report is in the public domain.
Analytical QA/QC	Rigourous validation schemes were established for each range of determinands. Schemes are detailed in the project report.
Utility	
Integrity	The data are managed by the Oracle® database administrator at CEH.
Transparency (Leads to reproducibility)	Methods are detailed in an unpublished field handbook; transcripts of this are available in other reports. Analytical techniques are detailed in the project report.
Reproducibility	The methods are described in sufficient detail for the results to be reproducible in future sampling campaigns.
Synthesised Product	This is not a synthesised product.
Interpreted Product	The initial sample frame is based on interpretation. The results of the survey are based on sample measurements.
Influential Information	Yes.

A5. Soil Data in relation to Sludge (Use in Agriculture) Regulations 1989. Sampling and Testing of Soil (Schedule 2, Regulation 3)

The Scottish Environmental Protection Agency (SEPA) provided a list of data they hold (M. Aitken. *pers. comm.*) and the information is summarised in Appendices 5, 6 and 7.

A5.1. Basic description

Title	Soil Data in Relation to Sludge (Use in Agriculture) Regulations. Sampling and Testing of Soil (Schedule 2, Regulation3)
Dataset acronym	None
Original purpose	To allow SEPA to audit sludge producers in relation to Sludge (Use in Agriculture) Regulations 1989
Dataset description	pH and potentially toxic element (PTE) analysis of soils which have received sewage sludge.
Data format	Paper records. Some of the data is electronic.
Data Path	Data held by SEPA Land Unit and also Agricultural Regulatory Team.
Creator or author	Created by sludge producers, such as Scottish Water or other PFI (Private Finance Initiative) operators and audited by SEPA.
Author credentials	Unknown
Contributor	SEPA contribute to auditing and supplementary field inspection and analysis.
Spatial coverage	Agricultural land where sludge has been applied (since 1989)
Time frame	From 1989 to present.
Spatial / temporal accuracy or precision	Grid references of fields supplied
Data currency	No temporal sampling is carried out unless further sludge is applied
Archival material	Data held by SEPA but soil samples are not archived.

A5.2. Recording methods and standards

Peer review	SEPA hold the register. Additional field inspection and samples are collected by SEPA to audit the register.
Standards	Additional sampling by SEPA is sometimes carried out. This can be during a field inspection of an agricultural unit, actioned as an outcome of a SEPA audit of a sludge producer register or for enforcement purposes.
Recording methods	Different recording methods used by each sludge producers e.g. Scottish Water or other PFI (Private Finance Initiative) operators.

A5.3 Recorded attributes

General data	Each field that has received sludge: Location; Amounts applied; Dates of application; Dry matter; weight of sludge applied, a Nutrient analysis; Heavy metal analysis; Type of sludge.
Mandatory analysis	Soil samples collected by the operator must be analysed for: pH; Cadmium; Copper; Chromium; Lead; Nickel; Zinc; Mercury.
Additional analysis	As listed in the Code of Practice and comprise: Molybdenum; Fluoride; Selenium; Total Nitrogen; Arsenic; Total Phosphorus

A5.4 Quality factors

Quality Factor	**Description**
Original data	Original data.
Primary / secondary data	
Objectivity of Substance e.g. sampling strategy	The sample frame is dictated by the locations of sludge. No control samples are collected from similar soil types with no sludge application, or from the field prior to application. Within each field or part-field soil cores are collected by auger using the 'W' pattern protocol to provide a single composite as per Sludge Regs the soil is sampled to a depth of 25 cm and field size is no greater than 5 ha. . The spatial separation of individual composite samples partially depends on field size and shape.
Objectivity of Presentation	Data held by SEPA Land Unit and also Agricultural Regulatory Team.
Analytical QA/QC	Methodology and standards as per Sludge (Use in Agriculture) Regulations 1989
Utility	Results could indicate, for example, how close to indicator levels the soil was in terms of the range of pollutants analysed.
Integrity	Data are held by SEPA and attribute values verified by further sample collection. See section on SEPA Field Inspections.
Transparency (Leads to reproducibility)	The 'W' sample gives a degree of anonymity of location which may reduce reproducibility in large fields. More use of GPS could be made to locate samples to reduce the impact of autocorrelation.
Reproducibility	This should be easily achieved as field locations are easy to re-locate. The W pattern may not be the same on subsequent visits.
Synthesised Product	No.
Interpreted Product	No.
Influential Information	This information is collected by SEPA to enforce the Sludge (Use in Agriculture) Regulations 1989

A6 Soil Data in relation to Sludge (Use in Agriculture) Regulations 1989. Sampling and testing of Sludge (Schedule 1, Regulation 3)

A6.1. Basic description

Title	Soil Data in Relation to Sludge (Use in Agriculture) Regulations 1989. Sampling and Testing of Sludge (Schedule 1, Regulation3)
Dataset acronym	None
Original purpose	When combined with application rates (where are these rates recorded?) can be used to determine heavy metal loadings on soils.
Dataset description	Nutrient and potentially toxic element (PTE) analysis of sludges which have been applied to soils.
Data format	Paper records . Some of the data is electronic.
Data Path	Data held by SEPA Land Unit and also Agricultural Regulatory Team.
Creator or author	Created by sludge producers, such as Scottish Water or other PFI (Private Finance Initiative) operators and audited by SEPA.
Author credentials	Unknown
Contributor	SEPA contribute auditing and supplementary field inspection and analysis
Spatial coverage	Records detail locations of fields where the sampled sludge has been applied
Time frame	From 1989 to present.
Spatial / temporal accuracy or precision	Agricultural land where sludge has been applied (since 1989)
Data currency	Current at the time of sampling. The material is applied to land.
Archival material	Data held by SEPA but sludge samples are not archived.

A6.2. Recording methods and standards

Peer review	SEPA hold the register. Additional samples are collected by SEPA to audit the register.
Standards	Additional sampling by SEPA is sometimes carried out. This can be during a field inspection of an agricultural unit, actioned as an outcome of a SEPA audit of a sludge producer register or for enforcement purposes.
Recording methods	Different recording methods used by each sludge producers e.g. Scottish Water or other PFI (Private Finance Initiative) operators.

A6.3 Recorded attributes

Site data	Date of sampling.
Mandatory analysis	A representative sample of sludge must be analysed for: pH; Cadmium; Copper; Chromium; Lead; Nickel; Zinc; Mercury; Dry matter (dm); Total Nitrogen (as %dm); Total Phosphorus (as %dm).
Additional analysis	Additional analysis as listed in the Code of Practice for: Molybdenum; Fluoride; Selenium; Ammoniacal nitrogen (NH_3-N); Arsenic

A6.4 Quality factors

Quality Factor	**Description**
Original data	Original data from sludge samples.
Primary / secondary data	Primary data
Objectivity of Substance e.g. sampling strategy	No details of sample selection procedure from bulk sludge.
Objectivity of Presentation	Data held by SEPA's Land Unit and also Agricultural Regulatory Team.
Analytical QA/QC	Methodology and standards as per Sludge (Use in Agriculture) Regulations 1989
Utility	Combine with application rates to determine heavy metal loading rates to soils. Could be used with current weather data to model changes in soil organic matter etc. after application.
Integrity	Data are held by SEPA and attribute values verified by further sample collection.
Transparency (Leads to reproducibility)	
Reproducibility	Sludge has gone to land so not possible to reproduce the sample.
Synthesised Product	No.
Interpreted Product	No.
Influential Information	This information is collected by SEPA to enforce the Sludge (Use in Agriculture) Regulations 1989

A7. British Geological Survey Data with sample Metadata page from the BGS website

A briefing document was prepared by BGS for the Scottish Executive (Lawley, Fordyce and Merritt, 2006). This document contains BGS input to the process of identifying soil threats.
Briefing document prepared by British Geological Survey for the Scottish Executive at their request in respect of the current state of Scottish soils, May 2006) in relation to soil threats in Scotland.

A7.1. List supplied by BGS

The contact person for BGS data is Ms Fiona Fordyce, Murchison House, West Mains Road, Edinburgh EH9 3LA.
Tel: +44 (0)131 667 1000. Email: fmf@bgs.ac.uk
The following list of data sets (B. Smith, Pers Comm;) are those which BGS judge to be most relevant for assessing the state of and threats to Scottish soils:

- DiGMapGB-50 Scotland (including memoirs/sheet explanations)
- Hydrogeology – Scotland – Aquifer Vulnerability
- G-BASE Stream Sediment Chemistry
- G-BASE Stream Water Chemistry
- G-BASE Soils - presently limited to Greater Glasgow
- Potentially Harmful Elements/Radon
- Geohazard Datasets (especially Landslide, Shrink-swell, Compressibles, Running Sand)
- Soil Parent Material Map
- Mineral Assessment Reports and other industrial mineral appraisals
- Mineral Resources Records
- NextMap DTM
- Remotely Sensed Data (Landsat to ATM)
- Aerial Photography
- Historic OS Maps (Landuse Change)
- Legacy Geology FieldSlips
- Borehole Archive
- Mine Abandonment Plan Archive
- Site Investigation Archive
- Britrocks Sites and Active Quarries

There are two online catalogues (B. Smith, Pers Comm) of data sources relating to BGS and NERC research activities:

- The first provides details of BGS-derived data sources available from the Geo-data portal (GeoIndex): http://www.bgs.ac.uk/geoindex/index.htm. This web site provides a GIS-like search facility to find information about all vector and raster datasets currently held and managed by BGS (ie DiGMapGB-50, SOBI, G-BASE, HiRES).
- The second website details availability of remotely sensed data available through the NERC Earth Observation Data Centre: http://www.neodc.rl.ac.uk/index.php. This website offers a spatial search facility to find information about data that has been derived from Satellite sensors (atsr1/2,ikonos, landsat-7 etm, radarsat, spot, avhrr, aatsr, envisat) and Airborne sensors (nextmap, atm, casi, lidar, shac, photography). Information relating to the characteristics of each data type can also be found at this site.

A7.2. Example of a BGS metadata sheet

British
Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

[BGS Discovery Metadata homepage]

Discovery Metadata Dataset:
GBASEGEOCHEM

TITLE	Geochemical Baseline Survey of the Environment (G-BASE) for the UK.
DATASET ORIGINATOR	ROBERT (TR) LISTER AT BRITISH GEOLOGICAL SURVEY, NOTTINGHAM
DATASET ORIGINATOR	CHRISTOPHER JOHNSON AT BRITISH GEOLOGICAL SURVEY, NOTTINGHAM
ABSTRACT	
The G-BASE programme involves systematic sampling and the determination of chemical elements in samples of stream sediment, stream water and, locally, soil, to build up a picture of the surface chemistry of the UK. The average sample density for stream sediments and water is about one site per 1.5-2km square. Analytical precision is high with strict quality control to ensure countrywide consistency. Results have been standardised to ensure seamless joins between geochemical sampling campaigns. The data provide baseline information on the natural abundances of elements, against which anomalous values due to such factors as mineralisation and industrial contamination may be compared. Analytical data for the 150 microns fraction of soil and stream sediment samples are available for some or all of: Ag, As, B, Ba, Bi, Be, Ca, Ce, Cd, Co, Cr, Cs, Cu, Fe, Ga, K, La, Li, Mg, Mn, Mo, Nb, Ni, P, Pb, Rb, Sb, Se, Sn, Sr, Th, Ti, U, V, Y, Zn, and Zr. Most water samples have been analysed for alkalinity, pH, conductivity, F and U and some for multi-element analyses including Al, Cl, Na, Si, SO4,NO4, and TOC.	
STATUS OF START DATE OF DATA CAPTURE	Known
START DATE OF DATA CAPTURE	01 JAN 1968
STATUS OF END DATE OF DATA CAPTURE	Ongoing
FREQUENCY OF UPDATE OF DATA	Annually
PRESENTATION FORMAT	Map
ACCESS RESTRICTIONS	Financial
CONSTRAINTS ON USAGE	Copyright control. Landowners permission given for non-site specific survey.
SYSTEM OF SPATIAL REFERENCING BY COORDINATES	British National Grid
WEST BOUNDING COORDINATE	50000
EAST BOUNDING COORDINATE	550000
NORTH BOUNDING COORDINATE	1220000
SOUTH BOUNDING COORDINATE	160000

NATIONAL EXTENT	Scotland
NATIONAL EXTENT	Wales
NATIONAL EXTENT	England
SPATIAL REFERENCE SYSTEM	BRITISH NATIONAL GRID
LEVEL OF SPATIAL DETAIL	
Samples av. 1 per 1.75 km square collected using 1:50 000 OS base maps.	
SUPPLY MEDIA/FORMAT	Paper
DATA STORAGE FORMAT	ORACLE
ADDITIONAL INFORMATION SOURCE	
Www.bgs.ac.uk/gbase	
ASSOCIATED DATASET	GBASEURBAN= Geochemical Baseline Survey of the Environment (GBASE) for UK soils in urban areas.
ASSOCIATED DATASET	URGNTMETALBIOAV= Metal Speciation and Bioavailability for Risk Assessment and Remediation.
SUPPLIER CONTACT NAME	ENQUIRIES AT BRITISH GEOLOGICAL SURVEY
SUPPLIER FULL POSTAL ADDRESS	
KINGSLEY DUNHAM CENTRE, KEYWORTH, NOTTINGHAM, NOTTINGHAMSHIRE.	
SUPPLIER POSTCODE	NG12 5GG
SUPPLIER TEL. NO.	0115 936 3143
SUPPLIER FAX NO.	0115 936 3192
SUPPLIER EMAIL ADDRESS	enquiries@bgs.ac.uk
DATE METADATA LAST UPDATED	21 MAR 2003

A8. SNH data list.

There do not seem to be any sets of soil samples in the SNH data. SNH generally commission research and data are generated for them under contract. In the listing here, the first two columns list the data sent from SNH, and columns three and four indicate the project team's assessment of their applicability to the threats to soil.

A8.1. List of SNH Information on Soils

No.	SNH Information	Useful for Threat	Note
1	Bing sites	Soil sealing	
2	Cairngorms Geomorphology West		Not relevant as too localised and not soils data
3	EUrosion data		Includes land cover for 10km coastal strip among other data. Likely that any soils data will be derived from national soils data set and this proviso will apply to all European studies.
4	Landscape Character Assessments	Cultural heritage assessment	
5	Landscape Character Revision 1. 1.4		The previous data reclassified / revised
6	Saltmarsh sites	Location of some saline soils	
7	Sand Dune Sites	Erosion OM decline Rare soils Development for Golf	Full but incomplete cover of Scotland
8	LCM2000 Land Cover Map 2000	Above-ground Biodiversity	Automatic / knowledge base classification of satellite images. Compatible with Broad Habitat classes defined for Biodiversity Action Plan. Accuracy concerns for heathlands and grasslands / bogs
9	CORINE	Sealing. Resolution / accuracy may be an issue.	Land cover derived from satellite data.
10/11	Grazing and trampling impact case studies.	Compaction Above-ground biodiversity	Macaulay carried out work
12	Native Woodland Model		Uses existing soil data
13	Inventory of Ancient and Long-Established Woodland Sites	OM changes Rare soil distribution	
14	Caledonian Pinewood Inventory	Rare soil distribution.	
15	National Inventory of Woodlands and Trees		LCS88 augmented by Forestry Commission
16	Dedicated Woodland	OM changes	
17	Scottish Forestry Grant Scheme	Above-ground biodiversity Flood management??	
18	Scottish Forestry Grant		

	Scheme – Fences		
19	Scottish Semi-Natural Woodland Inventory	Rare soils	
20	Scottish Semi-Natural Woodland Inventory on Ancient and Long-Established Woodland Sites	Rare soils	
21	Felling Licence Applications	Catchment hydrology change OM change Erosion	
22	Forest Districts		
23	Forest Enterprise Land		
24	Forest Plans – Approvals		
25	Forestry Conservancies		
26	Indicative Forestry Strategy		
27	Intermediate Peat Bogs in Scotland	Rare soils	
28	Peat Soils		Poor resolution
29	Lowland Raised Bogs		
30	BGS Solid Geology	Original data from BGS	
31	BGS Sand and Gravel – Midland Valley	Original data from BGS	
32/33	BGS Solid Geology – Midland Valley	Original data from BGS	
34	Environmentally Sensitive Areas		Aim to reduce the impact of threats
35	Less Favoured Areas		OM increasing – less ploughing?
36	Biological Records Centres		
37	Higher Plants in Scotland		
38	Rare Plants Database	Biodiversity Rare soils/habitats	
39	NVC Surveys	Biodiversity Rare soil / vegetation combination	
40	Birks and Ratcliffe Surveys		Some correspondence with NVC but requires interpretation
41	Local Biodiversity Action Plan (LBAP) Areas		
42	Groundwater Nitrate Vulnerable Zone (NVZ)	Contamination	
43	Historic Land Use Assessment	Cultural Heritage	
44	Land Cover of Scotland 1988 (LCS88)	Soil Sealing Biodiversity	
45	Register of Species Rich Hedgerows in Scotland	Biodiversity	

46	Scottish Wildlife Trust Wildlife Sites	Biodiversity	Surveys of the Site habitats are carried out according to SWT manual.
47	Scottish Wildlife Trust Reserves		
48	Woodland Grant Scheme		Natural regeneration or neglected woodland management categories may be of use.

A9. Scottish Soil Fertility Information System pre 1996

A9.1. Basic description

Title	Scottish Soil Fertility Information System pre 1996
Dataset acronym	SSFIS1996
Original purpose	Analysis carried out for soils which had some fertility-related problem
Dataset description	
Data format	Oracle table
Data Path	
Creator or author	Scottish Agricultural College
Author credentials	
Contributor	Samples collected by SAC staff or by landowner/user
Spatial coverage	Agricultural areas in Scotland. Samples are collected where a fertility lack is suspected.
Time frame	Discontinued in 1996. Replaced by SSFIS1996+
Spatial / temporal accuracy or precision	Sampling carried out on a 'W' pattern within a field or unit of 5 hectares, whichever is smaller. The samples are thus accurate to an area of approximately 5 ha.
Data currency	Discontinued in 1996. Replaced with a LIMS-based system. See Appendix A11.
Archival material	

A9.2. Recording methods and standards

Not available at time of compilation.

A9.3 Recorded attributes

Site data	National Grid Reference; Code for Scottish Agricultural College office nearest to the farm; Farm type (Hill; Upland; Lowland; Horticulture); Enterprise type (Dairy; Beef/sheep; Arable; Mixed; X=other); Soil series from soil maps; Year and month of receipt for analysis.
Analytical data	pH in water; Acetic acid extractable phosphorous (to end March 1992); Ammonium acetate/acetic acid extractable phosphorous (May 1992 onwards)

A9.4 Quality factors

Quality Factor	**Description**
Original data	Analytical data from samples collected in the field.
Primary / secondary data	Primary data.
Objectivity of Substance e.g. sampling	Sampling carried out on a 'W' pattern within a field or unit of 5 hectares, whichever is smaller.

strategy	
Objectivity of Presentation	
Analytical QA/QC	
Utility	
Integrity	
Transparency (Leads to reproducibility)	
Reproducibility	
Synthesised Product	
Interpreted Product	
Influential Information	

A10. Scottish Soil Fertility Information System post 1996

A10.1. Basic description

Title	Scottish Soil Fertility Information System post 1996
Dataset acronym	SSFIS1996+
Original purpose	Analysis carried out for soils which had some fertility-related problem
Dataset description	The Soil Fertility Information System, SFIS, database was discontinued in 1996. At that time the laboratory moved over to a LIMS system which is still in use today. There were plans to migrate the data from the SFIS system to the LIMS system but unfortunately it has never been completed. One problem with the migration was the extraction methods for the soil routine method had changed from acetic acid to Modified Morgan's. (Routine P, K, Mg, Ca and Na). It had been recognised that with acidic soils the Modified Morgan's method was more appropriate. (*Pers comm*. From Alister Gay, SAC)
Data format	Laboratory Information Management System
Data Path	
Creator or author	Scottish Agricultural College (SAC)
Author credentials	
Contributor	Samples collected by SAC staff or by landowner/user
Spatial coverage	Agricultural areas in Scotland. Samples are collected where a fertility lack is suspected.
Time frame	Continuation from SSFIS
Spatial / temporal accuracy or precision	Sampling carried out on a 'W' pattern within a field or unit of 5 hectares, whichever is smaller.
Data currency	1996 onwards
Archival material	

A10.2. Recording methods and standards

Peer review	
Standards	
Recording methods	

A10.3 Recorded attributes

Site data	Not recorded on a systematic basis.
Soil data	Texture Classification; Texture Lime requirement arable; SOLRAI; Lime requirement grass; SOLRGI
Analytical data	Fresh pH; pH Total nitrogen; Soil Total Carbon; Derived Organic Matter; Organic matter by LOI; Organic Matter (wet oxid); Mineralisable ammonium; Mineralisable nitrate; Nitrate nitrogen (CaSO4) Acid soluble fluoride; Water extract. sulphate Cation exchange capacity ADAS pH; ADAS ext. potassium; ADAS ext. magnesium; ADAS ext. sodium; ADAS ext. phosphorus Conductivity; Conductivity (sat. CaSO4)
Aqua regia digests	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; Nitrate; Phosphorus; Lead; Sulphur; Zinc
Extractable after 28 day incubation	NH4; NO3

A10.4 Quality factors

Quality Factor	**Description**
Original data	Analytical data from samples collected in the field.
Primary / secondary data	Primary data.
Objectivity of Substance e.g. sampling strategy	Sampling carried out on a ‘W’ pattern within a field or unit of 5 hectares, whichever is smaller.
Objectivity of Presentation	
Analytical QA/QC	
Utility	
Integrity	
Transparency (Leads to reproducibility)	
Reproducibility	
Synthesised Product	
Interpreted Product	
Influential Information	

A11. Trends in Pollution of Scottish Soils

A11.1. Basic description

Title	Trends in Pollution of Scottish Soils
Dataset acronym	TIPSS
Original purpose	To provide a 'snapshot in time' of the pollution loadings in some Scottish soils and provide some indication of what might be considered the background levels in more pristine environments
Dataset description	Scotland, like many countries in Europe, has a legacy of pollution largely emanating from the Industrial Revolution in the 19th Century, although some pollution can be traced back to even our earliest civilizations. In addition, some types of pollution have no boundaries and arrive here from other countries on the prevailing winds. In 1990, the Macaulay Institute undertook a survey of a series of surface soils from four transects across Scotland to assess the pollution caused by atmospheric deposition.. Data are presented on levels of persistent organic pollutants, such as polychlorinated biphenyls (PCBs) and polynuclear aromatic hydrocarbons (PAHs), as well as radiocaesium and the heavy metals, cadmium, copper, lead, nickel and zinc. Further information is available at http://www.macaulay.ac.uk/tipss, where the survey is described and maps of pollutants are displayed (pages active on 27 June 2006).
Data format	Spreadsheets
Data Path	
Creator or author	Macaulay Land Use Research Institute
Author credentials	Sites selection / sample collection by an experienced soil survey staff member.
Contributor	None
Spatial coverage	Equal spaced intervals along four transects crossing mainland Scotland: • North Scotland from Applecross to Caithness (8 samples) • Central Highlands from Argyll to Buchan (8 samples) • Central Valley from Renfrew to Angus (6 samples) • Southern Uplands from Wigtown to Berwickshire (8 samples) Surface soil horizons, mainly under heather moorland.
Time frame	Samples were collected in 1990 and 1999. No analysis has yet been done for the 1999 sample set.
Spatial / temporal accuracy or precision	Precise locations of the sample points are confidential.
Data currency	
Archival material	Samples are stored in the National Soils Archive of Scotland

A11.2. Recording methods and standards

As for the National Soils Inventory described in Appendix A1.

A11.3 Recorded attributes

Site data	Elevation; Vegetation type; Site photographs
Soil data	Soil types
Analytical data	Caesium-137; polycyclicaromatic hydrocarbons (PAHs); polychlorinated biphenyls (PCBs); Cadmium; Copper; Zinc; Lead; Nickel

A11.4 Quality factors

Quality Factor	**Description**
Original data	Measurements made on soil samples
Primary / secondary data	Primary data
Objectivity of Substance e.g. sampling strategy	Sample sites were selected to be approximately equally space along four transects aligned from south-west to north-east.
Objectivity of Presentation	Presented on the Macaulay web site
Analytical QA/QC	
Utility	
Integrity	
Transparency (Leads to reproducibility)	
Reproducibility	
Synthesised Product	No
Interpreted Product	No
Influential Information	Not relevant

Appendix B. Soil maps, soil memoirs and soil handbooks.

Introduction.

Soil maps record the distribution of soil types in Scotland at scales from 1:250 000 to 1:10 000. Soil series are the primary mapping unit on the detailed soil maps (1:63 360, 1:25 000 or 1:10 000 scales). Any area mapped as a given series is **predominantly, but not necessarily exclusively**, composed of profiles belonging to the profile series of the same name. Soil series are grouped into soil associations, which represent a characteristic soil pattern in the landscape, closely related to the parent material. The soil association is a compound mapping unit, which comprises a number of different soils, differing in profile morphology and/or drainage category and where the distribution of each component is delineated. The names of associations and series refer to the locality where it was first mapped. A further mapping unit is the soil complex, composed of two or more soil series which occur across the landscape in units which are too small to map individually. The 1:250 000 scale maps use soil associations and soil complexes as the basic mapping units as the scale limits the amount of information that can be shown.

The 1:63 360 scale maps mainly cover the lowland agricultural areas of Scotland. The remainder of the country was mapped in less detail for publication at 1:250 000 scale in 1984. New survey was carried out in the field for the uplands and areas not previously mapped in more detail. This involved the same methodology, but was carried out using a systematic approach in the field, with survey planned around and integrated with collection of NSIS information., but the mapping still involved field investigations.

Soil classification in Scotland

Since the maps are based on classification of soils, a brief description of soil classification is given here. In Scotland the soil parent material has generally moved only short distances and the soils are comparatively young (less than 12 000 years), therefore, they still retain many of the chemical characteristics of the underlying parent rock. For this reason, the classification places great emphasis on the stratigraphy of the parent rocks. The current system of soil classification was coordinated by the Soil Survey of Scotland during soil mapping for the 1:250 000 scale soil survey described in the appendix (Soil Survey Staff, 1984) and is based on the evolving classification described in previous soil memoirs. The soil classification is typological not definitional (Butler, 1980); in other words, it is essentially a descriptive system which uses little or no quantitative data on soil properties. The basic building blocks of the classification are soil horizons and soil profiles. Soil horizon features and juxtaposition are used to infer the soil processes that influenced the soil's formation. The type and arrangement of horizons and their associated soil properties is used to inform the soil classification. The features considered for each soil horizon are colour, texture, structure, consistence, organic matter, roots, stones, moisture, mottles and thickness of the horizon. Soil types are identified from the soil horizon sequences that make up the soil profile morphology. The soil type classification system has five categorical levels:

- Division: reflects the dominant soil forming processes which influence the soil. There are five divisions in Scotland: Immature soils; Non-leached soils; Leached soils; Gleys; Organic Soils

- Major Soil Group: comprises soils at a similar stage of development which have been subjected to the same soil forming processes. There are 11 major soil groups.
- Major Soil Subgroup: soils with similar type and arrangement of horizons. May contain information on several pedogenic processes. There are 25 major soil groups.
- Soil Association: a grouping of different soil series developed on similar parent materials. This grouping has a common geochemical signature. There are around 165 soil associations.
- Soil Series: soils of a specific Major Soil Subgroup, developed on the same parent materials and belong to the same natural drainage class. The Soil Series is the lowest class in the hierarchy and represents the individual soil type as defined by both the soil forming processes and characteristics inherited from the parent material such as soil texture or geochemistry.There are around 1100 soil series.

B1. Printed Soil Maps of Scotland at 1:250 000 scale

B1.1. Basic description

Title	Soil Maps of Scotland at 1:250 000 scale
Dataset acronym	QMSoils – Paper
Original purpose	To provide complete coverage of soil mapping at a broad, regional scale over the whole of Scotland using a common approach to classification and mapping.
Dataset description	QMSoil is a soil map at 1:250 000 scale covering the whole of Scotland. The map was compiled from prior 1:63 360 and 1:50 000 scale soil maps where these existed. In unsurveyed areas, new mapping was carried out from 1978 to 1981.
Data format	QMSoil is a series of seven printed maps and handbooks. The data have been digitised. • Vector-digitised dataset • Raster dataset (100m square) derived from the vector dataset a spatial dataset which exists in several formats:
Data Path	The maps are published and available from the Macaulay Institute.
Creator or author	Soil surveyors employed by the Macaulay Institute.
Author credentials	Soil surveyors with extensive field experience of soil classification and mapping carried out the field work.
Contributor	As for creator or author
Spatial coverage	Soil map covers the whole of Scotland on seven paper map sheets.
Time frame	Compilation and field survey took four years: 1978 to 1982
Spatial / temporal accuracy or precision	The map units are accurate to the precision of a 1:250 000 scale map.
Data currency	The new mapping was carried out 24 to 28 years ago. The original 1:63 360 mapping simplified for the bulk of the lowland areas is up to 65 years old.
Archival material	Aerial photographs used in the field mapping are stored at the Macaulay Institute.Clean copy 1:50 000 maps were produced from the aerial photographs and are also stored.

B1.2. Recording methods and standards

Peer review	Soil survey methods were discussed from time to time at field meetings with soil survey organisations in the United States, Canada and Europe from the inception of the Soil Survey of Scotland.
Standards	The methodology for soil mapping was coordinated by the soil surveyors at regular field meetings, held jointly with the soil survey of England and Wales.
Recording methods	The field description and recording methods agreed at field meetings were published (Hodgson, 2004) and were adopted by the Soil Survey of Scotland with the exception of texture classification. The grid sample plan for the sampling was agreed with the Soil Survey of England and Wales and DAFS (now SEERAD).

B1.3 Recorded attributes

Site data	Locations of soil map polygons delineated using the OS Grid.
Soil data	Soil mapping units are delineated based on: Soil Association; Soil Parent Materials; Component Soils; Landforms; Vegetation Communities (Robertson, 1984)
Analytical data	No analytical data

B1.4 Quality factors

Quality Factor	**Description**
Original data	The soil map is original data prepared by soil surveyors from field mapping.
Primary / secondary data	The map units are secondary data inferred by soil surveyors from their field observations of soil profiles, landforms and vegetation.
Objectivity of Substance e.g. sampling strategy	Systematic coverage of the land with profile pits selected subjectively. Soil inspection pits selected by the field surveyors. The soils are mapped by a procedure known as 'free survey' in which the soil surveyor selects the soil profile sites by using his field knowledge of soil forming processes in relation to the factors he observes in the landscape.
Objectivity of Presentation	
Analytical QA/QC	Not relevant
Utility	Used for land evaluation and modelling of soil properties
Integrity	
Transparency (Leads to reproducibility)	
Reproducibility	
Synthesised Product	Soil classification and mapping is a synthesis of soil property, soil horizon, landform, vegetation and climate.
Interpreted Product	Soil types are interpreted in the field
Influential Information	Contributes data to land evaluation maps which are used to set policy.

B2. Soil maps at 1:63 360 or 1:50 000 scale

B2.1. Basic description

Title	Soil maps at 1:63 360 or 1:50 000 scale
Dataset acronym	One inch soil maps
Original purpose	To map the soils of Scotland, with the focus on agricultural areas.
Dataset description	
Data format	Paper maps.
Data Path	The maps are published and available from the Macaulay Institute.
Creator or author	Soil surveyors employed by the Macaulay Institute.
Author credentials	Soil surveyors with extensive field experience of soil classification and mapping carried out the field work.
Contributor	
Spatial coverage	OS third edition map sheets covering main agricultural areas as follows: Bown, C.J. and Heslop, R.E.F. 1971 Soil map of Kirkmaiden, Whithorn, Stranraer and Wigtown (Sheets 1, 2, 3, 4 and part 7). 1:63 360 Southampton: Ordnance Survey. Bown, C.J., Futty, D.W., Jardine, W.D., Walker, A.D., Heslop, R.E.F. and Strachan, W.R. 1968 Soil map of Carrick and part of Girvan (Sheet 8 and part of 7). 1:63 360 Southampton: Ordnance Survey. Dry, F.T., Duncan, N.A., Menzies, J., Bell, J.S., Lilly, A. and Towers, W. 1984 Soil map of Hamilton (Sheet 23). 1:63 360 Southampton: Ordnance Survey. Dry, F.T., Gauld, J.H. Heslop, R.E.F., Bell, J.S., Hipkin, J.A., Lilly, A. and Nolan, A.J. 1986 Soil map of Blairgowrie (Sheet 56) 1:63 360 Southampton: Ordnance Survey. Dry, F.T., Henderson, D.J., Hipkin, J.A., Nolan, A.J., Lilly, A. and Shipley, B.M. 1985 Soil map of Glasgow (Sheet 30). 1:63 360 Southampton: Ordnance Survey Futty, D.W. and Dry, F.T. 1972 Soil map of Latheron and Wick (Sheets 110, 116 and part of 117). 1:63 360 Southampton: Ordnance Survey. Futty, D.W., Towers, W. and Campbell, C.G.B. 1987 Soil map of Golspie (Sheet 103). 1:63 360 Southampton: Ordnance Survey. Futty, D.W., Towers, W., Dry, F.T., Mackay, J. and Bell, J.S. 1985 Soil map of Achentoul and Reay (Sheets 109 and 115). 1:63 360 Southampton: Ordnance Survey. Glentworth, R., Hart, R., Dion, H.G., Muir, J.W., Laing, D., Shipley, B.M., Smith, J. and Grant, C.J. 1959 Soil map of Inverurie (Sheet 76) 1:63 360 Chessington: Ordnance Survey. Glentworth, R., Hart, R., Muir, J.W., Romans, J.C.C., Mitchell, B.D. and Mulcahy, M.J. 1954 Soil map of Huntly (Sheet 86). 1:63 360 Chessington: Ordnance Survey. Glentworth, R., Laing, D., Muir, J.W., Hart, R., and MacKenzie, R.C. 1962 Soil map of Aberdeen (Sheet 77). 1:63 360 Chessington: Ordnance Survey. Glentworth, R., Mitchell, B.D. and Grant, R. 1954 Soil map of Banff (Sheet 96). 1:63 360 Chessington: Ordnance Survey. Glentworth, R., Muir, J.W., Shipley, B.M., Grant, R., Bown, C.J., Hart, R. and Dion, H.G. 1962 Soil map of Peterhead and Fraserburgh (Sheets 87 and 97). 1:63 360 Chessington: Ordnance Survey. Glentworth, R., Muir, J.W., Romans, J.C.C., Birse, E.L., Smith, J. and Shipley, B.M. 1966 Soil map of Banchory and Stonehaven (Sheets 66 and 67) 1:63 360 Southampton: Ordnance Survey. Grant, R. Bown, C.J. and Birse, E.L. 1967 Soil map of Ayr (Sheet 14 and part of 13). 1:63 360 Chessington: Ordnance Survey.

	Grant, R., Birse, E.L. and Harper, P.C. 1956 Soil map of Elgin (Sheet 95). 1:63 360 Chessington: Ordnance Survey. Heslop, R.E.F. and Campbell, C.G.B. 1981 Soil map of Tomintoul (Sheet 75). 1:63 360 Southampton: Ordnance Survey. Laing, D., Lawrence, E., Robertson, J.S. and Merrilees, D.W. 1975 Soil map of Kinross, Elie and Edinburgh (Sheet 40 and parts of Sheet 41 and 32). 1:63 360 Southampton: Ordnance Survey. Laing, D., Romans, J.C.C., Lawrence, E., Walker, A.D., Bown, C.J. and Law, R.D. 1968 Soil map of Perth and Arbroath (Sheets 48 and 49). 1:63 360 Southampton: Ordnance Survey. Mitchell, B.D., Jarvis, R.A., Muir, J.W. and Davies, D.T. 1956 Soil map of Kilmarnock (Sheet 22 and part of 21). 1:63 360 Chessington: Ordnance Survey. Muir, J.W., Mulcahy, M.J., Ragg, J.M., Mitchell, B.D., Harper, P.C. and Smith, J. 1955 Soil map of Jedburgh and Morebattle (Sheets 17 and 18). 1:63 360 Southampton: Ordnance Survey. Muir, J.W., Romans, J.C.C., Laing, D., Smith, J. and Glentworth, R. 1964 Soil map of Forfar (Sheets 57 and 57A). 1:63 360 Southampton: Ordnance Survey. Ragg, J.M., Futty, D.W. and Bown, C.J. 1966 Soil map of Haddington, Eyemouth and N. Berwick (Sheets 33, 34 and part 41). 1:63 360 Chessington: Ordnance Survey. Ragg, J.M., Shipley, B.M., Duncan, N.A., Bibby, J.S. and Merrilees, D.W. 1977 Soil map of Airdrie (Sheet 31) 1:63 360 Southampton: Ordnance Survey. Ragg, J.M., Smith, J., Muir, J.W. and Birse, E.L. 1959 Soil map of Berwick upon Tweed (Sheet 26) 1:63 360 Chessington: Ordnance Survey. Ragg, J.M., Smith, J., Muir, J.W. and Birse, E.L. 1959 Soil map of Kelso (Sheet 25). 1:63 360 Chessington: Ordnance Survey. Ragg. J.M., Bibby, J.S., Orbell, G.E. and Duncan, N.A. 1975 Soil map of Peebles and part of Edinburgh (Sheet 24 and part 32). 1:63 360 Southampton: Ordnance Survey. Romans, J.C.C., Grant, R., Walker, A.D., Strachan, W.R. and Robertson, J.S. 1972 Soil map of Cromarty and Invergordon (Sheet 94). 1:63 360 Southampton: Ordnance Survey. Romans, J.C.C., Hudson, G., Grant, R., Birse, E.L., and Harper, P.C. Sheet 95 revision by R.E.F. Heslop and C.G.B. Campbell 1980 Soil map of Rothes and Elgin (Sheets 85 and 95) 1:63 360 Southampton: Ordnance Survey. Romans, J.C.C., Lang, D.M. and Cruickshank, J. 1972 Soil map of the Black Isle (Part of Sheets 83, 84, 93 and 94). 1:63 360 Southampton: Ordnance Survey. Shipley, B.M., Stevens, J.H., Lawrence, E. and Jarvis, R.A. 1968 Soil map of Stirling and part of Airdrie (Sheet 39 and part of 31). 1:63 360 Southampton: Ordnance Survey. Shipley, B.M., Stevens, J.H., Lawrence, E. and Jarvis, R.A. 1968 Soil map of Stirling and part of Airdrie (Sheet 39 and part of 31). 1:63 360 Southampton: Ordnance Survey. Shipley, B.M., Stevens, J.H., Merrilees, D.W., Morris, R.J.F. and Wright, G.G. 1983 Soil map of Crieff (Sheet 47). 1:63 360 Southampton: Ordnance Survey. Walker, A.D., Grant, R., Law, R.D., Jack, J.I. and Gauld, J.H. 1976 Soil map of Nairn and Cromarty (Sheet 84 and part of 94) 1:63 360 Southampton: Ordnance Survey.
Time frame	Soil Survey for this series of maps began in the 1934 and the first map was published in 1954.
Spatial / temporal accuracy or precision	The spatial accuracy varies depending on maps available at the time of the survey. Air photographs were used for field mapping on selected map sheets from about 1966.
Data currency	Mapping was carried out from 1934 to 1987. Each map took between 5 and 15 years to complete. Soil samples were collected as the mapping progressed.
Archival material	Field documents (annotated maps, annotated air photographs and field note books) are archived at the Macaulay Institute, but not in a dedicated repository.

B2.2. Recording methods and standards

Peer review	Soil survey methods were discussed from time to time at field meetings with soil survey organisations in the United States, Canada and Europe from the inception of the Soil Survey of Scotland.
Standards	The methodology for soil mapping was coordinated by the soil surveyors at regular field meetings, held jointly with the soil survey of England and Wales.
Recording methods	The field description and recording methods agreed at field meetings were published (Hodgson, 2004?) and were adopted by the Soil Survey of Scotland with the exception of texture classification. The grid sample plan for the sampling was agreed with the Soil Survey of England and Wales and DAFS (now SEERAD).

B2.3 Recorded attributes

Site data	Locations of soil map unit boundaries delineated using the OS Grid.
Soil data	Soil mapping units are delineated based on: Soil Association; Soil Parent Materials; Component Soils; Landforms. Soil mapping unit attributes; Derived soils information
Analytical data	No analytical data

B2.4 Quality factors

Quality Factor	Description
Original data	The soil map is original data prepared by soil surveyors from field mapping.
Primary / secondary data	The map units are secondary data inferred by soil surveyors from their field observations of soil profiles, landforms and vegetation.
Objectivity of Substance e.g. sampling strategy	Systematic coverage of the land with profile pits selected subjectively. Soil inspection pits selected by the field surveyors. The soils are mapped by a procedure known as 'free survey' in which the soil surveyor selects the soil profile sites by using his field knowledge of soil forming processes in relation to the factors he observes in the landscape.
Objectivity of Presentation	
Analytical QA/QC	
Utility	
Integrity	
Transparency (Leads to reproducibility)	
Reproducibility	
Synthesised Product	
Interpreted Product	
Influential Information	

B3. Soil Memoirs and Handbooks

B3.1. Basic description

Title	Soil Memoirs and Handbooks
Dataset acronym	
Original purpose	To describe the soils of the soil map the memoir accompanies
Dataset description	A soil memoir or handbook includes descriptions of the topography, climate and parent materials of the area. Soil forming processes were described and the classification and mapping procedures at the time of the mapping were also recorded. The main part of the memoir describes the distribution, field properties and analytical data of soils and peat of the map. Vegetation and major land uses of agriculture and forestry are also described.
Data format	Printed book
Data Path	
Creator or author	Soil Survey Staff members.
Author credentials	Soil surveyors with extensive field experience of soil classification and mapping.
Contributor	
Spatial coverage	Handbooks of the 1:250 000 scale survey cover all of Scotland in a series of seven books. Memoirs for 1:63 360 maps are available for a limited number of areas including the following examples: Glentworth, R. 1954. The Soils of the country round Banff, Huntly and Turriff (Sheets 86 and 96). Edinburgh, HMSO. Mitchell, B.D. and Jarvis, R.A. 1956. The Soils of the country round Kilmarnock (Sheet 22 and part of21). Memoirs of the Soil Survey of Scotland. Edinburgh, HMSO. Muir, J.W. 1956. The soils of the country round Jedburgh and Morebattle (Sheets 17 and 18). Memoirs of the Soil Survey of Scotland. Edinburgh, HMSO. Ragg, J.M. and Futty, D.W. 1967. The soils of the country round Haddington and Eyemouth (Sheets 33 and 34 and part of sheet 41). Memoirs of the Soil Survey of Scotland. Edinburgh, HMSO. Ragg, J.M. 1960. The soils of the country round Kelso and Lauder (Sheets 25 and 26). Memoirs of the Soil Survey of Scotland. Edinburgh, HMSO. Grant, R. 1960. The Soils of the country round Elgin (Sheet 95). Memoirs of the Soil Survey of Scotland. Aberdeen: Macaulay Institute for Soil Research. Glentworth, R. and Muir. J.W. 1963. The Soils of the country round Aberdeen, Inverurie and Fraserburgh (Sheets 77, 76 and 87/97). Memoirs of the Soil Survey of Scotland. Edinburgh, HMSO. Bown, C.J. 1973. The Soils of Carrick and the country round Girvan (Sheets 7 and 8). Memoirs of the Soil Survey of Scotland. Edinburgh, HMSO. Laing, D. 1976. The Soils of the country round Perth, Arbroath and Dundee (Sheets 48 and 49). Memoirs of the Soil Survey of Scotland. Edinburgh, HMSO. Futty, D.W. and Dry, F.T. 1977. The Soils of the country round Wick (Sheets 110, 116 and part 117). Memoirs of the Soil Survey of Scotland. Aberdeen: Macaulay Institute for Soil Research. Bown, C.J. and Heslop, R.E.F. 1979. The soils of the country round Stranraer and Wigtown. Memoirs of the Soil Survey of Great Britain. Aberdeen: Macaulay Institute for Soil Research. Romans, J.C.C. 1984. The Soils of the Black Isle (Parts of Sheets 83, 84, 93 and 94) Memoirs of the Soil Survey of Great Britain. Aberdeen: Macaulay Land Use

	Research Institute
Time frame	Memoirs were written between 1954 and 1984 for one inch soil maps. The 1:250 000 Handbooks were written in 1982.
Spatial / temporal accuracy or precision	Not relevant
Data currency	The material is of historical interest.
Archival material	No electronic copies of these publications exist.

B3.2. Recording methods and standards

As for the 1:63 360 maps described in B2.

B3.3 Recorded attributes

Site data	General descriptions of the sheet topography and of soil profile sites are given.
Soil data	Soil classification used in the mapping for the described map sheet. Soil mapping units are described in detail.
Analytical data	Analytical data from soil profiles selected to be typical of the soils in the area.

B3.4 Quality factors

B4. List of ad hoc soil maps at various scales

(J.S. Bell *Pers. Comm.*)

The Macaulay Institute has carried out *ad hoc* soil surveys of farms, estates or other areas. Many of the maps are archived at the Institute. A list of these maps follows:

Geographical Area of Soil Map	**Map Scale**
Achany-Lairg	1:5 000
Aldroughty Farm	1:2 500
Annan-Gretna	1:25 000
Badden & Kilmory Farms, Argyll	1:5 000
Baddengowan Wood	1:10 560
Balloan Farm – Cawdor Estate	1:2 500
Balnastraid Farm	1:2 500
Balquhain and West Balquhain Farms	Not known
Barrachander Farm, Kilchrennan	1:10 000
Bush Estate – Dryden Farm	1:10 560
Cambusmore Estate, Callander	1:10 560
Candacraig & Glenbuchat	1:25 000
Coll & Tiree	1:63 360
Craibstone & Bellastrade Farms	1:5 000
Crichton Royal Farm Dumfries	1:10 560
Culbin	1:25 000
Cubbox & Killochy	1:10 560
Doune Estate	1:10 560
Dumbretton Farm, Dumfries	1:2 500
Garden estate, Stirlingshire	1:5 000
Glenborrowdale	1:63 360
Glen Derry & Glen Luibeg	1:10 000
Ey	1:25 000
Glenfeshie Estate	1:25 000
Glen Isla	1:10 560
Glensaugh	1:10 560
Grangemouth – Falkirk	1:63 360
Hannah Dairy Research Institute	1:2 500
Hillbrae Farm – Aberdeen University	1:5 000
Invergordon – Alness	1:25 000
Kirkconnel, Dumfries	1:10 560
Lawers School of Agriculture	1:2 500
Leaths Farm, Castle Douglas	Not known
Lennoxtown	1:25 000
Lephinmore, Argyll (1953 and 1976)	1:10 560
Linn of Dee to South Bynack lodge	1:25 000
Mar Estate	1:25 000
Meikle and Little Kildrummie	Not known
Minnigryle Farm, Dumfries	1:10 000
Montrose Basin	1:10 560
Mull	1:25 000

Mylnefield – SCRI	1:2 500
Rahoy Estate	Not known
Ross of Mull	1:25 000
Rhum	1:63 360
Rhum	1:25 000
Stirlingshire	1:250 000
Strathdon – Reconnaissance	Not known
Tullos Hill	1:5 000
Weyland & Waterside Farms (NOSCA)	1:2 500
Whim Estate, Penicuik	1:10 560

B5. Forestry Commission Soil Maps

B5.1. Basic description

Title	Forestry Commission Soil Maps 1:10 000 scale
Dataset acronym	FCSoilMaps
Original purpose	To provide soil mapping of forestry acquisitions that could assist forest planning and management.
Dataset description	The Forestry Commission have been mapping soils in forest acquisitions at a scale of 1:10 560 or 1:10 000 for many years. The maps are based on ecological site classification systems, which include soil and site characteristics such as vegetation and are based on free survey techniques. The maps cover forestry acquisition areas (map?)
Data format	The maps are in paper or digital formats.
Data Path	The maps have a restricted circulation.
Creator or author	Soil and site surveyors employed by the Forestry Commission..
Author credentials	Soil surveyors with extensive field experience of soil classification and mapping carried out the field work.
Contributor	As for creator or author
Spatial coverage	Soil map covers Forestry Commission forested areas in Scotland.
Time frame	Surveying is ongoing.
Spatial / temporal accuracy or precision	The map units are accurate to the precision of a 1:10 000 scale map.
Data currency	Cover a long time period.
Archival material	Not known at the time of compilation

B5.2. Recording methods and standards

Peer review	Soil survey methods were discussed from time to time at field meetings with soil survey organisations in the United States, Canada and Europe from the inception of the Soil Survey of Scotland.
Standards	The methodology for soil mapping was coordinated by the soil surveyors at regular field meetings.
Recording methods	The latest version of the ecological site classification builds on earlier versions (e.g. Pyatt, 1995) and is coded in a decision support system (Ray, 2001).

Appendix C. Quality of Selected Biodiversity Information

C1. British Mycological Society Fungal Records Database

This material was obtained from the web pages of the British Mycological Society

C1.1. Basic description

Title	British Mycological Society Fungal Records Database
Dataset acronym	BMSFRD
Original purpose	
Dataset description	Database containing over 1 million records of around 16 900 species of fungi. The database contains links to over 2000 distribution maps of single species. There are copyright issues to be resolved before the full information can be made available 'live' on the web and the society are working towards this.
Data format	A database which serves internet queries through a web browser interface.
Data Path	On 23 May 2006 the link was: http://194.203.77.76/fieldmycology/BMSFRD/bmsfrd.asp
Creator or author	British Mycological Society (BMS)
Author credentials	The BMS is a 'learned society' with international status and exists to promote all aspects of mycology. The society organises forays into the field and systemises the recording of fungi.
Contributor	Records of fungi from forays of the British Mycological Society, Association of British Fungus Groups Various surveys, (e.g. SNH waxcap in grasslands survey) Local Recording Groups throughout United Kingdom Individual and published records of British fungi from • Transactions of the British Mycological Society, the Bulletin, and their successors • Mycological Research • Mycologist • Field Mycology • Data collection sponsored by JNCC (Cannon, *Mycologist* **12**(1): 25, 1998)
Spatial coverage	The British Isles
Time frame	Ongoing contributions of records dating back approximately 100 years.
Spatial / temporal accuracy or precision	Workshops, partial or sample surveys and forays.
Data currency	The data cover a long time period.
Archival material	

C1.2. Recording methods and standards

Peer review	The Society organises regular workshops for field mycologists
Standards	Colin – what standards of observation??
Recording methods	The BMS website make MycoRec available for download. This is a simple database package written by Jerry Cooper in MSAccess97, designed specifically for recording fungi. Records stored in MycoRec are compatible with the BMSFRD. On 24 May 2006 the link was: http://194.203.77.76/fieldmycology/MycoRec/MycoRec.htm MycoRec also contains a checklist of fungus names and synonyms, covering all the records in the BMSFRD and many more names used to record fungi in the British Isles

C1.3 Recorded attributes

Estimated from BMSFRD	Species name; Recording date; Location name with vice-county number; Grid reference; Recorder name; Publication reference; Elevation;

C1.4 Quality factors

Factor	**Description**
Original data	Original data collected in the field.
Primary / secondary data	Directly collected primary data.
Objectivity of Substance e.g. sampling strategy	Records are made during forays into the field. Some partial and systematic surveys are also carried out of habitats or areas under the auspices of the BMS or SNH.
Objectivity of Presentation	The data are released in raw form on the internet via a web browser interface. Some surveys are published in journals or transactions of the BMS. SNH publish results of surveys as research reports.
Analytical QA/QC	No analytical data are collected.
Utility	Data are used by researchers in mycology for a wide range of purposes.
Integrity	The database is securely maintained within the BMS web site.
Transparency (Leads to reproducibility)	Field recording methods were published and species identification is regulated by experts and field keys.
Reproducibility	Data are collected by a peer-group of experts in field mycology.
Synthesised Product	These are raw data.
Interpreted Product	Specimens are allocated to species names with reference to a key. For recent records, photographs are often taken for identification by other experts.
Influential Information	The information influences for example biodiversity action plans.

C2. Survey of 'Tooth' (stipitate hydnoid) fungi in native pinewoods.

C2.1. Basic description

Title	Survey of ‘Tooth’ (stipitate hydnoid) fungi in native pinewoods
Dataset acronym	
Original purpose	
Dataset description	Stipitate hydnoid fungi (specifically members of the genera Bankera, Hydnellum, Phellodon, Sarcodon) have become the focus of increasing conservation concern, particularly following the detection of widespread declines in abundance.
Data format	
Data Path	Newton, A., Holden, L., Davy, L. & Watling, R. 2001. Survey of 'Tooth' (stipitate hydnoid) fungi in native pinewoods. SNH report.
Creator or author	Newton, A., Holden, L., Davy, L. & Watling, R.
Author credentials	
Contributor	
Spatial coverage	To assess the status in Scotland, 103 field surveys were undertaken, including searches of 50 of the 77 native pinewood sites, traversing a total of 902 km
Time frame	
Spatial / temporal accuracy or precision	
Data currency	
Archival material	

Appendix D. Digital Soil Map Data

Digital soil map data generally have similar quality factors to the underlying maps. An example data quality description for the 1:250 000 scale soil maps as digitised by MLURI is given below.

D1. At 1:250 000 scale.

D1.1. Basic description

Title	Digital Soil Maps of Scotland at 1:250 000 scale
Dataset acronym	QMSoils – Digital
Original purpose	To facilitate soil modelling in a GIS for Scotland.
Dataset description	QMSoils – Digital is the vector-digitised copy of the soil map at 1:250 000 scale covering the whole of Scotland.
Data format	The vector digitised data set has been converted into several forms: • Original vector-digitised dataset • Original vector dataset with soil boundaries interpolated through built up areas. • Raster dataset 100m grid squares (with / without built up areas) • Dominant soil in each one kilometre grid square (with / without built up areas)
Data Path	Data are available from the Macaulay Institute under lease.
Creator or author	As for the paper version described in appendix B1.
Author credentials	As for the paper version described in appendix B1.
Contributor	
Spatial coverage	Data cover the whole of Scotland.
Time frame	As for the paper version described in appendix B1.
Spatial / temporal accuracy or precision	Accuracy of digitising is of minor contribution to the errors compared with the accuracy of drawing the original boundaries.
Data currency	As for the paper version described in appendix B1.
Archival material	As for the paper version described in appendix B1.

D1.2. Recording methods and standards

As for the paper version described in appendix B1.

B1.3 Recorded attributes

As for the paper version described in appendix B1.

B1.4 Quality factors

Appendix E. Scoring of relative importance of threats

We considered each individual threat against each of the six primary soil functions in terms of:
Consequence - What are the medium term (20-25 years) consequences of the threat or issue in relation to the six soil functions?
Extent – Does it impact at the plot, field, regional or Scottish national level?
Reversibility – The extent to which the effects of the threat are naturally attenuated, can be mitigated, remediated or reversed?
Level of uncertainty – How good is our understanding of the issue? How strong is the evidence base and data to support it?
To determine the overall importance of each threat for each function we scored the consequence, extent, uncertainty and reversibility on a simple three point scale. We also used a score of 0 for spatial extent where there was no current evidence of an effect in Scotland.

E1. Criteria for scoring relative importance of threats for different soil functions.

Score	Grade	Definition
Criterion a (consequence)		
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
Criterion b (spatial extent)		
0	Limited	very limited extent or confined to very specific environments
1	Local	confined to a limited number of soils or environments or occurring as low frequency events
2	Regional	impacts are confined to one major region or soil environment within Scotland (e.g. arable soils, upland areas)
3	National	impacts on almost all soils in Scotland
Criterion c (uncertainty)		
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.
Criterion d (reversibility)		
1	High	effects of the threat can be easily reversed by simple modifications to management practices or natural attenuation, reversal possible within a season
2	Moderate	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	Low	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

E2 Detailed scoring of threats

Comparison of threats across all soil functions

	Biomass, food & fibre production					Environmental interactions					Ecosystem support, habitats and biodiversity					Provision of a platform					Provision of raw materials					Protection of cultural heritage					**Overall Risk Product**	**Overall Risk Product**
Threat	Consequence	Extent	Uncertainty	Reversibility	F1 Sum	Consequence	Extent	Uncertainty	Reversibility	F2 Sum	Consequence	Extent	Uncertainty	Reversibility	F3 Sum	Consequence	Extent	Uncertainty	Reversability	F4 Sum	Consequence	Extent	Uncertainty	Reversibility	F5 Sum	Consequence	Extent	Uncertainty	Reversibility	F6 Sum	Additive for each function	Weighted 2x for Ecological functions
Climate change	2	3	3	3	18	2	3	3	3	18	2	3	3	3	18	2	1	3	2	4	2	1	2	3	6	2	1	3	3	6	**70**	**124**
Loss of organic matter	2	2	2	1	4	3	3	2	3	27	3	2	2	3	18	0	0	0	0	0	2	1	2	3	6	2	1	2	3	6	**61**	**110**
Sealing	3	1	2	3	9	3	1	2	3	9	3	1	2	3	9	0	0	0	0	0	3	1	1	3	9	3	1	2	3	9	**45**	**72**
Contamination by atmospheric N,S	1	2	1	3	6	2	3	1	3	18	2	3	2	3	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**42**	**84**
Loss of biodiversity	2	2	3	2	8	2	3	3	2	12	3	3	3	2	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**38**	**76**
Contamination by heavy metals	2	2	2	2	8	2	2	2	3	12	2	2	2	3	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**32**	**64**
Soil erosion	2	1	2	1	2	3	1	2	2	6	2	2	2	2	8	2	1	3	2	4	1	1	2	2	2	3	1	1	3	9	**31**	**47**
Soil contamination by land based activities	1	2	1	1	2	2	2	2	2	8	2	2	2	2	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**18**	**36**
Compaction and structure	2	1	2	1	2	2	1	1	1	2	2	1	2	1	2	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	**8**	**14**
Salinisation	2	0	1	3	0	2	0	1	3	0	2	0	2	3	0	1	0	2	3	0	1	0	2	1	0	2	0	1	3	0	**0**	**0**

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